Realistic Implementation of X2-based Interference Management for LTE Femtocells

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Abstract

Femtocells address one of the main issues of current broadband mobile communication networks, that is, the lack of in-building coverage. Apart from their benefits related to the better coverage and throughput, femtocells have several drawbacks, being the most significant one the interference with the macro-cellular network and with other femtocells. This paper focuses on LTE femtocells and tackles the problem of interference between femtocells using existing signalling and communication protocols. Two alternatives for resource allocation are proposed where each femtocell has a set of preferential RBs in which it can transmit even if it causes interferences to the neighbour femtocells. Whenever an excessive femto-to-femto interference would require coordination, the proposed solutions enhance spectrum efficiency and reduce interferences. Results indicate that the scheme that combines load indication messages and measurement reports from the users improves significantly the capacity without requiring complex computations in the femtocell.

Keywords: Femtocells, Interference, LTE, LTE-Advanced.

1. Introduction

The current evolutionary step in the 3rd Generation Partnership Project (3GPP) specifications for broadband mobile communications is the Long-Term Evolution Advanced (LTE-A) Release 11. On October 20th, 2010, the Radiocommunication Sector of the International Telecommunication Union (ITU-R) conferred International Mobile Telecommunication -Advanced (IMT-Advanced) status (4G) to LTE-A and WiMAX IEEE 802.16m [1]. The standardization efforts in 3GPP will be followed by work Release 12, which has already started.

Apart from improvements in standards, the evolution in network architecture from traditional macro-cell deployments to combined macro-cell/femto-cell deployments, usually referred to as Heterogeneous Networks (HetNets), is currently under way. The shift towards smaller base-stations, also known as femtocells, is promising in many ways, among others, due to increased network capacity, better and more predictable channel conditions and the possibility of offloading a large fraction of macro-cell traffic.

A femtocell is a low-power cellular base station that operates in a home or small business with a range of 10 to 20 m. The main difference between a femtocell and a relay is that femtocells are connected to the core network via a wired broadband connection like DSL or cable. Indeed, a femtocell permits the extension of coverage to indoor scenarios, as well as improving the user experience at the cell edge. According to the 3GPP terminology, a Home Node B (HNB) is a 3G femtocell whereas a Home eNode B (HeNB) is an LTE femtocell. HNB are widely deployed being the number of small cells greater than 6 million at the end of 2012, according to the small cell forum report. Many operators have launched femtocell service, like Vodafone, SFR, Mobile TeleSystems, AT&T, Sprint and Verizon. Concerning HeNB, several companies are currently developing femtocell products. In June 2013 the plugfest has taken place in Slovenia. In this process several devices will be connected with a real Evolved Packet Core (EPC) showing the performance of the HeNB in real operation conditions. One of these companies is SistelNetworks [2], who will contribute with its new HeNB device that will be release for purchase in January 2014.

A femtocell permits the extension of coverage to indoor scenarios, as well as improving the experience at the cell edge.

Apart from their benefits related to the better coverage and throughput, femtocells have several drawbacks. The main issue with femtocells is the interference with the macro-cellular network and with other femtocells. Inter-Cell Interference-Coordination (ICIC) and its evolution eICIC (enhanced ICIC), comprise several techniques aiming to reduce interference harmful effects, operating at medium time scale. In fact, static ICIC constitutes an important category itself [3]. The goodness of ICIC in the trade-off between spectral efficiency and users fairness is well known and open new challenges have been identified: comparative studies between distributed and (semi) centralized approaches indicate that the first group performs well under theoretical conditions or synthetic scenarios. However, in realistic networks gains are significantly reduced. The next step in ICIC research is to tackle these issues and develop new dynamic techniques suitable to realistic networks and introducing as a figure of merit the transversal Quality of Service (QoS) aspect. Initial studies addressing this area of research are [4] [5] with interference graph colouring [6]-[8] and game theory appearing as promising tools [9]. It is expected that dynamic clustering that adapts grouped cells to the changing load conditions increase the efficiency of these methods.

A. Related work

3GPP has defined three scenarios of study with three cases of distribution of femtocells, with isolated femtocells or with a cluster of femtocells that interferes mutually [10]:

- Scenario A: Small cells with non-co-channel macro coverage, that is, small cells and macro cells are on different frequency carriers.

