

Self-Organizing Interference Coordination for Future LTE-Advanced Network QoS Improvements

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Abstract—The new releases of Long Term Evolution (LTE) systems are attracting most of the mobile users by proposing of their capabilities in network satisfaction. Quality of service (QoS) and network capacity are being insisted as two dominant factors for the utmost network satisfaction within any mobile network contracts. On the other hand, the heterogeneous network (HetNet), which is constructed based on sub-network layers' cooperation between macrocell and shorter-range applications like micro, femto and relay nodes, is also proposed as an open door to the recent researches towards the desired network satisfaction for the recently upgraded networks like LTE-Advanced (LTE-A). Nevertheless, since any network cooperation is expected to include a number of confronts; this cooperation is not excluded of dealing with degrading effects, such as interference, among the sub-network elements. This paper presents a detailed discussion regarding the latest strategies to execute the evolved inter-cell interference coordination (eICIC) based on power control algorithm and relying on self-organizing networks (SON) plans. The presented power control algorithm in this work is also based on Channel Quality Indicator (CQI) adjustments, mainly focused on the planned cooperation between macro and femto sub-networks within the central platform of LTE-A network. Considering the SON attributes and concerns for the interference management is clarified as the main novelty of this work. The simulation results in this paper confirm the advancements in both quality and capacity of the signal when applying the proposed power control algorithm as the interference coordination solution.

Keywords—Inter-cell Interference Coordination (ICIC); Power Control; Self-organizing networks (SON); Channel Quality Indicator (CQI); Signal to Interference plus Noise Ratio (SINR); LTE-Advanced; Heterogeneous Networks (HetNet)

I. INTRODUCTION

The increasing demands for a ubiquitous wireless coverage and larger data rates have been tough for the wireless networks industry, especially with more than one billion wireless subscribers today, which are predicted to be tripled over the next five years. In order to support the high demand for data traffic, the third generation partnership project (3GPP) LTE release has been offering significant advantages with respect to its predecessor, High Speed Packet Access (HSPA), such as lower latency due to its flat all-IP network layer, and higher spectral efficiency, and larger throughputs at the physical layer.

However, the performance of this release does not completely meet the International Mobile Telecommunications (IMT)-Advanced requirements as was expected for the fourth generation (4G) of mobile networks defined by the International Telecommunication Union (ITU). Therefore, to fulfill the expected requirements, the new release 10, introduced as LTE-Advanced (LTE-A) is currently under investigation. The main objectives of LTE-A are expected as to produce downlink data rates of up to 100 Mb/s and 1Gb/s for mobile and nomadic users, respectively, by use of advanced technologies, e.g. carrier aggregation (CA), multiple-input multiple-output (MIMO) systems with up to 8×8 antenna arrays, coordinated multipoint (CoMP) transmission, relaying, etc. [1]. On the other hand, self-organizing networks (SONs) are expected to enhance the usage of radio resources, as well as simplifying network management and reducing the cost of operation [2]. The hierarchical trend of SON includes a number of general progressions to arrange the network, i.e. Self-Planning, Self-Configuration, Self-Optimization, Self-Operation and Self-Correction. Each of the mentioned procedures includes part of the novel features and matters within the proposed algorithm.

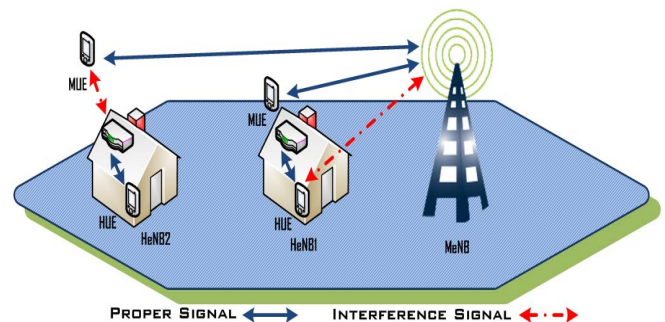


Figure 1. Intercell interference in HetNet sub-networks

Apart from the mentioned novel technologies and advanced features of this new release, the title of LTE-A is always accompanied with the dominant concept of heterogeneity within a unique characterization of a heterogeneous network (HetNet). As already mentioned, HetNet aims to obtain the utmost possible quality and capacity of the network, by making a configured cooperation between existing macro, and the shorter-range applications, e.g. micro, femto and relay

