ISSN 2348 – 7968

A Survey on Inter-Cell Interference Reduction Techniques in LTE-A Heterogeneous Networks

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Abstract

This paper is concerned with the Inter-Cell Interference Reduction techniques in the Long Term Evolution-Advanced Heterogenous Networks.The proposed system design aims at reducing the ICI in LTE-A Network. The small cell network (SCN) architecture can be designed in which the small scale group muting (SCGM) could mitigate the interference between the hosting macro-cell and small cells as well as the interference between adjacent small cells.This paper surveys the various ICIC avoidance schemes in the LTE-A Network.

Keywords

Small-cell networks (SCNs), small-cell group muting (SCGM), Inter-cell interference co-ordination (ICIC)

1. Introduction

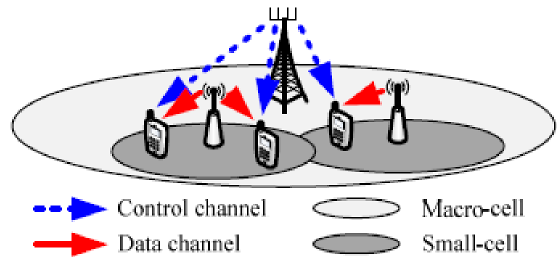
Owing to the high demand for broad services and new applications, today's wireless networks are facing the challenge of supporting exponentially increasing data traffic. With full frequency reuseand an increasing density of small-cell deployments, the interference between macro-cells and small-cells as well as interference between adjacent small cells is always a serious concern in SCNs . The widely used inter-cell interference mitigation technique in homogeneous networks is soft frequency reuse (SFR) . By dynamic spectrum access, SFR can effectively minimize interference. The small cell architecture (SCN) can be designed in which the small scale group muting (SCGM) could mitigate the interference between the hosting macro-cell and small cells as well as the interference between adjacent small cells.

It is envisioned that the next generation wireless networks will consist of macro-cells and ahigh density of small-cells with different capabilities including transmit power and coverage range [1].With full frequency reuse and an increasing density of small-cell deployments, the interference between macro-cells and small-cells as well as interference between adjacent small cells is always a serious concern in SCNs [2]. The widely used inter-cell interference mitigation technique in homogeneous networks is soft frequency reuse (SFR) [3]. By dynamic spectrum access, SFR can effectively minimizeinterference. However, as applying SFR in SCNs directly, the bandwidth assignment is facing a tough challenge due to the irregular distribution of a huge number of small-cells in SCNs. The network-centric enhanced inter-cell interferencecoordination (eICIC) technique with time domain muting hasbeen intensively studied in the 3rd Generation PartnershipProject (3GPP) community [4]. And it is now part of LTE-A.However based on the premise of low density of small-cells,the interference between adjacent small-cells is not consideredand only the interference from macro-cells to small-cells istherefore partly mitigated in eICIC.Other extensively-investigated inter-cell interferencemitigation techniques are downlink coordinated multi-point(CoMP) transmission [5]-[7] and interference alignment (IA)[8]. The former aims to mitigate inter-cell interference bycoordinating the transmission of several geographicallyseparated cells. With synchronized cells, inter-cellinterference in SCNs can be mitigated and even exploited byapplying multi-user based joint transmission techniques [6]. InIA, by restricting all inter-cell interference at each receiverinto a small space, a higher degree-of-freedom (DoF) thanconventional methods can be achieved. Since both CoMP andIA require reliable channel state information, significantmessage exchange between the cooperative cells, and highcomputational complexity, their benefits for practical SCNsare still unclear. Overall, how to efficiently and practicallymitigate inter-cell interference in SCNs with a very densedeployment of small-cells is still an open issue.

2. A Practical SCNS Architecturewith SCGM

Owing to the high demand for broad services and new applications, today's wireless networks are facing the challenge of supporting exponentially increasing data traffic . Recent efforts geared to small-cell networks (SCNs) promise to have great practical value because they are capable of offering the "jack of both trades". By a very dense deployment of low-cost, low-power base stations, both the spatial reuse of radio resource and transmit power efficiency can be potentially improved[11]. It is envisioned that the next generation wireless networks will consist of macro-cells and a high density of small-cells with different capabilities including transmit power and coverage range. With full frequency reuse and an increasing density of small-cell deployments, the interference between macro-cells and small-cells as well as interference between adjacent small cells is always a serious concern in SCNs.

Fig. Illustration of the proposed SCNs architecture.