- Scenario B: Small cells with co-channel macro coverage.

- Scenario C: Small cells without macro coverage.

On the one hand, some recent ICIC schemes addressing scenario B can be found in [11]-[15]. An approach based on interference estimation is presented in [11], where it is designed an algorithm that optimize power and bit allocation over a joint time-frequency domain. The interference is sensed and estimated over successive slots using a Markov model. The algorithm follows two different strategies: to maximize expected rate under a transmit power constraint and to minimize transmit power under the expected rate constraint.

Comparison between reinforcement learning and game theory techniques to optimize resource allocation in self-organized HetNets is done by Imran *et al*. in [12], studying the pros and cons of each one. An example of reinforcement-learning technique is presented in [13], where the coexistence between a macrocell and closed-access femtocell networks is modeled and analyzed. In this approach, femtocells are non-cooperative, thus they need to self-organize by gradually learning from their environment, and adapt their strategy until reaching convergence. Other proposals based on game theory can be found in [14] [15]. Zhang *et al*. proposed in [14] a semi-distributed algorithm for the uplink, based also on non-cooperative games, that tries to maximize network capacity. In this algorithm, each femtocell assigns subchannels to femtocell users and then allocates power to subchannels. The utility function of each femtocell includes a pricing term proportional to the interference that it causes to the macrocell, in order to minimize it. In [15] Mustika *et al*. proposed another scheme based on non-cooperative games in which each femto user attempts to select the most appropriate subset of resource blocks in a decentralized manner in order to manage the cross- and co-tier interference in the heterogeneous network.

On the other hand, several studies focus on interference management in Scenarios A or C [16]-[19]. Park and Bahk proposed in [16] a dynamic resource scheduling procedure designed to dense femtocell deployments. This procedure is divided into two steps: contention-scheduling and resource allocation. Each femtocell selects a user according to its own scheduling policy and contends with neighbors considered susceptible for interference for the channel access in the next allocation interval. Susceptible neighbors are those with SNR level below a specific threshold. Femtocells that win contention allocate resources to its users while losers remain silent. In environments with high levels of interference, several femtocells content for the channel access at each allocation interval and back-off periods could be too long, thus reducing the overall throughput.

Another scheme proposed by Wu *et al*. [17] divides bandwidth into dedicated and shared parts. Femtocells may decide autonomously on how to select each part. For the dedicated subband, selection is made according to the interference level. On the other hand, resource allocation in the shared subband is done in a cooperative manner, exchanging information through the X2 interface. This scheme does not adapt to low interference situations in which the use of dedicated bands per femtocell implies a significant waste of resources.

In [18], Liu *et al*. proposed a semi-static resource allocation scheme based on Fractional Frequency Reuse (FFR) that avoids interference on cell edge users for dense indoor femtocell deployments. The distribution of subbands among femtocells can be determined during the network planning stage, before the network roll-out, using graph coloring techniques. In [19], femtocells are grouped in virtual clusters maximizing distance among its members. Each cluster is managed independently and schedules all the subbands among the femtocells belonging to that cluster even if interference level is low, which leads to the underutilization of resources.

B. Contributions

This paper proposes a realistic and feasible procedure for interference management for LTE femtocells. This procedure pays special attention to clustering for efficient eICIC in HetNets together with the subsequent smart allocation of resource. By means of the channel state information feedback provided by the users and the interchange of information through the X2 interface defined in the LTE standard [20], femtocells are able to remove interferences in a ultra-dense deployment scenario. Moreover, provided the additional complexity of the system at hands, decision making capabilities are distributed among cooperative nodes. Pre-processing of cell measurements made by users and exchange of information between entities are necessary, in order to adjust the transmission parameters to avoid interference. The main relevance of this proposal arises from its immediate applicability in LTE-A, since all required signalling is currently available in the network and system modelling follows accurately the specifications. Specifically, our main contributions are as follows:

- Definition of a distributed clustering procedure in each node, which adapts dynamically to the interference level. This procedure allows femtocells to have priority over certain channels that can be used in a dedicated manner when it is necessary to reduce interference and improve SNIR levels.

- Smart allocation of resources, which allows ranging from frequency reuse 1, when interference is negligible, to the shared use of resources within the defined clusters.