nodes. However, this cooperation, besides its valuable benefits, would also bring some new confronts for network designers, such as interference between the higher and lower sub-networks (tiers) within a HetNet, as is depicted on Figure 1. The basic simulation results could confirm that the intercell interference between macro and femto applications result a huge packet drop in network layer, which result overall degradation in both network quality and capacity. Therefore, a smooth transmission platform should be planned by interference mitigation in new releases of LTE-A systems [3].

In LTE Rel-8 and 9 the ICIC messages can be exchanged via the X2 interface between macro stations and short-range stations. The ICIC messages which are transferred through the X2 interface could be listed as relative narrowband transmit power (RNTP), overload indicator (OI) and high interference indicator (HII). But, despite having good influences to alleviate the intercell interference on microcells, picocells and relay nodes by such messages over the X2 interface, this trend does not consider the HetNet settings and principal HetNet scenarios, and so does not exist for femtocells. Therefore new interference coordination approaches need to be considered to deal with femto within the cells [1]. Because of having no X2 interface between the first network layer (the main macro stations) and the second network layer (the femto stations), an alternative path is required to be selected through the network to initiate this communications. One possible solution is exchanging the information between macro and femto via the backhaul. Furthermore, because the same network operators may not be responsible for femto wire line backhalls, the delay also needs to be carefully considered, as shown in Figure 2. To overcome this difficulty, the applicable solutions could be introduced as the use of UE to relay data between the neighboring cells, or the exchange of messages between macro and femto nodes through the wireless channels. In this trend, for example, the victim macro user (MUE) could be detected either by macro or femto stations to take the best action through the backhaul connections.

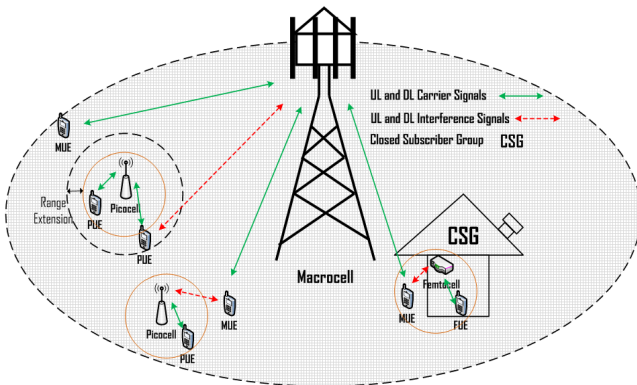


Figure 2. Cross-tier interference in presence of closed subscriber group

To address the interference difficulties within the new LTE-Advanced systems, which is almost based on HetNet characteristics, and more important about the macro-femto cooperation, the enhanced ICIC (eICIC) techniques have recently been investigated on Rel-10, which categorized into

three categories of time-domain, frequency-domain and power control [1]. This paper illustrate a novel power control algorithm for eICIC in new releases of LTE-A, considering SON strategy and simulated by OPNET modeler software. The proposed power control technique is based on the received SINR and the corresponding CQI to adjust the transmission power for interference coordination in a two-tier network.

The rest of this paper is planned as follows: in Section II the related works and researches are discussed as the background of existing works. Section III contains the proposed power control algorithm for eICIC by presenting the novel algorithm. In Section IV, the simulation results and relevant analysis are demonstrated to show the advancements of the suggested method over the existing work. Section V of this paper is the final conclusion, followed by the future work which is briefly discussed in Section VI.

II. RELATED WORKS

Various ideas have been under investigation to apply a power control strategy towards ICIC within the proposed heterogeneous networks. In case of downlink power control, in research [4], a novel downlink power control scheme is presented in LTE HetNet network, which is based on interference management for the macro users in heterogeneous networks, for both macro and femto users. Femtocells are being considered as low-power user-deployed base stations, which provide high-quality cellular service in indoor environments via operating in licensed spectrum and it has been proven that the traffic offload to femtocell can decrease the costs for the network operators by up to 70%. In this work, the co-channel deployment of femto with macro in a hierarchical cell structure, by proposing a novel MUE assisted HeNB power control scheme, has been presented to keep the increase in interference caused by femtocell low enough to have the least impact on the existing macrocell users.