The widely used inter-cell interference mitigation technique in homogeneous networks is soft frequency reuse (SFR). By dynamic spectrum access, SFR can effectively minimize interference. However, as applying SFR in SCNs directly, the bandwidth assignment is facing a tough challenge due to the irregular distribution of a huge number of small-cells in SCNs. The network-centric enhanced inter-cell interference coordination (eICIC) technique with time domain muting has been intensively studied in the 3rd Generation Partnership Project (3GPP) community and it is now part of LTE-A. However based on the premise of low density of small-cells, the interference between adjacent small-cells is not considered and only the interference from macro-cells to small-cells is therefore partly mitigated in eICIC. Other extensively-investigated inter-cell interference mitigation techniques are downlink coordinated multi-point (CoMP) transmission and interference alignment (IA) . The former aims to mitigate inter-cell interference by coordinating the transmission of several geographically separated cells. With synchronized cells, inter-cell interference in SCNs can be mitigated and even exploited by applying multi-user based joint transmission techniques. In IA, by restricting all inter-cell interference at each receiver into a small space, a higher degree-of-freedom (DoF) than conventional methods can be achieved. Since both CoMP and IA require reliable channel state information, significant message exchange between the cooperative cells, and high computational complexity, their benefits for practical SCNs are still unclear. Overall, how to efficiently and practically mitigate inter-cell interference in SCNs with a very dense deployment of small-cells is still an open issue.

3. System Analysis

The network-centric enhanced inter-cell interference coordination (eICIC) technique with time domain muting has been intensively studied in the 3rd Generation Partnership Project (3GPP) community and it is now part of LTE-A[11]. Since both CoMP and IA require reliable channel state information, significant message exchange between the cooperative cells and high computational complexity, their benefits for practical SCNs are still unclear. Overall, how to efficiently and practically mitigate inter-cell interference in SCNs with a very dense deployment of small-cells is still an open issue.

There are many interesting research directions that can be extended, such as

(1) to design an efficient grouping criterion for SCGM, since the criterions studied are not ingenious enough and the peak performance is not high relatively;

(2) to design inter-macro-cell SCGM;

(3) to evaluate the effects of imperfect backhaul on the proposed method.

4. ICI Reduction Techniques

The Methods used to reduce inter-cell interference in LTE-A network, proposed in this work would be as follows:

A. Design of Small cell network architecture with small cell group muting

The key idea of the proposed architecture is to configure the transmitting of control channel at macro-cells and data channel at small-cells[11]. In particular, macro-cells are muted in data channel and their functions are restricted to guaranteeing the coverage, assisting local area radio access, mobility management and so on. All UEs in SCNs first get access into macro-cells and then receive data service from small-cells by the assistance of macro-cells. Note that there is no control or common signalling transmitted by small-cells.

B.Adaptive Soft Frequency Reuse

SFR scheme divides the available spectrum into two reserved parts: a cell-edge bandwidth and a cell-center bandwidth. The Physical resource block (PRB) reuse avoidance feature could decrease inter-cell interference levels while improving the achievable average throughput per user, especially for those identified as cell-edge ones.

C. Simulation

We can implement the proposed SCNs architecture with SCGM in a quasi-dynamic system level simulator. This simulator includes explicit modeling of major radio resource management (RRM) algorithms such as packet scheduling, closed-loop MIMO with precoding and rank adaptation, link adaption, hybrid automatic repeat request (HARQ).

This section presents an overview of some of the important contributions in the field.

[1]Hoydis, J. ; RWTH Aachen Univ., Aachen, Germany; Kobayashi, M. ; Debbah, M.

The exponentially increasing demand for wireless data services requires a massive network densification that is neither economically nor ecologically viable with the current cellular system architectures. A promising solution to this problem is the concept of small-cell networks (SCNs), which is founded by the idea of a very dense deployment of self-organizing, low-cost, low-power, base stations (BSs). Although SCNs have the potential to significantly increase the capacity of cellular networks while reducing their energy consumption, they pose many new challenges to the optimal system design. In the method discussed in paper, a large system analysis based on random matrix theory (RMT) may provide tight and tractable approximations of key performance measures of SCNs.

[2] Razavi, R.(Bell Labs.,Alcatel-Lucent, Dublin, Ireland), Kucera, S. ; Androne,.;Claussen, H.

This paper investigates the effect of the other-cell interference in WCDMA small cell networks when operating on the same frequency channel of the hosting macrocell tier. In this paper, the problem formulation is presented and it is shown that the co-channel interference and the effective capacity can not be analytically traced. Consequently, using simulation and modelling, the paper investigates the interference exposure of the macrocell tier on the small cells in regards to the small cell's distance to the macrocell Base Station (BS), the small cell transmission power, the environment shadowing and macrocell load level. The results can serve as essential guidelines for operators when estimating the effective capacity of small cells in co-channel deployment scenarios.

