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مراجعة لطرق تجنب التشويش أو التدخل عبر الطبقة المتماثلة و المختلفة في شبكات خلية فيمتو

***شهريار سليم و**محمد حنيف**

*الجامعة الجوية، قسم الهندسة الكهربائية، إسلام آباد، الباكستان.

**جامعة فاونديشن، الحرم الجامعي راولبندي، قسم الهندسة الكهربائية، راولبندي، الباكستان.

الخلاصة

شبكات خلية الفيمتو هي الحل المقترح لمستخدمي الهاتف المحمول، للنشر في المنازل والأماكن المغلقة، وذلك لتحقيق سرعة تحميل عالية من الانترنت وإجراء مكالمات صوتية ذات جودة عالية. وتوفر شبكة خلية الفيمتو أيضا إغاثة لشبكة خلية الماكرو ذات التحميل المفرط من خلال خدمة مستخدمي الهاتف النقال في المنزل الذي من دون شبكة خلية الفيمتو ليتلقى الخدمة من خلال شبكة خلية الماكرو. لكن، وكما هو الحال مع جميع الشبكات اللاسلكية، شبكات خلية الفيمتو تعاني أيضا من مشكلة التداخل أو التشويش. وهذا التشويش يمكن تصنيفه إلى نوعين، تشويش بين طبقات غير متماثلة (بين خلايا الفيمتو وخلايا الماكرو) وتشويش بين طبقات متماثلة (بين خلايا الفيمتو). ولتجنب أو إدارة هذين النوعين من التداخل هو أمر حاسم لعمل خلية الفيمتو بالشكل الصحيح، أي توفير معدل مرتفع من البيانات وجودة صوت عالية لمستخدمي الهاتف النقال في الأماكن المغلقة. وقد تم اقتراح عدة تقنيات في الأبحاث الماضية تتناول تجنب هذه الأنواع من التدخلات. وهي الراديو الإدراكي، تخصيص الموارد، السيطرة على الطاقة، التعلم – ق (نوع من أنواع التعليم التعزيزي)، والتحكم في الوصول. من خلال هذه المراجعة نستنتج أن تقنيات الراديو الإدراكي والسيطرة على الطاقة والتعلم – ق المستخدمة في تجنب التدخل أو التشويش، تتفوق على تقنيتي تخصيص الموارد والسيطرة على الطاقة من حيث الكفاءة العالية وانخفاض أو اعتدال درجة التعقيد.

A review of techniques to avoid cross-tier and co-tier interference in femtocell networks

Shahryar Saleem* and Muhammad Haneef**

**Department of Electrical Engineering, Air University, Islamabad, Pakistan*

***Department of Electrical Engineering, Foundation University Rawalpindi Campus, Rawalpindi, Pakistan*

**Corresponding author: shahryar.saleem@mail.au.edu.pk*

ABSTRACT

Femtocell networks are the proposed solution for deployment in homes that enables an indoor mobile user to achieve high speed downloading from the internet and make good quality voice calls. A femtocell network also provides relief to an overloaded macrocell network by servicing mobile users at home, those without the femtocell network have to be served by the macrocell. However, like all wireless networks, femtocell networks suffer from the problem of interference. This interference can be divided into two types, Cross-tier (between femtocells and macrocells) and Co-tier (between femtocells). The avoidance or management of these two types of interference is crucial to the proper functionality of a femtocell, i.e. to provide high data rate and high quality voice calls to indoor mobile users. Several techniques have been proposed in literature to avoid these types of interference. These are cognitive radio, resource allocation, power control, Q-learning and access control. The findings in the review indicate that, interference avoidance techniques such as cognitive radio, power control and Q-learning outperforms the resource allocation and access control interference avoidance techniques in terms of high efficiency and low/moderate complexity.

Keywords: Co-tier interference; cross-tier interference; femtocell interference avoidance review; femtocell networks.

INTRODUCTION

Femtocell networks are the proposed solution to provide high quality wireless links and good spatial usage (Chandrasekhar *et al*., 2008). Femtocell is a low powered, low cost, plug and play device that increases the capacity of the wireless link indoors. Typical radius of a femtocell coverage area is around 40 m and the transmit power of a femtocell is usually less than 0.1 W (≤ 20dBm) (Chandrasekhar *et al.*, 2008). The femtocell is connected to the service provider network through optical cables or high speed digital subscriber line (DSL). A Femtocell network consists of a femtocell base station (FBS) and a femtocell user. Different femtocell terminologies are used by 3GPP and LTE standards. In 3GPP terms (3GPP TR 25.820 V8.0.0, 2008; 3GPP TR 25.968 V10.0.0, 2011), a FBS is known as a home node B (HNB) and a femtocell user is known as a home user equipment (HUE). Similarly, the macrocell base station (MBS) is in 3GPP terminology is known as macro-node B (MNB) and the macrocell user is known as the MUE. In Long Term Evolution (LTE) terminology, the FBS is known as home evolved node B (HeNB) and the MBS is termed as evolved node B (eNB). The HNB communicates with the HUEs that are present indoors and provide excellent voice and data traffic experience. The main benefits of femtocell networks are;

- Easy installation. Just plug the femtocell into the DSL or cable modem. No configuration is required by the home user.
- Seamless handover. Mobile phones associated with the femtocell automatically switch to the femtocell from the macrocell upon arrival into their homes.
- Excellent voice quality at home.
- High data rates for fast streaming and downloads by the indoor user.
- Increased mobile phone battery life. The mobile phone associated with a femtocell experience increase in battery life as compared to when connected to the macrocell.

The femtocell architecture is shown in Figure 1 (Ahmed *et al*., 2014). The femtocells usually operate in co-channel access mode in which the macrocell and the femtocell share the same frequency spectrum. Furthermore, closed access mode (Perez *et al*., 2010; Gur *et al*., 2010) is mostly chosen by the home users, as it provides security and privacy to the femtocell owners. The co-channel access and the closed access mode give rise to the most destructive type of cross-tier and co-tier interference.