Further to the downlink strategies, in case of uplink power control, research [5] is about the LTE/LTE-A uplink power control (ULPC) procedures in co-channel operation of macro and femto base stations in heterogeneous networks. The Uplink power control for LTE is defined by 3GPP as a combination of open and closed loop components. The open loop power control (OLPC) is responsible for a rough setting of UE transmit power and compensates slow changes of path-loss (including shadowing) in order to achieve a certain mean received signal power for all users. According to this work, there are two different cases of interference that could happen with uplink transmission in heterogeneous networks. First is the very high interference level that exists at the edge of a macrocell. This is because the macro-UEs transmit with high powers to overcome high path-loss towards their serving macro-eNBs located in a farther distance. The femto-UEs are the main victims in this case. The second case is the interference caused by a femto-UE on a nearby macro-eNB. Comparing of these two different cases of interference in the uplink, the level of the interference at the edge of a macrocell generated by macro-UE is more intensive, and therefore the

femto-UEs in such locations should use a higher power to overcome this interference. On the other hand, the femto-UEs close to the macro-eNB should transmit at a lower power to avoid causing interference on the macrocell.

Paper [6] focuses on multi-layer cell deployment when applying femtocell nodes, and applying of self-organizing trend in the network as the main contribution of the work. Furthermore in paper [7], authors propose a distributed method of ICIC based on dual decomposition for cellular networks. The proposed formulation decompose the problem into a number of small sub-problems, each of which with an independent solution through an iterative sub-gradient method. The problems are also addressed with binary-valued variables within the proposed method. The simulation results with the proposed algorithm show the effectiveness of the algorithm with small number of iterations especially for femtocells, although proposing complex formulation and a large number of calculations.

In research [8] a different attitude has been considered for interference coordination. The fractional frequency reuse scheme is used to manage the interference among different nodes in heterogeneous networks to ensure better QoS. The Article focuses on evaluating three fractional frequency reuse (FFR) deployment schemes: strict FFR, soft FFR and FFR-3. Furthermore, a variation of the FFR-3, referred to optimal static FFR (OSFFR) scheme is presented. In results analysis, some performance values such as spectral efficiency, average network sum rate and outage probability are evaluated using of Monte Carlo Simulations. The simulation results of this work shows that the improvements of spectral efficiency (b/s/Hz) of the network for the suggested technique compared to the strict FFR, soft FFR and FFR-3 techniques.

As a more usual implementation mode, femtocell users work in closed subscriber group (CSG), in which only the users available on the subscriber list are allowed to join the network, while the remaining users can only use macrocell as the public network.

Paper [9] focuses on control channel interference mitigation in femto-overlaid LTE-A networks when the closed subscriber group is presented. In this case, only a limited number of subscribed users are served with femtocells, which interfere with both the control and data channels of the non-subscribed users. The paper mostly focuses on control channel interference in LTE-A networks overlaid by CSG femtocells, which is the main reason of link or access failure. The final results of this work shows the effect of the femtocell deployment density and control region load on the frequency domain, time domain, power control and resource allocation approaches inside the cell. The coordination seems to be a principal feature for carrier aggregation (CA) and almost blank subframes (ABS), while both the schemes can guarantee the interference avoidance caused by coordinated interference nodes. Furthermore, power control and resource allocation

techniques can be adapted to the interference level, while alleviating interference from the uncoordinated nodes.

III. NOVEL SON POWER CONTROL ALGORITHM BASED ON CQI ADJUSTMENT

A. Network Structure

The proposed eICIC algorithm in this research is a self-organizing power control technique for two-tier LTE_A networks. The network scenarios in this work have been created based on macro-femto network cooperation to evaluate the handover characteristics in presence of indoor applications. Figure 3 shows the available interfaces for a LTE-A macro-femto network. From the users' point of view, there is no internal interface in practice between the indoor nodes in the second network layer, i.e. femtocells, because they are separately operated in personal areas, e.g. houses, offices, schools, etc. In this case, the S1 interface and gateways are responsible to relay femtocell information and pass the required information to the macrocell nodes.