[3] YoujiaChen ,Zihuai Lin, BrankaVucetic , JianyongCai

Inter-cell interference coordination (ICIC) and resource allocation problems are fundamental challenges for the design of wireless networks. In this paper, a distributed network inter-cell control scheme is proposed and Belief Propagation (BP) framework is introduced to solve the optimization problem. The goal is to maximize the sum rate of those Base Stations (BS). This new approach assumes that the inter-cell interference is a set of stochastic variables. Based on a set of prior distributions, it calculates the posterior distributions of the scheduling variables. The solution allocates PRBs to Mobile Stations (MS) in the cells, including optimization of the transmit powers in each subcarrier. Numerical results demonstrate that the algorithm provided achieves a good result in typically a couple of iterations.

[4] Boudreau, G. ; Nortel, Toronto, ON ; Panicker, J. ; NingGuo ; Rui Chang

This article provides an overview of contemporary and forward looking inter-cell interference coordination techniques for 4G OFDM systems with a specific emphasis on implementations for LTE. Viable approaches include the use of power control, opportunistic spectrum access, intra and inter-base station interference cancellation, adaptive fractional frequency reuse, spatial antenna techniques such as MIMO and SDMA, and adaptive beamforming, as well as recent innovations in decoding algorithms. The applicability, complexity, and performance gains possible with each of these techniques based on simulations and empirical measurements will be highlighted for specific cellular topologies relevant to LTE macro, pico, and femto deployments for both standalone and overlay networks.

[5] Xuehong Mao ; ECE Dept., Univ. of Utah, Salt Lake City, UT ; Maaref, A. ; Koon HooTeo

This paper proposes a decentralized adaptive soft frequency reuse scheme for the uplink of 4G long-term evolution (LTE) systems. While universal frequency reuse (UFR) is being targeted for next generation multi-cellular wireless networks, ongoing efforts supporting the LTE standard have proved that actual implementations of UFR in LTE lead to unacceptable interference levels experienced by user equipments near the cell edge area in a multi-cellular configuration. The herein proposed adaptive soft frequency reuse scheme is a step forward towards effective inter-cell interference coordination (ICIC) in next-generation wireless networks. Our solution to the uplink ICIC problem stands out for its two essential features that consist of physical resource block (PRB) reuse avoidance/minimization and cell-edge bandwidth breathing which can be implemented at the cost of a negligible information exchange over the X2 interface (backbone). The PRB reuse avoidance feature significantly decreases inter-cell interference levels while improving the achievable average throughput per user, especially for those identified as cell-edge ones. The cell-edge bandwidth breathing strategy allows to track and adapt to semi-static changes in traffic loading and user distributions within each cell which drastically reduces the blocking probability of incoming calls under cell-edge bandwidth constrained traffic.

[6] Yuanye Wang ; Aalborg Univ., Aalborg, Denmark; Pedersen, K.I.

The performance of enhanced Inter-Cell Interference Coordination (eICIC) for Long Term Evolution (LTE)- Advanced with co-channel deployment of both macro and pico is analyzed. The use of pico-cell Range Extension (RE) and time domain eICIC (TDM muting) is combined. The performance is evaluated in the downlink by means of extensive system level simulations that follow the 3GPP guidelines. The overall network performance is analyzed for different number of pico-eNBs, transmit power levels, User Equipment (UE) distributions, and packet schedulers. Recommended settings of the RE offset and TDM muting ratio in different scenarios are identified. The presented performance results and findings can serve as input to guidelines for co-channel deployment of macro and pico-eNBs with eICIC.

[7] Yong-Ping Zhang ; Huawei Technologies Co., Ltd, Beijing, P. R. China.

SCNs architecture with small cell group muting (SCGM) is proposed to mitigate the interference between the hosting macro-cell and small-cells as well as interference between adjacent small-cells. SFR scheme divides the available spectrum into two reserved parts: a cell-edge bandwidth and a cell-center bandwidth.
By separating the transmission of control channel at macro-cells and data channel at small-cells, the proposed architecture can exclude the interference between macro-cells and small-cells completely and achieve lower power consumption. Use of ASFR can decrease inter-cell interference level.