The rest of this paper is organized as follows. In Section 2, the current status of the standards is discussed together with the proposed X2-based eICIC schemes. Section 3 defines the simulation setup and provides numerical results

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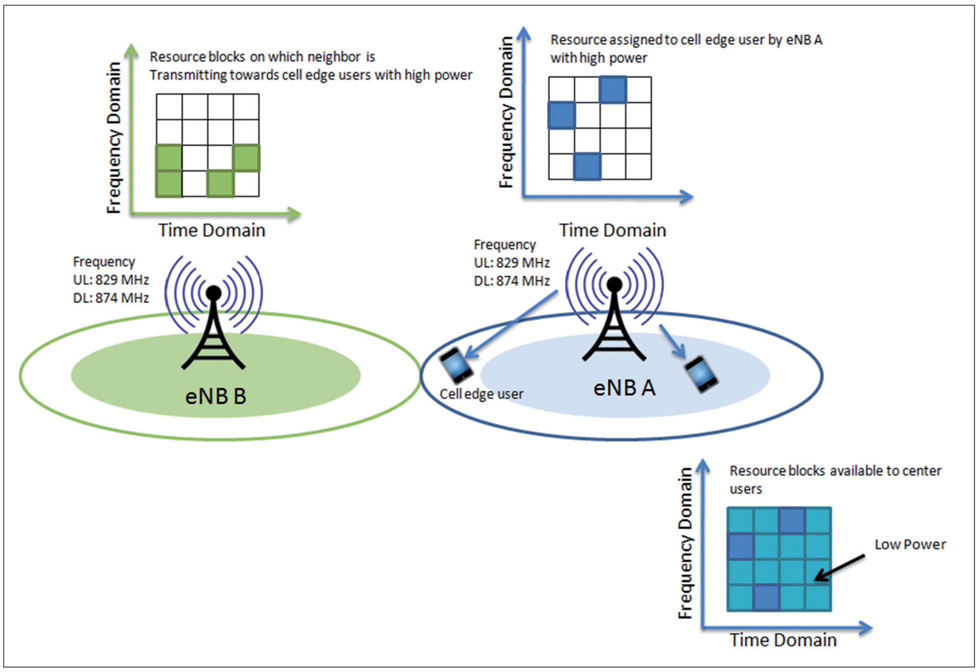
on the comparison of these schemes with frequency reuse 1. Concluding remarks and future lines of work are given in Section 4.

2. Inter-Cell Interference Coordination

A. Current status of the standards

LTE specifications highlight the importance of signalling for interference control among HeNBs [21]. Therefore, direct femtocell-to-femtocell message exchange via the X2 interface [20] has recently been included in the standard (from Release 10 on), although the information flow and interference mitigation mechanisms have not been clarified. Direct communication requires knowing the neighbour cells in advance. This is not a problem, since HeNBs are connected via S1 to a HeNB gateway (HeNB-GW) that could send a list with the IP directions of these neighbours.

Once connected, HeNBs can coordinate themselves autonomously using the LOAD INDICATION procedure in the X2 Application Protocol (X2-AP). This procedure enables HeNBs to inform about their loads and interference conditions to neighbour HeNBs. Applied to Radio Resource Management (RRM), this kind of self-organization should allow making a dynamic and automatic optimum coordination of the radio resource utilization among cells in close vicinity sharing the same frequency band, in order to reduce interference and avoid performance loss or service degradation. The general setting of this problem can be seen in Figure 1.



■ **Figure 1.** *Interference coordination between LTE eNodeBs.*

Using X2-Basic and X2-UEs the total throughput per femtocell can be increased more than 30% and 50 % with respect to non-ICIC case.

In the downlink, a bitmap known as Relative Narrowband Transmit Power (RNTP) indicator can be exchanged among eNodeBs through this X2 interface. This ON-OFF indicator informs the neighbour cells if the eNB or HeNB intends to transmit on a certain Resource Block (RB) over a certain power threshold or not. One bit per RB in the frequency domain is sent. The exact value of the upper limit and the periodicity in the reporting are configurable.