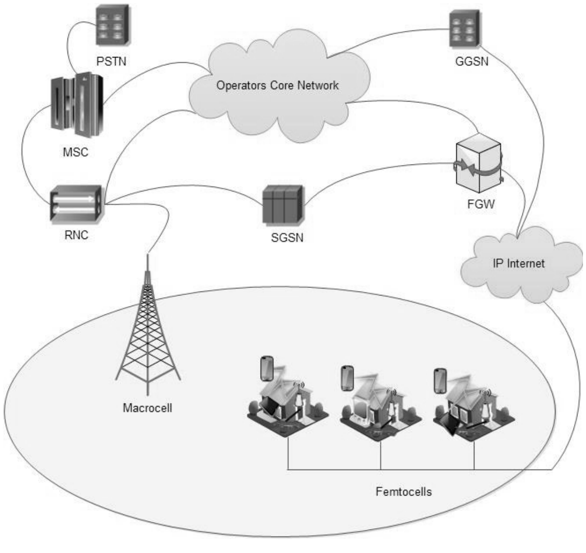


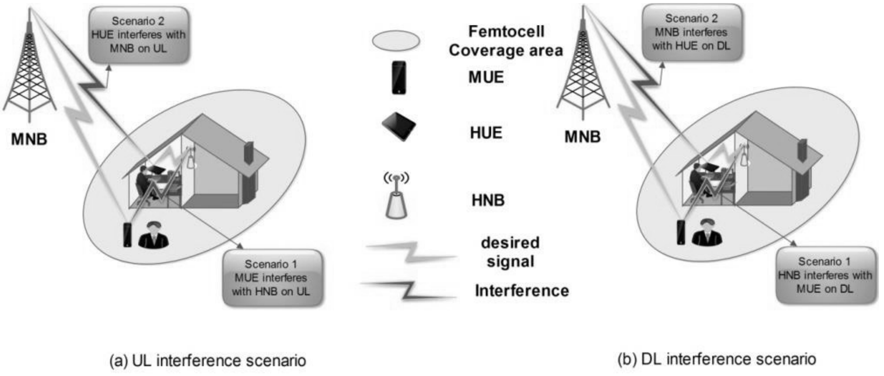
Fig. 1. Femtocell architecture

FEMTOCELL INTERFERENCE

Interference results, when a receiver picks up an undesired signal on the same channel on which it is supposed to receive a desired signal. Interference arises in almost every wireless networks whether it is a WiFi or a wireless sensor network (WSN) Rathna & Sivasubramanian (2014). The measure of the amount of interference received is given by the signal to interference and noise ratio (SINR). In case of femtocells, typically two types of interference exists, one is cross-tier interference and the other is co-tier interference. Both of these interference types are particularly severe when closed access mode coupled with co-channel operation is employed in the network. An explanation of both these interference types is given below.

Cross-tier interference

Cross-tier interference, as the name implies is between entities that belong to different tiers or networks (Saquib *et al.*, 2012; Perez *et al.*, 2009; Yavuz *et al.*, 2009). Such interference exists between femto-macro and macro-femto networks. In the uplink (UL) direction (direction of signal from a mobile to its base station), a MUE near a HNB and away from its MNB transmitting in the UL direction at high power will drown the UL signal from the HUE to its HNB (scenario 1 in Figure 2 (a)), or a HUE near the MNB can drown the UL signal from a far away MUE transmitting to its MNB on the same channel (scenario 2 in Figure 2 (a)). In the downlink (DL) direction (direction of signal from a base station to its mobile), a HNB transmitting to its HUE on the DL will drown the signal of the MNB to its MUE on the DL using the same channel (scenario 1 in Figure 2 (b)). Similarly, a MBS transmitting at high power to its MUE located in the coverage area of a HNB will drown the DL signal from a HNB to its HUE (scenario 2 in Figure 2 (b). Both scenarios for UL and UL interference are shown in Figure 2.



(a) UL interference scenario

(b) DL interference scenario

Fig. 2. Cross-tier interference scenarios: (a) UL and, (b) DL

Co-tier interference

Co-tier interference is the interference between entities that belong to the same tier or network (Saquib *et al.*, 2012; Perez *et al.*, 2009; Yavuz *et al.*, 2009). In case of a femtocell network, the co-tier interference occurs between neighbouring femtocells. In the UL direction, a HUE (aggressor) causes interference to the nearby HNB by drowning the signal from the HNB's served HUE. In the DL direction, a HNB causes interference to the nearby HUEs belonging to different femtocell networks. Co-tier interference scenario is depicted in Figure 3.

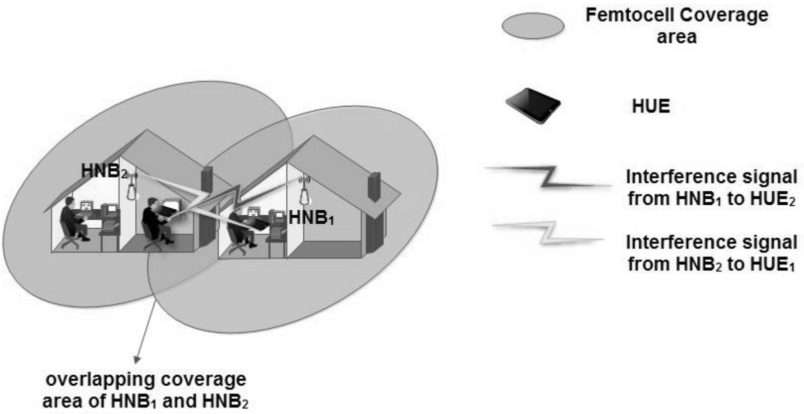


Fig. 3. Co-tier interference scenario

The above mentioned interference types have severe impacts on the performance of the femtocell network as well as the macrocell network. The severity of the interference is due to the co-channel spectrum access of femtocell plus closed access mode. Due to these two interference types the advantage of high capacity wireless links diminish. Thus, in order to extract the most out of the femtocell network, schemes are necessary to avoid both the cross-tier and co-tier interferences.

FEMTOCELL/MACROCELL CAPACITY

Just as avoiding cross-tier and co-tier interference is of utmost importance for proper functioning of a femtocell inside a macrocell. The femtocell and macrocell capacity is also vital. Capacity, usually measured in b/s/Hz is the rate at which data is being transferred from base station towards its UE and vice versa.

RELATED WORK

Although there has been some literature on the review of interference avoidance in femtocells, most of them only considered a few interference avoidance techniques and left out the rest. In Chandrasekhar *et al.* (2008), the authors only considered time and frequency hopping, directional antennas and adaptive power control. The authors left out interference avoidance techniques such as cognitive radio (CR), Q-learning and access control. Authors in Ahmed *et al.*(2014) left out the power control interference avoidance technique. In contrast, authors in Mhiri *et al.*(2013) reviewed almost all techniques. All of the above mentioned papers only provided a comprehensive review of the techniques at the end. In this paper, we take a step further and provide a comparison of individual techniques in CR, resource allocation, power control, Q-learning and access control. Furthermore, a comprehensive comparison between the interference avoidance techniques is presented at the end.