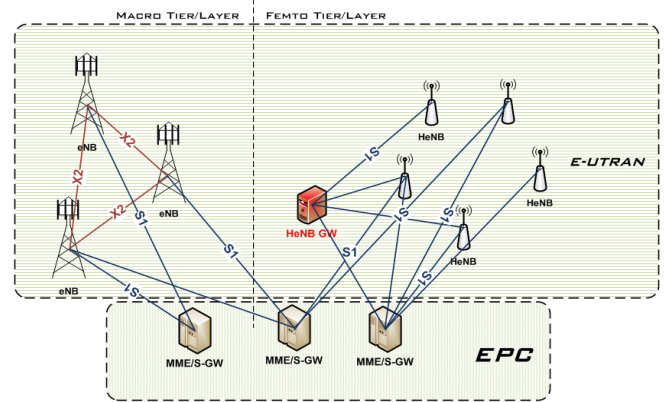


Figure 3. Practical interfaces among heterogeneous network tiers/layers

B. Methodology

The novel SON power control technique contains three phases as depicted in Figure 4. In the first phase, the user equipments (UEs) calculate the value of the signal to interference plus noise ratio (SINR) from its received interference and signal power values. In the second phase, the calculated value of SINR is mapped into the corresponding value of channel quality indicator (CQI) to define the modulation type, code rate and spectral efficiency for the received signals. At the third phase, the transmission power of the nodes is amended according to the updated values of CQI reported by UEs. Because of self-organizing trend of the suggested power control algorithm, the transmission power of the nodes is avoided to exceed the allowed threshold to prevent causing interference to the neighboring nodes.

In this scheme, the CQI can be adjusted by estimating the interference caused by the aggressor Nodes. This eICIC technique is a time-domain interference coordination scheme which is similar to ICIC in frequency domain. In this technique the aggressor nodes stop transmission in some of the sub-

frames in order to protect the edge UEs in protected cells, and might only transmit the control signaling e.g. cell-specific reference signaling (CRS), etc. The measurement of sub-frame by the small cells may or may NOT be the same type (i.e. an almost blank, normal or protected subframe) as the true corresponding sub-frame of the CQI due to the time delay of the CQI report. So, if the CQI of sub-frames being used and measured are different, the channel estimation will not be reliable, and therefore the selected Modulation and Coding Scheme (MCS) may result in transmission inefficiency or transmission failure. Therefore using of different CQIs for normal and protected subframes is necessary [10].

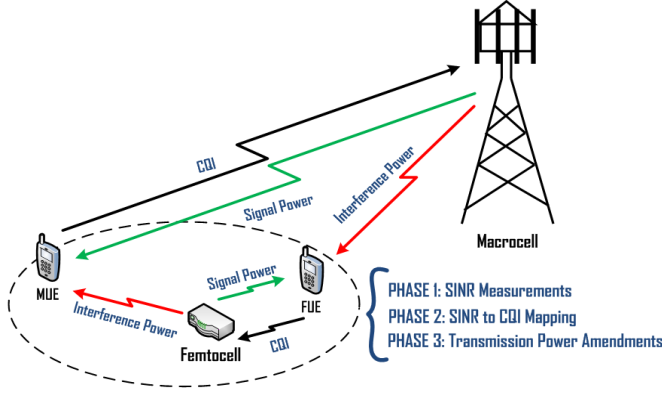


Figure 4. Phases of the proposed SON power control technique

Figure 5 shows the macrocell and femtocell subframe architecture for the aggressor and protected cells respectively. It is necessary to estimate the interference (SINR) from the aggressor nodes and then adjust the reported CQIs of the UEs in the protected nodes, in order to reduce the signaling overhead of the CQI reports. The UE in the protected cells (macro or femto) experience different interference levels due to the Almost Blank Sub frames (ABSs) configured at aggressor nodes. Therefore, if no ABS is introduced, the UEs in the protected cells can measure the SINR at any time.