The use of the RNTP indicator allows HeNBs to choose the proper RBs when scheduling users according to the interference level introduced by their neighbours. The decision making process followed by HeNBs after receiving RNTP indicators is not standardized, which fosters competence among different implementations.

In the uplink, two messages are exchanged: the Interference Overload Indication (IOI), which indicates the interference level on all RBs, and the High Interference Indication (HII), which informs about the future plans for the uplink transmission. The receiving cells should take this information into account not scheduling cell-edge users in these RBs.

This paper focuses on Scenario A and, therefore, will only investigate on ICIC based on the X2 exchange of LOAD INDICATION messages. Provided that the signalling is already standardised, the main challenge is to design simple but yet effective resource allocation schemes that minimize interference while maximizing the resource usage. Next section is devoted to this resource allocation problem.

B. Proposed solutions

The aim of the proposed algorithms is to manage interferences among users without using a fixed initial frequency reuse planning. For this purpose, this paper proposes two approaches where each femtocell has a set of preferential RBs in which it can transmit even if it causes interferences to the neighbour femtocells. Neighbour femtocells may use these RBs if this does not deteriorate the performance of the femtocell that has higher priority over those RBs. Femtocells exchange messages among them to coordinate the resource usage. The two schemes proposed in this paper differ in the way femtocells create and process the messages exchanged.

1. Selection of the Preferential Resource Blocks

We define the Preferential Resource Blocks of a serving femtocell i (PRB_i) as the set of RBs that the femtocell can allocate without taking into account the status of its neighbour femtocells. Even so, the femtocell i shall communicate the decision of using these RBs to its neighbours. $PRBs$ are different for each femtocell belonging to the same cluster G, in such a way that, after the proper exchange of messages, every femtocell can use their PRB_i simultaneously without interfere the other femtocells in G.

For the two mechanisms of interference management defined in this paper, the PRB_i assigned to each femtocell are chosen in a distributed and dynamic manner. Once femtocell i switches on, it starts monitoring the channel and creates the cluster G including its neighbours, that is, those cells with a measured power above a given threshold $I_{N_{th}}$. Then, femtocell i will interrogate femtocells in G about their PRB and will choose as PRB_i those RBs that are not being used by any other cell (see Figure 2) or those with the lower level of interference power. Femtocells inform about their PRB using HII messages. In Figure 2 femtocell F1 measures the interference power received from all the neighbour femtocells. In this example, femtocells with red coverage generate interference power in F1 above a threshold whereas femtocells with blue coverage generate interference power in F1 below the threshold. Therefore, F1 group G will be composed by femtocells F2, F3, F4, F5, F6 and F7. Looking at the table of $PRBs$, F1 can choose between RBs not used by any of the femtocells in G. Therefore, F1 can choose either RB7 or RB8.