REVIEW

In this section, a comprehensive review of techniques proposed in literature that have been used to avoid cross-tier and co-tier interference is performed. The techniques under review are cognitive radio, resource allocation, power control, Q-learning and access control. Our performance metrics are the complexity (implementation and computational) and efficiency (interference and throughput). These performance metrics are further classified into high, moderate and low. High complexity implies that, both the implementation costs and signalling overheads are high. Moderate complexity implies that the implementation cost is higher and the signalling overhead is lower or the implementation cost is lower and the signalling overhead is higher. Low complexity implies that both the implementation cost and signalling overheads are low. In terms of efficiency, high efficiency implies high femtocell throughout and lower femtocell interference. Moderate efficiency implies that the femtocell throughput is low and femtocell interference is lower. Low efficiency implies that the femtocell throughput is low and the interference from the femtocell is high. In our review, only the most cited journals and conference papers from the past and the recent research papers have been studied.

Cognitive radio based femtocell interference avoidance

Mitola (2000) proposed the idea of cognitive radio (CR). The idea of using CR to minimise the underutilisation of the frequency spectrum was proposed by FCC ET docket No. 03-108. 2005 and Benedetto *et al.* (2008). In CR terms, the cognitive enabled femtocell base station is often termed as a secondary base station (SBS), the user accessing the SBS is termed as secondary user equipment (SUE). The macrocell base station is termed as primary base station (PBS) and its user is termed as primary user equipment (PUE). Three secondary techniques based on the primary CR technique have been proposed in the literature. These are sensing and transmission, CR and resource scheduling, self-organised and self-optimised interference avoidance techniques.

Sensing and transmission based interference avoidance techniques

A combination of CR and a conventional femtocell was proposed to reduce the cross-tier interference from femtocells to macro-users (Gur *et al*., 2010). In the paper, the authors proposed a cognitive radio femtocell base station (CFBS). The CFBS senses the radio environment and constructs the radio environment map (REM). The REM consists of the spectrum measurements performed by the CFBS. The REM is used by the CFBS to assign resources to its subscribed users, thus avoiding cross-tier interference. The authors compared two scenarios, scenario 1, in which SUEs sense the radio frequency spectrum and assigns resources to itself based on the sensing results and scenario 2, the proposed CFBS senses the spectrum and allocate resources to SUEs based on the sensing results. The results showed that scenario 2 increased the overall throughput of the cognitive femtocell network. In Zhang *et al*. (2010), the authors proposed a CR based interference avoidance scheme for LTE-A system. In their scheme, a HeNB allocated component carriers (CC) to its UEs for transmission. However, due to the presence of neighbour HeNBs using the same CCs, the HeNB has to cognitively allocate CCs to its UEs so that no co-tier interference takes place. The allocation of CC is done by the UE. The UE performs path loss measurements based on the reference symbol received power (RSRP) from its HeNB and neighbouring HeNBs. If the RSRP on one of the CCs is low, then the HeNB selects that CC as the primary CC. Thus, co-tier interference is avoided. Authors in Li *et al*. (2009) and Li & Sousa (2010) proposed an opportunistic channel scheduler for co-tier interference avoidance in 3G and 4G systems, which selects the best channel from the interference signature perceived by the cognitive femtocell. The results indicate lower SINR outage probability with cognitive channel reuse as the number of femtocells increase. The idea of opportunistic channel scheduler is again utilised in Li & Sousa (2012) to avoid cross-tier interference. In this case open access network is considered. First the authors try to limit the interference caused by the femtocell to the macrocell user by opportunistically allocating orthogonal channels. If the channel allocation does not solve the interference issue, then a handover to the femtocell is considered. In Oh *et al*. (2010), the authors proposed to sense the UL signal received from the PUE and select the best sub-channel for the femto-user. The authors used the UL band for both sensing and transmission. A time division duplex (TDD) femto scheme operating in UL spectrum was proposed in Pantisano *et al*. (2010). UL spectrum was chosen, because the position of the PUE's was unknown and so interference avoidance could not be guaranteed. The PBS position is known and so interference to the PBS can be controlled. Compared to that Berangi *et al*. (2011) and Ahmed *et al*. (2011) proposed an alternative TDD CR femtocell network (CRFN) scheme in the DL macrocell spectrum. The proposed scheme mitigates cross-tier interference by employing UL sensing and DL transmission. The SBS senses the UL for the presence of any PUEs located nearby. If PUEs are detected, the SBS does not employ those PUE resources.

The rest of the resources are used by the SBS for transmission. In order to increase the femtocell capacity, the SBS employs water-filling power allocation. Thus, an interweave and underlay approach is applied, that reduces the outage probability to PUEs and also increase the cognitive femtocell capacity. A hybrid cognitive approach (HCA) for cross-tier interference avoidance is proposed in Mach & Becvar (2014). In the paper, the authors propose that the femtocell performs power control on its allocated channels to mitigate interference to macrocell users. In order to increase the quality of service (QoS) of the femtocell, the femtocell can also access the unused resources via cognitive sensing. In Wang *et al*. (2013), the authors propose a cognitive relay to increase the femto-user capacity, while reducing femto to macro interference. The relay unit relayed information about nearby PUEs, so that SUEs can make better decisions as to which slot should be used. Table 1 presents the important characteristics of the techniques mentioned above.

Table 1. Comparison of sensing and transmission based interference avoidance approach

Reference	**Sensing and transmission (UL or DL) scheme**	**Interference mitigated (cross-tier or co-tier)**	**Access Mode (closed, open, hybrid)**	**Complexity**	**Efficiency (interference and/ or throughput)**
Gur *et al.* (2010)	DL sensing and DL transmission	Cross-tier	Closed	**High:** Too much signalling to and from the CFS to the CFBS	**High:** Capacity: 18.90 Packets/timeslot
Zhang *et al.* (2010)	DL sensing and transmission	Co-tier	Closed and Open	**Low**	**High:** Spectral Efficiency is high
Li *et al.* (2009), (2010)	DL sensing and transmission	Co-tier	Closed	**Low:** Sensing and opportunistically allocation spectrum	**High:** Low outage probability almost 18%
Li *et al.* (2012)	DL sensing and transmission	Cross-tier	Open	**Low:** Sensing and allocating orthogonal channels to FAP	**High:** The PUE outage probability is less than 10%
Oh *et al.* (2010)	UL Sensing UL transmission	Cross-tier	Closed	**Low:** Sensing only spectrum holes in UL	**High:** Capacity:7.5 b/s/Hz for 30 femtocells