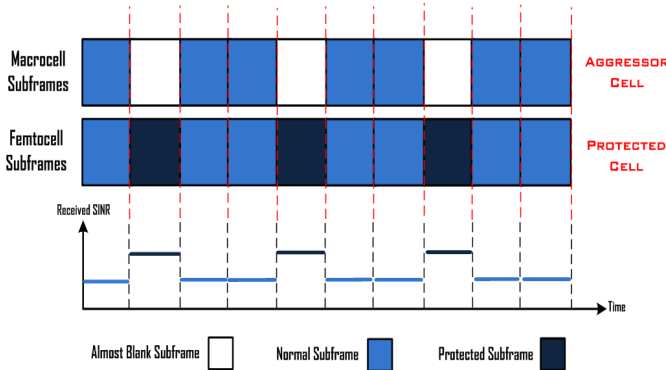


Figure 5. Subframe structure based on the received SINR for different cells

Assuming the macro UE (MUE) as the desired node for SINR calculation, the value of the received SINR in a MUE is calculated by Equation 1 [11].

$$SINR_{macro} = \frac{P_{m,v}^{macro}}{\sum_{i=1, i \neq m}^M P_{i,v}^{macro} + \sum_{j=1}^F P_{j,v}^{femto} + N_v} \quad (1)$$

In which $P_{m,v}^{macro}$, $P_{i,v}^{macro}$ and $P_{j,v}^{femto}$ represent Received power from the serving macrocell, Received power from the interfering macrocell and Received power from the interfering macrocell respectively and N_v is the thermal noise power.

In [12] the Effective Exponential SNR Mapping (EESM) is used for SINR to CQI mapping by converting different gains of multiple sub-channels, through which a codeword is transmitted, into a single effective flat-fading gain with the same codeword error rate. Each user computes the CQI and feeds it back to the base station.

The spectrum is partially shared between macro and femto applications; the macro application can use the full available frequency band and the femto application can use only a part of the available frequency band. Therefore, the co-channel interference occurs within the overlapped frequency band [11]. In this work, partial sharing of spectrum by femto application is considered to avoid huge inter-cell interference, while optimizing the available frequency band. Furthermore, working within closed subscriber group (CSG) is considered in this work since the femtocells generally deployed by the end users.

Table 1 shows the CQI to modulation and coding scheme (MCS) mapping table which is used at the last stage to adjust the transmission power. The quantized CQI is sent from UEs to macro or femto base station and results in a finite solution set, so makes the power control easier. The SINR is measured at the UE, compressed into 4-bit CQI and sent back to the base station.

CQI Index	Modulation Type	Code Rate $\times 1024$	Efficiency [bits/s/Hz]
0	Out of Range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Table 1. CQI to MCS mapping table for transmission power adjustment

Each CQI corresponds to a unique modulation and coding scheme (MCS) which contains information of modulation type, code rate and spectral efficiency according to the CQI-MCS mapping table, as shown in the table.

Therefore, for high measured SINR, the eNodeB or HeNodeB can use high-order modulation and high coding rate for high spectral efficiency, and the node can use low-order modulation and high coding rate for error protection in channels with low SINR [11].

IV. SIMULATION AND ANALYSIS

To show the effects of the proposed novel eICIC technique in HetNets, various scenarios are developed in OPNET modeler software. In one scenario, only macrocell nodes are used to support all of the users, and in the remaining scenarios, different number of femtocell nodes are developed. For simplicity in analysis, firstly the macro to macro intercell interference has been excluded. Also in the macro-only scenario, no eICIC technique has been used to also obtain the same results when no eICIC is planned, even when only macrocell nodes are presented.

Figure 6 presents the downlink throughput in simulated scenarios. As the results show, firstly the throughput value for the scenarios with the proposed eICIC algorithm is higher than the scenario with only macrocells and with no eICIC technique. Furthermore, when the proposed power control technique is applied for interference coordination, by raising the number of femto cells the total throughput also increases due to femtocell cooperation.