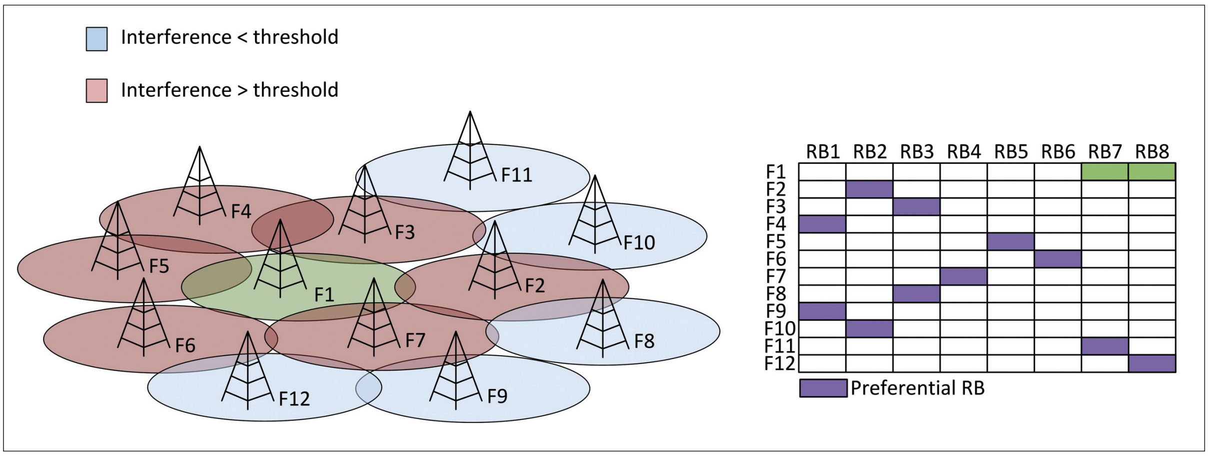


Figure 2. *Example of selection of Preferential Resource Blocks.*

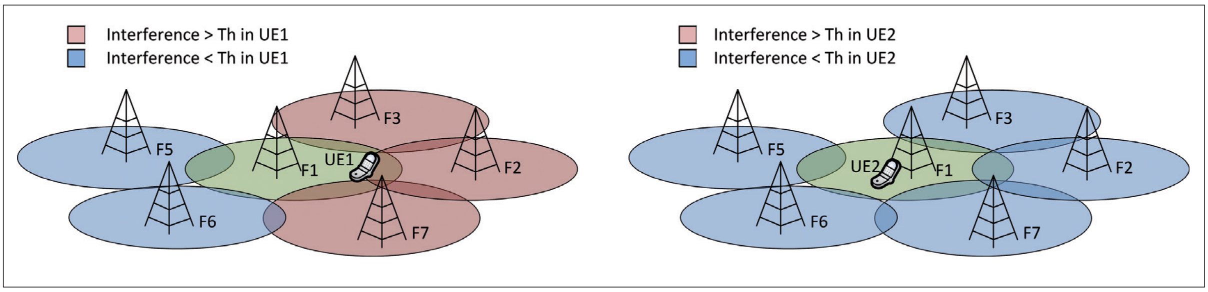


Figure 3. *Example of identification of critical users.*

2. Resource Allocation Schemes

The first approach, hereinafter referred to as X2-Basic, is based on [22]. Initially, every femtocell can use every RB. Each time a femtocell allocates any RB it must send a new HII message to inform its neighbours. Femtocells save in a table the information received through HII messages from its neighbours, so each femtocell knows at every moment the RBs under usage in G. When the level of interference measured in a RB by the femtocell is above a certain threshold $I_{UL_{th}}$, the femtocell blocks and stops using the RB unless it was within PRB_i. However, if the RB is one of the PRB_i, the femtocell continues using the RB and sends an IOI message to the neighbour/s supposed to be generating the interference, that is, all neighbours in the table using that RB. After a certain period of time T_r, the femtocell resets the RBs that have been blocked and starts using all RBs again.

In the second approach, called X2 with UE support (X2-UES), a UE j is classified as critical in relation to a cluster N of femtocells if the signal to noise plus interference ratio SNR_j experienced by the user is below a target SNR_{min}, where N is composed by all the femtocells generating to UE j an interference power I above a threshold $I_{DL_{th}}$. Specifically, a UE j with $SNR_j<SNR_{min}$ is considered as critical in relation to a group of femtocells N if the interference power it receives from each of the femtocells in N is above a threshold $I_{DL_{th}}$ and is not critical in relation to a group of neighbour femtocells M if the interference power it receives from each of the femtocells in M is lower than the same threshold. Hence, critical UE j is supposed to generate high interference to the femtocells in N and low interference to femtocells in M. Therefore, the set of RBs assigned to UE j should not be used by any UE of femtocells in N although they can be used by any UE of femtocells in M. Figure 3 illustrates an example of this operation. In the example, UE1 and UE2 of femtocell F1 experience low SNR from some femtocells. They measure the interference power received from all the neighbor femtocells. Femtocells with red coverage generate interference power above the threshold and femtocells with blue coverage generate interference power below the threshold. Therefore, UE1 is a critical user in relation to the group N of femtocells, composed by femtocells F2, F3 and F7, and is not critical in relation to the group M, composed by F5 and F6. UE2 is not a critical user in relation to any of the neighbor femtocells. It is important to highlight here that the identification of critical users is made by the serving femtocell, that accquires the interference information via the measurement reports that the UE sends in its normal operation.