Pantisano *et al.* (2010)	UL Sensing UL transmission	Cross-tier	Closed	**Low:** Sensing only in spectrum holes	**Low:** Capacity: 3.5 b/s/Hz for 16 femtocells which decrease to less than 1 b/s/Hz for 100 femtocells
Berangi *et al.* (2011)	UL Sensing DL transmission	Cross-tier	Closed	**Low:** Sensing spectrum holes and grey spaces	**High:** Outage: 12 % at cell edge Capacity: 7 b/s/Hz at cell edge
Mach & Becvar (2014)	DL sensing and transmission	Cross-tier	Closed	**Low**	**High:** FUE traffic served 88% Sensing overhead 3.44<5.00 for CF
Wang *et al.* (2013)	Decode and forward scheme	Cross-tier	Closed	**High:** Maintenance of relay node	**High:** 1.25b/s for 20dB macrocell SINR requirement

CR and resource scheduling information based interference avoidance techniques

In this approach, a femtocell performs energy detection or any other form of sensing to detect the PUEs either on the UL or DL. To reinforce the sensing results, the femtocell obtains the scheduling information of the PUEs from PBS. After comparison of the sensing results with the resource scheduling information obtained from the PBS, the femtocell can make a correct choice to use the resources that do not cause any interference to PUEs. Huang & Zhu (2013) proposed a joint opportunistic interference avoidance scheme using Gale-Shapley spectrum sharing (GSOIA) in which the cognitive femtocell access point (CFAP) listens to the scheduling information from the MBS. The MBS broadcasts the scheduling information with high power in the signalling channel so that the MUEs as well as the CFAP can get the resource map. Sahin *et al.* (2009) proposed that a femtocell can avoid interfering with a MUE in the UL and DL if the femtocell uses the resource blocks (RBs) of those MUEs that are located far away from it. In Cheng *et al.* (2010), the authors also focused to exploit the user level scheduling information to avoid cross-tier interference from a femtocell to MUEs in the DL only. However, rather than obtaining the scheduling information directly from the MBS, the authors proposed to cognitively sense the user level scheduling information from the MBS by assigning a special identity to the FBS (meaning that the FBS connects to the MBS pretending to be a MUE). In comparison to the approaches above, the authors in Guvenc *et al.* (2010) proposed a scheme for

3GPP femtocell in which a HeNB does not require an X2 interface connection to the eNB to obtain the MUE resource scheduling information. The scheme is based on DL and UL coupling of the MUE resources. Table 2 provides a comparison of different CR and resource scheduling information techniques.

Table 2. Comparison of CR and resource scheduling information based interference avoidance technique

Reference	**Scheme**	**Access mode (closed, open or hybrid)**	**Interference mitigated (cross-tier or co-tier)**	**Complexity**	**Efficiency (interference and/or throughput)**
Huang & Zhu (2013)	Opportunistic interference avoidance using gale-shapely spectrum sharing (GSOIA)	Closed	Cross-tier and co-tier	**High:** 1. In practice CR femtocells and the MBS do not belong to the same network. Hence, "eavesdropping" is not easy. 2. Not easy to decode the resource map.	**High:** Overall served femtocell throughput is high when the number of femtocells increases
Sahin *et al.* (2009)	Joint spectrum sensing and resource scheduling	Closed	Cross-tier	**High:** 1. Backhaul from the MBS increases cost (especially to every femtocell deployed) 2. Not easy to decode scheduling information from the MBS	**High**
Cheng *et al.* (2010)	Cognitively sense the resource scheduling information from the MBS by assigning a special ID to the femtocell BS	Closed	Cross-tier	**High:** 1. The MNB keeps a list of all its serving MUEs. Assigning a special ID to a femtocell means that the MNB has to put this femtocell into its list of serving MUEs. This increases the complexity of operation at MNB. 2. Also decoding the PDCCH to get the scheduling information is a complex process	**High**
Guvenc *et al.*(2010)	Resource partitioning, sensing and coupling of UL and DL resources	Closed	Cross-tier	**Moderate:** No requirement of X2 interface from the MNB to extract the scheduling information	**High:** Increased SINR for both UL and DL for both MUE and HUE

Self organised and self optimised CR based interference avoidance techniques

The basic idea behind the self configuration and self optimisation is that a FBS senses the radio frequency spectrum and decides to use the spectrum based on the sensing results, and also due to the fact that the radio environment can change abruptly, the FBS also needs to keep up with the changing radio frequency environment to optimise its network. Perez *et al*. (2009) proposed self organisation and self optimisation schemes to avoid cross-tier interference from OFDMA enabled femtocells to MUEs. The only drawback is the increased complexity, which is due to the processing overhead for the sub-channel broker. As opposed to the centralised approach adopted by Perez *et al*. (2009), the authors in Barbarossa *et al*. (2010) and Mustika *et al*. (2011) proposed a decentralised approach for non co-operative femtocells to self organise and self optimise in OFDAM based networks. In Barbarossa *et al*. (2010), OFDMA based cognitive femtocells were proposed to sense the radio frequency spectrum and assigns spectrum holes based on the sensing results to self-organise and avoid interference to macro-UEs. In Mustika *et al.* (2011), the authors propose that a self-organised resource allocation scheme be modelled as a potential game, which guarantees the convergence to Nash equilibrium, as long as the distributed sequential play based on the best response strategy is adopted. The authors propose that the HUE has cognitive abilities in it to sense the frequency spectrum and allocated the best channel for its communication. A trade off between transmission energy for frequency resource to reduce the downlink transmission power and obtain a given target bit rate is presented in Bennis *et al*. (2011). A radio resource management scheduler is proposed, which first selects the femto user's transmission parameters such as QoS and power constraints. Then according to these parameters, scheduler allocates number of RBs, modulation and coding scheme and transmission power. Table 3 presents some key features of techniques discussed above.

Table 3. Comparison of self organised and self optimised CR interference avoidance approach

Reference	**Scheme**	**Access mode (closed, open or hybrid)**	**Interference mitigated (cross-tier or co-tier)**	**Efficiency(interference and/ or throughput)**
Perez *et al.* (2009)	Co-channel assignment and centralised planning	Closed	Cross-tier	**High:** 1. Low outage probability 2.35% 2. High femtocell throughput 123.64 Mbps
Barbarossa *et al.* (2010)	Distributed framework in which each femtocell senses and makes the best decision	Closed	Cross-tier	**Low:** 2.5 Mbps for femtocells

Mustika *et al.* (2011)	Each femtocell self organises and allocates RBs according to sensing results	Closed	Cross-tier and co-tier	**Moderate:** Femtocell throughput is 20Mbps for 5 RBs. MUE throughput is 1.85 Mbps for one apartment block but decreases as the number of blocks increase.
Bennis *et al.* (2011)	A RRM scheduler selects the QoS and power constraints and then based on the constraints allocates a RB to FBS	Closed	Cross-tier	**High:** Low femto and macro outage probability