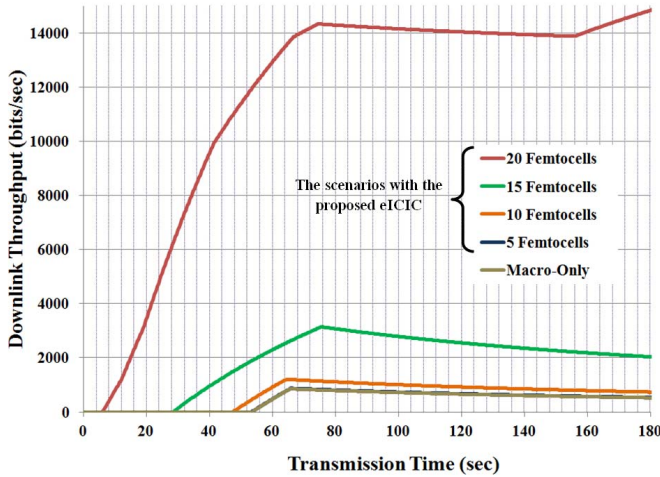


Figure 6. Downlink throughput with and without the proposed eICIC

In case of delay also, the scenarios with the proposed eICIC technique present lower values of delay compared to the macro-only scenario, as is shown in Figure 7. By using of more femtocell nodes, the interference is expected to also increase if no interference coordination applied, and this causes delay in transmission due to having a larger number of dropped packets especially at cell boundaries.

However, by applying the power control technique among the deployed femtocells, a decrease in delay is less likely, because the user congestions are split among a larger number of nodes at both the cell-centre and the cell boundary. The results also confirm the advantages of using a larger number of femtocell nodes in a defined geographic area.

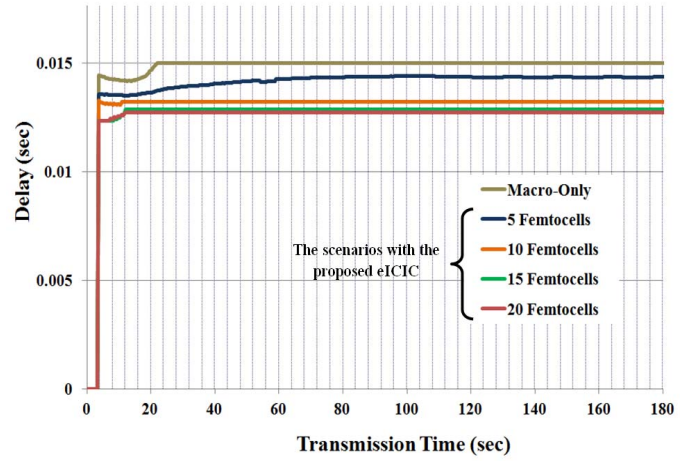


Figure 7. Transmission delay with and without the proposed eICIC

For a more detailed comparison to illustrate the advantages of the proposed power control eICIC technique over the existing methods, Figure 8 depicts the end-to-end (ETE) delay for three different scenarios. The simulation results over 180 seconds confirm that there is a lower ETE value for the simulated LTE-A network when the novel algorithm of power control is applied. The conventional technique and single-layer network with only macrocells are located in next situations respectively.

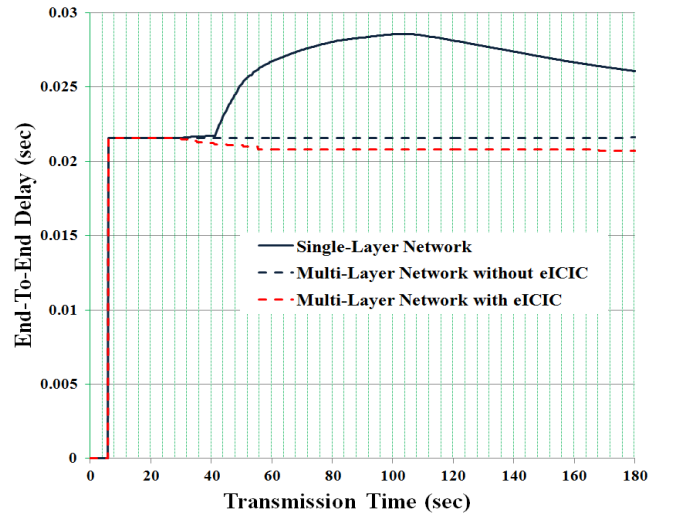


Figure 8. End-To-end Delay comparison for different eICIC techniques

A critical advantage of applying the self-organizing interference coordination is the decreased number of packet drops and disconnected transmissions. The LTE-A nodes in this regards receive the updated transmission power statistics from their allocated users, and decide to increase or decrease the transmission power to avoid intercell interference to their neighboring nodes. Hence, the SON attribute of the proposed algorithm is the key advantage of the work over the conventional techniques.