The femtocell allocates resources to UEs according to their classification as critical or not. When a UE of femtocell i is classified as critical in relation to a group of femtocells N, it gets only PRB_i. The serving femtocell i must communicate this decision to the femtocells in N through a HII message, in order to avoid them using these RBs. Hence, each femtocell has to save in a table the information in the messages received from neighbours, to know which PRB are under use at every moment. When UEs are not classified as critical, they can be scheduled to any free available resource. Free available resources are those that meet two conditions: they are neither used by critical users in the serving femtocell nor by the femtocell with preference over these RBs, information that has been provided using X2 messages.

Finally, it is worth noting that, in the allocation of UL resources, proportional fair scheduling is used.

3. Performance Evaluation

A. Simulation setup

This section assesses the performance of X2-Basic and X2-UES together with the frequency reuse 1 scheme, that is, the case in which not any ICIC mechanism is applied. Simulation models follow 3GPP specification [10], more specifically focusing on the test case with an indoor cluster of femtocells. As a difference from [10], in this paper an ultra-dense deployment is considered, with 60 femtocells per floor, distributed in a grid of 5 rows of 12 femtocells, as depicted in Figure 4. The distance between femtocells in the

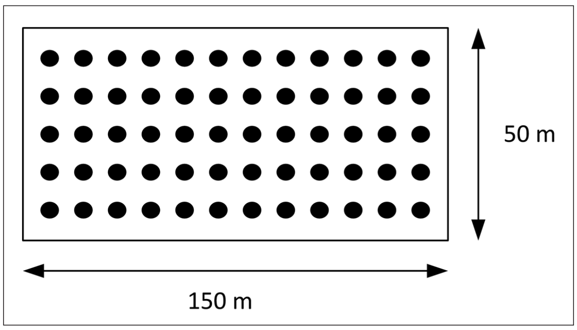


Figure 4. *Deployment scenario: 60 femtocells per floor.*

SIMULATION SETTINGS			
Carrier frequency	2 GHz	Neighbour threshold INth	-90 dBm
RB BW	180 kHz	X2-UES SNRmin	-7 dB
Available RBs	100	X2-UES IDLth	-90 dBm
Preferential RB per femtocell	3	X2-Basic IULth	-45 dBm
Users per femtocell	1-10	Transmission Time Interval	1 ms
Transmit power HeNB	29 dBm	Simulated time	60 s
Transmit power UE	23 dBm	X2-Basic Tr	50 ms
MCL	55 dB		

Table 1. *Simulation parameters.*

same row is 12.5 m and the distance between rows is 10 m. The height of each floor is 6 m. The channel model is the ITU Indoor Hotspot. Traffic is full buffer. Other important parameters in the simulation are detailed in Table 1.

B. Numerical results

Figure 5 and Figure 6 show the behaviour of X2-UES and X2-Basic algorithms as a function of the number of UE per femtocell. The benefits of ICIC mechanisms in terms of throughput per UE begin with a single user per femtocell and remain when the number of users per femtocell increases, as it is shown in Figure 5. In Figure 6 is represented the throughput per femtocell achieved by each one of the algorithms. The best overall performance is obtained by X2-UES while the worst performance corresponds to the non-ICIC case.

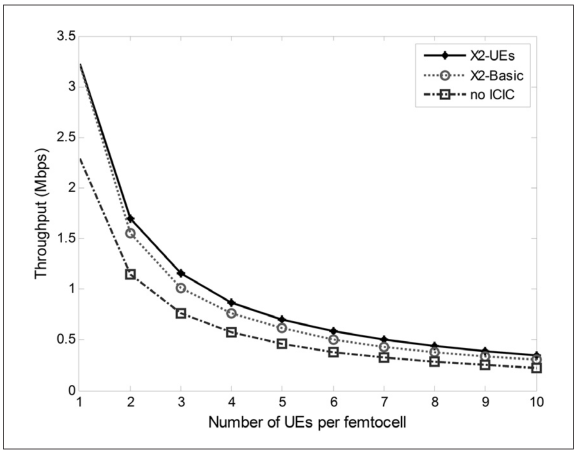


Figure 5. *Total throughput per user as a function of the number of simulated users per femtocell.*