Resource allocation based interference avoidance techniques

In resource allocation approach, resources are allocated to both femtocells and macrocells to reduce the cross-tier and/or co-tier interference and also increase the capacity (b/s/Hz) of both femtocells and macrocells. Authors in (Chandrasekhar & Andrews, 2008) and (Chandrasekhar & Andrews, 2009) proposed fixed frequency allocation for both femtocell and macrocell. Authors in Yi *et al.* (2009) proposed a partial co-channel deployment scheme that consists of a femtocell/macrocell shared band and a macrocell dedicated band. Chowdhury *et al.* (2010) proposed a dynamic frequency re-use scheme to divide the whole macrocell frequency band B into 3 equal parts B_{m1}, B_{m2} and B_{m3}. Each of the three sectors of the macrocell uses any of the three frequency bands. Saleem & Horace (2012) proposed an orthogonal resource allocation for femtocells to mitigate co-tier interference between them. The closed access femtocells are allocated orthogonal RBs, while the open access femtocells' coverage area is divided into inner and outer coverage areas. The inner coverage area of an open access femtocell will use the RB that is allocated to the nearby closed access femtocell. The outer coverage area of the femtocell will use the RB that is allocated to a far away femtocell. A cooperative resource allocation for OFDM femtocells based on enhanced modified iterative water-filling (EMIWF) is proposed in Lee *et al.* (2011). The designed algorithm takes into account cell capacity and traffic load during power allocation. In terms of fairness, the proposed EMIWF performs better than a modified iterative water-filling (MIWF), while in terms of capacity; the MIWF gives slightly high b/s/Hz for FBS to FUE distance of 10 m compared to EMIWF. The only drawback in terms of complexity is that the cooperation requires an X2 interface between FBS, which should be delay intolerant. A price-based resource allocation for OFDMA femtocells has been presented in Kang *et al.* (2012) where the macrocell puts a price on the interference from femtocell users. Sparse and dense femtocell deployment scenarios are considered. The results show that the MBS revenue increases as a function of interference threshold Q. In Zhang *et al.* (2012), authors proposed resource allocation with interference mitigation in OFDMA femtocells for co-channel deployments. The authors assume a non-cooperative game in which each femtocell assigns sub-channels to its users and then allocate power to those sub-channels. The authors perform this work for the UL. Results show improved capacities for both femtocell and macrocell. Fair resource allocation for OFDMA femtocell with macrocell protection has been proposed in Ha & Le (2014). The objective was fair resource sharing for users in femtocell to maximise the total spectral efficiency of all femtocells subject to protection constraints for prioritised macrocell users. The results indicate that the proposed solution closely follows the optimal solution for total minimum spectral efficiency of femtocells. A demand based spectrum orthogonalisation scheme for interference avoidance in LTE-advanced network was proposed in Siti *et al.* (2014). The objective is to maximise the overall system throughput based on the requirement of physical spectral resources to satisfy the users' traffic demand. The results show that the proposed scheme provides lower macrocell throughput than that with dedicated frequency allocation (DFA). However, the proposed scheme outperforms all other schemes in terms of femtocell throughput. Table 4 presents the key feature of orthogonal resource allocation techniques.

Table 4. Orthogonal resource allocation techniques

Reference	**Scheme**	**Access mode (Closed, open or hybrid)**	**Interference mitigated (cross-tier or co-tier)**	**Efficiency (interference and/or throughput)**
Chandrasekhar & Andrews (2008),(2009)	Dedicated/ fixed frequency allocated to macro-BS and femto-BS.	Closed	Cross-tier	**Moderate:** 7 b/s/Hz for 10 femtocells. For 100 femtocells the throughput is less than 3 b/s/Hz).
Yi *et al.* (2009)	Partial co-channel deployment that consists of femto/macro shared band and a macro dedicated band.	Closed	Cross-tier	**Moderate:** Femto throughput is approximately 2.9 Kbps which decreases as the number of femtocell increases.
Chowdhury *et al.* (2010)	Whole frequency band is divided into 3 sub-bands. These sub-bands are allocated to femtocells and macrocells so as to avoid interference	Closed	Cross-tier and co-tier	**High:** Low outage probability approximately 20 % outage
Saleem & Horace (2012)	Allocate orthogonal frequency to closed access femtocells, while open access femtocells use different inner and outer frequency bands	Closed and open	Co-tier	**High:** 1- Low HUE interference probability approximately 20% 2- High capacity: only 5 RBs used by all 15 femtocells (33%)

Lee *et al.* (2011)	Cooperative resource allocation based on enhanced modified iterative water-filling (EMIWF)	Closed	Co-tier	**High:** 1-EMIWF provides better fairness than modified iterative water-filling (MIWF) 2- In terms of average cell capacity the MIWF-4 cell provides slightly high capacity than EMIWF at FBS to FUE distance of 10m.
Kang *et al.* (2012)	Price-based resource allocation in which MBS puts price on the interference caused by the femtocells	Closed	Cross-tier	In terms of MBS revenue, the larges the interference constraint Q that larger the revenue that the MBS generates.
Zhang *et al.* (2012)	Resource allocation with interference mitigation in OFDMA femtocells for co-channel deployment	Closed	Cross-tier	**High:** 1-Total capacity of femtocell system is 10x10^9 bps for 50 femtocells with 6 users in each femtocell. 2-Macrocell capacity is almost 5.5x10^7 for 50 femtocells with 6 users in each femtocell.
Ha & Le (2014)	Fair resource allocation for OFDMA femtocell networks with macrocell protection	Closed	Cross-tier	**High:** 5.5b/s/Hz for more than 1000 femtocells inside the macrocell
Siti *et al.* (2014)	Demand based spectrum orthogonalisation scheme for interference avoidance in LTE-advanced HetNets	Closed	Cross-tier and co-tier	**Moderate for macrocell** For 20 femtocells the throughput is 10 Mbps **High for femtocell** For 20 femtocells, the throughput is 180Mbps