5.Comparison of Various Existing Systems

A comparison of the key literatures that has been used to propose the given work is as follows:

Sr No.	References	Inter-Cell Interference Reduction	Problem Formulation	Conclusion
01.	Hoydis, J. [2] (2011)	Large system analysis based on random matrix theory (RMT) can provide tight and tractable approximations of key performance measures of SCNs. .	Small Cell Network	SCNs have the potential to significantly increase the capacity of cellular networks while reducing their energy consumption
02.	Razavi, R. [4] (2012)	Using simulation and modelling, the paper investigates the interference exposure of the macrocell tier on the small cells in regards to the small cell's distance to the macrocell Base Station (BS), the small cell transmission power, the environment shadowing and macrocell load level.	Simulation and modelling	The interference is not maximised at the macrocell edge. This is due to the fact that the small cell coverage would also simultaneously expand when moving away from the macrocell BS, mitigating the effect of higher transmit power from macrocell users.
03.	Youjia Chen [10] (2013)	A framework based on the BP algorithm is developed to solve the inter-cell interference problem for heterogeneous networks. A factor graph is designed to represent the inter-cell interference probabilistic relationship with various communication resources Based on a set of prior distributions, it calculates the posterior distributions of the scheduling variables algorithm achieves a good result in typically a couple of iterations.	Inter-cell control scheme and Belief Propagation (BP) framework	The BP algorithm is used to solve the optimization problem. It translates the optimization problem into a marginal distribution computing problem. From the numerical results, it can be seen that the BP approach performs much better than the reuse scheme

04.	Boudreau, G [12] (2009)	Viable approaches include the use of power control, opportunistic spectrum access, intra and inter-base station interference cancellation, adaptive fractional frequency reuse, spatial antenna techniques such as MIMO and SDMA, and adaptive beamforming, as well as recent innovations in decoding algorithms.	A combination of these approaches are employed	In the short term a combination such as fractional power control and adaptive fractional frequency reuse based on scheduling in high SINR regions could form the basis of a robust LTE ICIC strategy. Longer term gains in ICIC performance could potentially be achieved through the use of inter-base station network based algorithms, including network MIMO, opportunistic and/or organized beamforming, and distributed power control, as well as coding strategies such as sphere decoding or dirty paper coding.
05.	Xuehong Mao [13], (2008)	The solution to the uplink ICIC problem stands out for its two essential features that consist of physical resource block (PRB) reuse avoidance/minimization and cell-edge bandwidth breathing. The cell-edge bandwidth breathing strategy allows to track and adapt to semi-static changes in traffic loading and user distributions within each cell which drastically reduces the blocking probability of incoming calls under cell-edge bandwidth constrained traffic.	Adaptive soft frequency reuse scheme	The PRB reuse avoidance feature significantly decreases inter-cell interference levels while improvingthe achievable average throughput per user, especially for those identified as cell-edge ones.
06.	Yuanye Wang [9], (2012)	The use of pico-cell Range Extension (RE) and time domain eICIC (TDM muting) is combined. The performance is evaluated in the downlink by means of extensive system level simulations that follow the 3GPP guidelines.	System level simulations	The relative eICIC gain increases for lower pico-eNB transmit power levels, but is less sensitive to the spatial distribution of UEs.
07.	Yong-Ping Zhang, Shulan Feng, Philipp Zhang, Liang Xia, Yu-Chun Wu, and Xiaotao Ren [11], 2013	SCNs architecture with small cell group muting (SCGM) is proposed to mitigate the interference between the hosting macro-cell and small-cells as well as interference between adjacent small-cells.	SCN architecture with small scale group muting and adaptive soft frequency reuse scheme	By separating the transmission of control channel at macro-cells and data channel at small-cells, the proposed architecture can exclude the interference between macro-cells and small-cells completely and achieve lower power consumption.

ISSN 2348 – 7968

6 Conclusion

The various contributionsfor reducing the Inter-Cell Interference in LTE-A can be summarized as follows:

1. Analysation of the performance of enhanced Inter-Cell Interference Coordination (eICIC) for Long Term Evolution (LTE)- Advanced with co-channel deployment of both macro and pico cells.
2. Evaluation of the performance of the downlink by means of extensive system level simulations that follow the 3GPP guidelines. The use of pico-cell Range Extension (RE) and time domain eICIC (TDM muting) is combined. The overall network performance is analyzed for different number of pico-eNBs, transmit power levels, User Equipment (UE) distributions, and packet schedulers. Recommended settings of the RE offset and TDM muting ratio in different scenarios are identified.
3. The presented performance results and findings can serve as input to guidelines for co-channel deployment of macro and pico-eNBs with eICIC.
4. Comparison of the proposed Inter-cellular interference management system with the other prevalent systems

The proposed model will lead to a methodological innovation that could be incorporated in the Long Term Evolution-Advanced system for a 5G mobile applications.

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