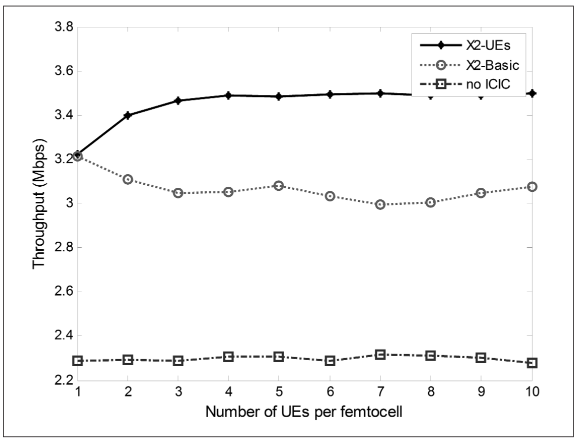


Figure 6. *Total throughput per femtocell as a function of the number of simulated users per femtocell.*

Scheme	Throughput [Mbps]	Improvement [%]
Without ICIC	2.3080	-
X2-Basic	3.0795	+33.43%
X2-UES	3.4855	+51.02%

Figure 6. *Total throughput per femtocell in Mbps.*

Table 2 compares the total throughput per femtocell achieved by each algorithm in the case of 5 UEs per femtocell. This table shows that using X2-Basic and X2-UEs the total throughput per femtocell can be increased more than 30% and 50 % with respect to non-ICIC case, respectively.

On the other hand, we have simulated the behaviour of the algorithms in less crowded scenarios. Figure 7 depicts the throughput per user of each algorithm as a function of the number of femtocells per floor. Again, the number of users per femtocell is 5. Results show that ICIC mechanisms are useful only in dense scenarios where the number of femtocells per floor is higher than 50, which means that users are close to the neighbours and interference is critical. Otherwise, throughput achieved by the three algorithms is almost equal.

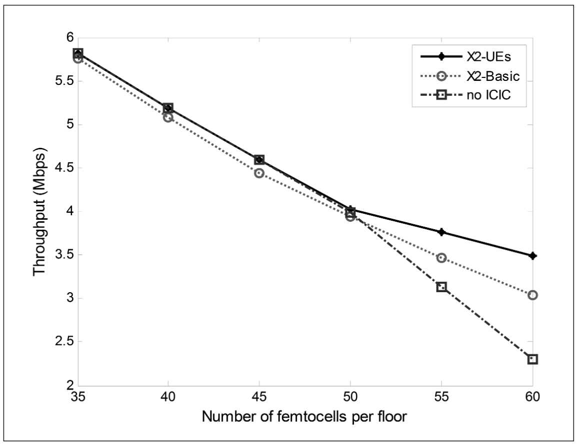


Figure 7. *Throughput per user as a function of the number of femtocells per floor.*

4. Discussion and Future Research

In this paper, we have proposed two dynamic and distributed resource allocation algorithms for interference management in ultra-dense femtocell deployments, based on the exchange of X2 interface messages defined from Release 10 of LTE-A onwards. Both algorithms make use of preferential RBs in a dedicated way at each femtocell if interference is high and share all the available RBs between femtocells otherwise. Indeed, the preferential RBs assigned to each femtocell are established in a self-organizing way. We have shown that the proposed mechanisms achieve a significant improvement in terms of total throughput per femtocell and mean throughput per user. We can remark that this improvement is even greater for X2-UES where, taking into account the relative position of users in relation to neighbour femtocells, the algorithm can assign dedicated resources only to critical users while reutilizing resources in the remaining users.

We leave as future work the study of the evolution of these ICIC approaches towards new emerging scenarios in which femtocells may not be static. This is the case of the scenario depicted in the European project METIS [23], in which femtocells are deployed in vehicles in order to overcome the fact that in-vehicle users experience nowadays a limited QoS due to the lack of mobility management and high penetration loss of the vehicle shell. Therefore, the proposed algorithms should be adjusted to the case in which femtocell positions may vary over time and the scheduling of preferential RBs has to be modified accordingly.

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References

[1] ITU-R Report M.2134, "Requirements related to technical performance for IMT-Advanced radio interface(s)," November 2008.

[2] www.sistelnetworks.com

[3] D. González, M. Garcia-Lozano, S. Ruiz, J. Olmos, V. Corvino, "Performance Evaluation of Downlink Interference Coordination Techniques in LTE Networks", IEEE VTC Fall, Ottawa, Canada, 2010.