Clustering based resource allocation approaches for interference mitigation have been proposed in the literature to mitigate cross-tier and co-tier interference. Li *et al*. (2010) and Li *et al*. (2011) proposed a combination of frequency bandwidth dynamic division and clustering algorithm (CFCA). The entire frequency band is divided into two portions. One portion is dedicated for the MNB use. The other portion is shared between HNB and MNB. The MNB dedicated portion effectively solves the dead zone problem. For the shared portion, a clustering algorithm is proposed, which puts the HNBs into clusters based on their geographical locations. Graph theory mathematics is used to put different HNBs into the same cluster. The only drawback is the processing load on femto-GW, which has to allocate transmit power and sub-channel allocation. In Li *et al*. (2012), the authors propose a dynamic clustering based sub-band allocation scheme (DCSA), in which the DCSA constructs a weighted interference graph based on user measurement report. A max k- cut clustering algorithm based on the weighted interference graph is used to disjoint the femtocells into different clusters to reduce inter-femto-interference (IFI). Lastly, a heuristic algorithm assigns sub-bands to the clusters to increase the SINR of femtocells. The authors in Hatoum *et al.* (2011) propose that each femtocell creates its one-hop neighbouring list, which consist the identities of femtocells interfering with its user. This list is shared with all interfering femtocells. The femtocell having the highest degree of interference becomes the cluster head (CH) and all other neighbours become the cluster-members. The CH then allocates resources to its members based on min-max optimisation problem. To avoid interference between femtocells of different clusters using the same resources, each affected femtocell resolves contention on the collided resources by sampling a Bernoulli distribution. Authors in Abdelnasser *et al.* (2014) proposed a clustering, sub-channel and power allocation in a semi-distributed manner. In their approach, the femtocell gateway (FGW) is responsible for assigning femtocells into disjoint clusters. After the formation of disjoint clusters, one FAP becomes a cluster head (CH) and allocates sub-channels and power to other FAP in its cluster. Table 5 presents the key features of the above mentioned techniques.

Table 5. Clustering based resource allocation techniques

Reference	**Scheme**	**Access mode (Closed, open or hybrid)**	**Interference mitigated (cross-tier or co-tier)**	**Efficiency (interference and/or throughput)**
Li *et al.* (2010), (2011)	Clustering of femtocells based on the interference threshold distance	Closed	Cross-tier and co-tier	**High:** Femtocell throughput is almost > 1000 bits/Hz
Li *et al.* (2012)	Construct an interference graph, then cluster femtocells based on interference graph	Closed	Co-tier	**Moderate:** 1- Average spatial SINR of proposed scheme is lower than fixed spectrum allocation 2- Average femtocell throughput is higher for small femtocell densities but decreases as the femtocell density increases
Hatoum *et al.* (2011)	A cluster head (CH) allocates resources to its cluster members (CMs)	Closed	Co-tier	**High:** Femtocell throughput is higher
Abdelnasser *et al.* (2014)	Joint clustering, sub-channel and power allocation	Closed	Co-tier	**High:** 1- Clustering FAPs transmit more power (more than 3 mW) 2- Clustering FUEs interference is decreased

Fractional frequency reuse (FFR) approach has been proposed by in the literature. The basic idea behind FFR is to divided the whole frequency spectrum into several smaller segments and allocate the smaller segments such that femtocells and macrocells use orthogonal spectrum in the same area. In Lee *et al*. (2010) (a) and Lee *et al*. (2010) (b), the authors proposed cross-tier interference mitigation framework based on FFR for LTE and OFDMA based femtocells. The same idea has been adopted in Bouras *et al*. (2012) for LTE based femtocells. The total available frequency band is divided into several bands. One band is used for the inner coverage area and has a reuse factor of 1. The femtocells in the outer coverage area can use any other band except the band that has been allocated to the outer converge area. In Tariq *et al*. (2011), the authors proposed a hybrid recourse management algorithm (HRMA), which is also based on FFR. In addition to the division of the whole frequency band into several bands, the proposed algorithm also keeps a reserved frequency band $f_{R,}$ which is used to settle severe interference problems between femtocells. An optimal static FFR (OSFFR) scheme is proposed in Saquib *et al*. (2013). In that, the authors compare the proposed scheme to three different FFR schemes namely, strict FFR, soft FFR, and FFR-3 schemes. The proposed scheme outperforms other three schemes in terms of outage probability, average network sum rate and average spectral efficiency. The key characteristics of the proposed FFR techniques are presented in Table 6.

Table 6. Fractional frequency reuse based interference avoidance techniques

Reference	**Scheme**	**Access mode (Closed, open or hybrid)**	**Interference mitigated (cross-tier or co-tier)**	**Efficiency (interference and/or throughput)**
Lee *et al.* (2010)	Fractions of the frequency band is allocated to both femtocell and macrocell	Closed	Cross-tier and co-tier	**High:** 1- High macro and femto throughput (for 180 femtocells, the data rate for macro+femto users is more than 100Mbps at macrocell edge 2- For SINR threshold of 30 dB, the outage probability of macro+femto users is 0.85 which is less than FFR-3 and No FFR-3
Lee *et al.* (2010)	Fractional Frequency Reuse	Closed	Cross-tier and co-tier	**Moderate:** The combined macro+femto throughput is more than 70 Mbps at cell edge.
Bouras *et al.* (2012)	Adaptive frequency reuse scheme	Closed	Cross-tier	**Low:** Average femtocell throughput is roughly 0.5 Mbps, but efficient as compared to IFR1 and IFR3.

Tariq *et al.* (2011)	Hybrid resource management algorithm (HRMA)	Closed	Cross-tier and co-tier	**High:** For 200 femtocells, the HRMA provides throughput of more than 3b/Hz per transmission frame 50% of the time as compared to other schemes.
Saquib *et al.* (2013)	Optimal static fractional frequency reuse (OSFFR)	Closed	Cross-tier and co-tier	**High:** 1- 60% outage probability for a SINR threshold of 14 dB. 2- For 40 HeNBs the average network sum rate is 60Kbps

Power control techniques

Transmit power control of femtocell in the UL and DL can lead to lower cross-tier and co-tier interference. In the UL, the femtocell allocates its transmit power so that no interference is caused to macrocell base station. In the DL, the femtocell allocates its tranmsit power so that no interference is caused to macrocell users and other femtocell users in its vicinity. Power control in two-tier network was proposed by Chandrasekhar *et al.* (2009). A distributed utility based SINR adaptation alogorithm is proposed in femtocells where each femtocell, aims to maximise its SINR meanwhile maintaining low interference to macro-users. In an event when the macro-user required SINR is below a target value, an algorithm is designed, which reduces the tranmit power of strongest femtocell interferers. Authors in Jo *et al.* (2009), proposed an UL (FUE->MBS) power control scheme for femtocell users that adjusts the maximum transmit power Pmax as a function of the cross-tier interference level in an open loop and closed loop technique. A DL power control scheme based on achieveable SINR of the femtocell and the macrocell users is given in Li *et al.* (2009). The transmit power of the femto base station (FBS) is controlled such that the received SINR at the femto-user and the macro-user is above a predefined threshold γ_{th}. Authors in Kim *et al.* (2010) proposed to first approximte the channel gains between the MMS and the FBS as this information is not available to the FBS. After channel approximation, the propsed neighbour friendly (NF) power allocation scheme is employed in which the FBS allocates power to those sub-channels, which experience less FBS interference. This improves femtocell throughtput and decreases the cross-tier interference to the neighbouring M-MS. A decentralised power control scheme was proposed in Hong *et al.* (2009). A system model with a noncooperative game model is described and a payoff function to provide fairness and interference minimisation is formulated. Authors in Mach & Becvar (2011) proposed to decrease the FAPs transmitting power to fully utilise its frame, while interference to users of neighbouring FAPs and to macrocell users is limited. The idea is that, if the carrier to interference and noise ratio (CINR) of a FAP is higher than the target CINR, which is required by the femto user, then the FAP must lower is transmitting power, so that $CINR \geq CINR_{target}$. By doing so, the frame utilisation of FAP is increased and both the co-tier and cross-tier interference is minimised for closed access, while for open access the probability of a mobility event becomes very low. A distributed power control for spectrum sharing femtocell networks using stakelberg games was presented in Kang *et al*. (2011). In that approach, the interference constraint power constraint is imposed on MBS and MBS protects itself through pricing on the interference from the femtocell users. The results show that the proposed iterative power allocation algorithm coverges to the optimal solution rapidly. Another power control scheme to avoid cross-tier interference was proposed in Ahmed *et al*. (2013) . In that the authors proposed a quality of service based fractional power control (QoS-FPC). Comparison of the proposed scheme is performed with a conventional fractional power control (C-FPC) and the results indicate that the proposed QoS-FPC outperforms the C-FPC in terms of UE's SINR and throughtput. Key features of the power control techniques with respect to efficiency is provided in Table 7.