V. CONCLUSIONS

This paper proposes a novel power control algorithm for interference coordination in new releases of LTE-A network. The suggested eICIC algorithm is planned based on self-organizing strategy to provide self-correction in an autonomous manner. The simulation results, using OPNET modeler, clearly confirm that the novel power control algorithm presets lower delay in transmission, as well as higher total throughput in the network due to the communicative links between macro and femto nodes. As expected, the awareness of transmitters in the network could obtain transmission power balance by the nodes, which results in less intercell interference.

VI. FUTURE WORK

The self-organizing strategy which is applied in this work is also under research to be applied for other LTE-A requirements such as channel allocation and handover optimization in an interference mitigated network.

REFERENCES

- [1] D. Lopez-Perez, I. Guvenc, G. de la Roche, M. Kountouris, T. Q. S. Quek, and J. Zhang, "Enhanced Inter-cell Interference Coordination Challenges in Heterogeneous Networks," *IEEE Wireless Communications*, vol. 18, no. 3, June 2011, pp. 22-30.
- [2] M. Dirani, and Z. Altman, "Self-organizing networks in next generation radio access networks: Application to Fractional Power Control," *Elsevier Journal of Computer Networks*, vol. 55, no. 2, February 2011, pp. 431-438.
- [3] Behjati, M., Cosmas, J.: 'Self-Organizing Network Interference Coordination for Future LTE-Advanced Networks', *IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, London, UK, June 2013.
- [4] Z. Wang, W. Xiong, C. Dong, J. Wang, S. Li, "A Novel Downlink Power Control Scheme in LTE Heterogeneous Network," *International Conference on Computational Problem-Solving (ICCP)*, Chengdu, China, October 2011, pp. 241-245.
- [5] J. Góra, K. I. Pedersen, A. Szufarska and S. Strzyz, "Cell-Specific Uplink Power Control for Heterogeneous Networks in LTE," *IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall)*, Ottawa, ON, Canada, September 2010, pp. 1-5.
- [6] Behjati, M., Cosmas, J.: 'Multi-Layer Cell Deployment Strategy for Self-Organizing LTE-Advanced Networks', *IEEE International Wireless Communications and Mobile Computing Conference (IWCMC)*, Cagliari, Italy, July 2013.
- [7] C. Kosta, B. Hunt, A. U. Qaddus, R. Tafazolli, "A Distributed Method of Inter-Cell Interference Coordination (ICIC) Based on Dual Decomposition for Interference-Limited Cellular Networks," *IEEE Communications Letters*, vol. 17, no. 6, June 2013.
- [8] N. Saquib, E. Hossain, D. I. Kim, "Fractional Frequency Reuse for Interference Management in LTE-Advanced HetNets," *IEEE Wireless Communications*, vol. 20, no. 2, April 2013, pp. 113-122.
- [9] D. Tsolkas, N. Passas, L. Merakos, "Alleviating Control Channel Interference in Femto-Overlaid LTE-Advanced Networks," *IEEE Communications Magazine*, vol. 51, no. 10, October 2013, pp. 192-200.
- [10] L. Jiang and M. Lei, "CQI Adjustment for eICIC Scheme in Heterogeneous Networks," *IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Sydney, NSW, Australia, September 2012, pp. 471-476.
- [11] X. Xu, G. Kutrolli, and R. Mathar "Dynamic Downlink Power Control Strategies for LTE Femtocells," *International Conference on Next Generation Mobile Applications, Services and Technologies*, November 2013, pp. 181-186.
- [12] S. N. Donthi and N. B. Mehta, "An accurate model for EESM and its application to analysis of CQI feedback schemes and scheduling in LTE," *IEEE Transactions on Wireless Communications*, vol. 10, no. 10, October 2011, pp. 3436-3448.