[4] L. Chen L, D. Yuan, "Soft frequency reuse in large networks with irregular cell pattern: How much gain to expect?" In Proc of IEEE Personal, Indoor and Mobile Radio Communications, PIMRC 2009.

[5] L. Chen, D. Yuan, "Generalizing FFR by flexible subband allocation in OFDMA networks with irregular cell layout" in Proc. of IEEE Wireless Communications and Networking Conference Workshops, WCNC 2010.

[6] M.C. Necker, "A Graph-Based Scheme for Distributed Interference Coordination in Cellular OFDMA Networks". In Proc. of IEEE Vehicular Technology Conference, 2008. VTC Spring 2008.

[7] Y. Chang, Z. Tao, J. Zhang, C. Kuo, "A Graph-Based Approach to Multi-Cell OFDMA Downlink Resource Allocation". In Proc. of Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008.

[8] Y. Chang, Z. Tao, J. Zhang, C. Kuo, "A Graph Approach to Dynamic Fractional Frequency Reuse (FFR) in Multi-Cell OFDMA Networks. In Communications", In Proc of IEEE International Conference on Communications, 2009. ICC 2009.

[9] Y. Chen, K. Hoo, S. Kishore, J. Zhang, "Inter-cell Interference Management in Wimax Downlinks by a Stackelberg Game Between BSS". In Proc of IEEE International Conference on Communications, 2008. ICC 2008.

[10] 3rd Generation Partnership Project (3GPP). 3GPP TR 36.932, "Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN," March 2013.

[11] S. Sardelliti, A. Carfagna and S. Barbarossa, "Optimal resource allocation in femtocell networks based on Markov modeling of interferers' activity", EURASIP Journal on Wireless Communications and Networking, 2012.

[12] A. Imran, M. Bennis and L. Giupponi, "Use of learning, game theory and optimization as biomimetic approaches for self-organization in macro-femtocell coexistence", IEEE Wireless Communications and Networking Conference Workshops (WCNCW), 2012.

[13] M. Bennis and D. Niyato, "A Q-learning Based Approach to Interference Avoidance in Self-Organized Femtocell Networks", IEEE Global Communications Conference (GLOBECOM), 2010.

[14] H. Zhang, X. Chu, W. Ma, W. Zheng and X. Wen, "Resource allocation with interference mitigation in OFDMA femtocells for co-channel deployment", EURASIP Journal on Wireless Communications and Networking, September 2012.

[15] I.W. Mustika, K. Yamamoto, H. Murata, and S. Yoshida, "Potential Game Approach for Self-Organized Interference Management in Closed Access Femtocell Networks", IEEE 73rd Vehicular Technology Conference (VTC Spring), 2011.

[16] S. Park and S. Bahk, "Dynamic Inter-Cell Interference Avoidance in Self-Organizing Femtocell Networks", IEEE International Conference on Communications (ICC), June 2011.

[17] Y. Wu, H. Jiang and D. Zhang, "A Novel Coordinated Spectrum Assignment Scheme for Densely Deployed Enterprise LTE Femtocells", Vehicular Technology Conference (VTC Spring), May 2012.

[18] J. Liu, J. Wu, C. Jiming, P. Wang and J. Zhang, "Radio Resource Allocation in Buildings with Dense Femtocell Deployment", 21st International Conference on Computer Communications and Networks (ICCCN), August 2012.

[19] F. Tariq, L.S. Dooley and A.S. Poulton, "Virtual clustering for resource management in cognitive femtocell networks", 3rd International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), October 2011.
[20] 3rd Generation Partnership Project (3GPP). 3GPP TS 36.423, "X2 application protocol," March 2013.
[21] 3rd Generation Partnership Project (3GPP). TR 36.921, "FDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis," September 2012.
[22] Wenxin Liu, Chunjing Hu, Dongyan Wei, Peng, M. and Wenbo Wang, "An overload indicator & high interference indicator hybrid scheme for inter-cell interference coordination in LTE system," Broadband Network and Multimedia Technology (IC-BNMT), pp. 514-518, October, 2010.
[23] www.metis2020.com

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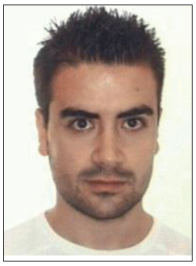

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