Table 7. Power control approach

Reference	**Scheme**	**Access mode (Closed, open or hybrid)**	**Interference mitigated (Cross-tier and co-tier)**	**Efficiency (interference and/ or throughput)**
Chandrasekhar *et al.* (2009)	Distributed power control algorithm in which Each femtocell maximizes their individual utility consisting of a SINR based reward less an incurred cost (interference to the macrocell)	Closed	Cross-tier	**High:** Only 16% femtocells have SINR below their target SINR while 95% of macrocell users achieve desired SINR.
Jo *et al.* (2009)	UL power control using open-loop and closed-loop power control techniques	Closed	Cross-tier	**High:** Closed-loop control scheme provides better femtocell throughput relative to the open-loop control at a minimal cost of macrocell throughput.
Li *et al.* (2009)	Centralised and distributed DL power control	Closed	Cross-tier	The distributed power control ensures MUEs are always given priority.
Kim *et al.* (2010)	DL power control	Closed	Cross-tier	**High:** Neighbour friendly (NF) power control performs better than Equal Power (EQ) and Femto-centric (FC) power control schemes.

Hong *et al.* (2009)	Decentralised power control	Closed	Co-tier	**Moderate:** The capacity of femtocell with 3 users is almost 2 Mbps.
Mach & Becvar (2011)	Reduce the FAP transmit power so that the $\text{CINR} \geq \text{CINR}_{\text{target}}$	Closed and open	Cross-tier and co-tier	**High:** 1- mobility events (handover) is less than 20% 2- High throughput upto 80% throughput provided to serving FAP user.
Kang *et al.* (2011)	Distributed Power Control for Spectrum-Sharing Femtocell Networks Using Stackelberg Game	Closed	Cross-tier	**Low:** No results on throughput and interference power were shown
Ahmed *et al.* (2013)	Quality of service based fractional power control (QoS-FPC)	Closed	Cross-tier	**High:** 33% improvement in UE SINR 40 % improvement in UE throughput than the C-FPC

Q-Learning based interference avoidance techniques

The process of acquiring knowledge of an environment by learning and making decisions according the knowledge obtained to reach a specific result is the process of Q-learning. In case of femtocells, Q-learning approach means that a femtocell adapts its strategy and gradually learns by interacting with its environment (other interfering femtocells) (Nazir *et al.*, 2010). A distributed reinforcement-learning mechanism is analysed in Bennis & Niyato (2010) in which the macrocell network is underlaid with femtocells that share the same spectrum. Each FBS interacts with its local environment and gradually learn about it through trial and error. Once the FBS understand the environment it adapts a channel selection strategy that selects the best channel for its transmission, thus mitigating interference. Another distributed Q-learning approach has been examined in Tefft & Kirsch (2013) in which the Q-table is shared between users. A new reward function (RF) is also devised, which is based on the proximity of MUE to FBS, MUE and FUE capacity. Saad *et al.* (2013) proposed that cooperative learning (CL) is better than independent learning (IL). In IL all femtocells learn independently while in CL, the femtocells share partial information during the learning process in order to strike a balance between practical relevance and performance. The same authors in Saad *et al.* (2014) proposed a cooperative Q-learning approach for distributed resource allocation in multi-user femtocell networks. In that approach, the authors proposed a multi-agent learning technique based on distributed Q-learning called subcarrier-based distributed resource allocation using Q-learning (SBDRA-Q) operating under three different learning paradigms that are IL, CL and a weighted cooperative learning (WCL). The results show that WCL outperforms both CL and

IL in terms of aggregate femtocell capacity. WCL and CL are more robust than the IL to new femtocell deployment. Opposed to the cooperative learning approach and multi-agent learning, authors in Ghaffar & Ho (2013) proposed spectrum splitting in which there is a macrocell dedicated band and a femto/macro shared band. The scheme employed single-agent control problem in which using reinforcement-learning with a Q-learning implementation, the agent learns the optimal interference constellation from its femto BSs. Authors in Galindo & Giupponi (2013) discussed about implementing distributed Q-learning in self-organised femtocells which have no coordination with macrocell. A self-organised power allocation scheme to solve the interference problem caused by femtocell networks to macrocell users in an OFDMA system was proposed by Galindo & Giupponi (2010). Using Q-learning technique, each femtocell learns about its surrounding environment in a distributed manner and learns a policy to solve the interference problem. Table 8 presents the salient features of Q-learning based interference avoidance techniques.

Table 8. Q-learning based interference avoidance approach

Reference	**Scheme**	**Access mode (Closed, open or hybrid)**	**Interference mitigated (Cross-tier and co-tier)**	**Efficiency (interference and/ or throughput)**
Bennis & Niyato (2010)	Q-learning based channel and power allocation	Closed	Cross-tier	**Moderate:** MBS capacity using Q-learning approach is above 2.4 Mbps as compared to static and random allocation
Tefft & Kirsch (2013)	Accelerated learning in machine learning-based resource allocation methods for Heterogeneous Networks	Closed	Cross-tier	**High** The proposed RF outperforms RF* in terms of sum FUE capacity.
Saad *et al.* (2013)	A cooperative Q-learning Approach for Online Power Allocation in Femtocell Network	Closed	Cross-tier	**Moderate** Average femtocell capacity with SBDPC-Q CL is around 2 b/s/Hz
Ghaffar & Ho (2013)	Cross-tier interference mitigation in femto-macro cellular architecture in downlink	Closed	Cross-tier	**High** Sum rate up to 35Mbps as compared to 26 Mbps for dedicated and 14Mbps for co-channel
Saad *et al.* (2014)	A cooperative Q-learning approach for distributed resource allocation in multi-user femtocell networks	Closed	Cross-tier	**High** SBDRA-Q with WCL achieves average femtocell capacity of almost 160 b/s/Hz

Galindo & Giupponi (2013)	Fuzzy Q-learning (FQL) for self-organised femtocells	Closed	Cross-tier	**High:** Macrocell capacity is above 9.5 Mbps as compared to Q-learning and smart power control (SPC) Femtocell throughput is 10 Mbps.
Galindo & Giupponi (2010)	Distributed Q-learning	Closed	Cross-tier	**High:** 1- Femtocell throughput is maintained above 10 Mbps for 50% femtocell densities 2- Macrocell throughput is maintained above 6 Mbps for 50% femtocell densities

Access control techniques

How a subscriber accesses a femtocell is of utmost importance in providing high throughput and minimizing interference. As discussed earlier, closed access femtocells prevents access to un-registered or un-subscribed users. Open access, on the other hand provides access for all users. Authors in Jo *et al*. (2012) discussed both closed and open access approaches in context of macrocell base station to femtocell distance. It was shown that while the home users preferred closed access, the cellular users preferred open access. A shared access approach was presented in which, time slots were allocated in adjustable fashion so that minimum throughput rate for both home and cellular users is provided. Authors in Roche *et al*. (2010) discussed the existing closed and open access methods for femtocells and their benefits and drawbacks. Furthermore, the need for hybrid access method was presented. The authors in Xia *et al.* (2010) proposed that CDMA femtocells should adopt the open access approach. This leads to capacity gains of almost 200% for home user, by reducing the near-far problem experienced by the femtocells. Furthermore, the authors proposed that TDMA and OFDMA femtocells should adapt to cellular user density. Authors in Cheung *et al.* (2012) considered an OFDMA system in which the macrocell employed closed access policy while the femtocell employed both closed and open access policy. Joint sub-channel and disjoint sub-channel allocations were implemented and the result showed that the femtocell with closed access policy, provided the highest throughput for both joint and disjoint sub-channel allocation; whereas, femtocells with open access policy provided highest throughput for joint sub-channel allocation for all femtocell densities.

COMPARISON OF INTERFERENCE AVOIDANCE TECHNIQUES

As discussed earlier, there are plenty of schemes and techniques to mitigate cross-tier and co-tier interference in femtocell networks. There are other schemes which focus on other aspect like beamforming (Husso *et al.*, 2010 (a); Husso *et al.*, 2010 (b)), load balancing (Elsässer *et al.*, 2002; Le *et al.*, 2012) and Neural networks Yizhe & Zhiyong (2011) to name a few. In beamforming strategy, different beam-forming weights are assigned to the aggressor femtocell transmitter so that steers a null in the direction of the victim femtocell. In load balancing, a femtocell shares the traffic load of another femtocell under an overlapping coverage area, only if the femtocell taking up the traffic load has free channels to support the other femto's UE. In neural network based approach, a femtocell is first trained according to the environment (interference levels). After training, the femtocell self-optimises itself to provide high throughput and minimise interference. In Table 9, an overall comparison of all the above interference avoidance schemes is presented in terms of control approach, efficiency, complexity, access mode, power required and type of interference these schemes tend to avoid. Our first interference avoidance technique is CR. The CR works in a distributed fashion, where each CR enabled femtocell tries to maximise its throughput while minimising the interference to other femtocells or macrocells. CR technology tends to be quite efficient in terms of both femto and macro throughput, but its main drawback is the increased complexity both in implementation cost and signalling overheads. Our second technique is resource allocation based interference avoidance. The resource allocation technique is mainly centralised in which there is usually a central femtocell entity that allocates the resources to femtocells in order to keep the interference to a minimum and increase the femtocell throughput. Orthogonal frequency allocation approaches provide better femtocell throughput than the clustering or the FFR. The major drawback of resource allocation based technique is the increased signalling overheads associated with exchange of information between the femtocells and the central femtocell entity. Power control technique can work in centralised or decentralised manner. The advantage of this technique lies in its complexity, which is lower than that for CR and resource allocation. As power control techniques are basically implemented in the form of algorithms, there complexity is lower. However, the power requirement of the power control technique is quite high. Q-learning approach is mainly employed in a distributed manner. Each femtocell learns the environment independently and makes decisions based on the knowledge of the interference environment. The efficiency of Q-learning approach is quite high, as it is a variant of CR technology that employs learning before making decisions. The operations involved in Q-learning approach are power hungry and requires more power. Lastly, access control technique has the lowest complexity and the lowest power requirement of all the techniques. The throughput of this technique is lower than the rest. Based on the statistics in the table, it is concluded that in case where power requirement is not a problem, the techniques that operate well are CR, Power control and Q-learning, as they give the highest efficiency. The case where power requirements are limited, resource allocation technique works well.

Table 9. Comparison of different interference avoidance techniques

Scheme	**Control approach**	**Efficiency (throughput)**	**Complexity (implementation and signalling overhead)**	**Access mode**	**Power required**	**Type of interference**
Cognitive radio	Distributed	High	High	Closed and open	High	Co-tier, cross-tier
Resource allocation	Centralised	High	High	Closed	Moderate	Co-tier, cross-tier
Power control	Centralised/ distributed	High	Moderate	Closed, open and hybrid	High	Co-tier, cross-tier
Q-learning	Distributed	High	Moderate	Closed and open	High	Co-tier, cross-tier
Access control	Centralised/ distributed	Medium	Low	Closed	Low	Co-tier, cross-tier

CONCULSION

Femtocells are a promising solution to meet the increased demand for high speed reliable data access for users primarily based indoors. The only major issue in deployment of femtocells is the interference caused by the femtocells to macrocells and to other femtocells. Thus, interference avoidance mechanisms or techniques must be implemented in femtocell networks for efficient femtocell deployment. In this paper, a comprehensive review of some interference avoidance techniques such as cognitive radio, resource allocation, power control, Q-learning and access control was provided. Each of the above mentioned schemes aim to avoid interference but possess complexity and efficiency issues. Choosing an interference avoidance scheme depends upon the environment, where the femtocell has to be deployed. The environment varies from dense femtocell-macrocell deployment to sparse femto-macro deployment. Whatever the case maybe, interference avoidance techniques are necessary to draw full potential of femtocells to provide a reliable and fast data access for indoor users.

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