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Full Length Research Paper

Review of interference avoidance schemes in femtocell networks

Sabarina Ismail, Chee Kyun Ng, Nor Kamariah Noordin, Aduwati Sali and Borhanuddin Mohd Ali

Department of Computer and Communication Systems Engineering, Faculty of Engineering, University Putra Malaysia, UPM Serdang, 43400 Selangor, Malaysia.

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Femtocell is a solution to increase the system capacity and coverage to meet the high demand of the next generation of services on broadband wireless access. However, the deployment of a new femtocell layer may have an undesired impact on the performance of the macrocell layer. The allocation of spectrum resources and the avoidance of electromagnetic interference are some of the more urgent challenges that operators face before femtocells become widely deployed. In this paper different interference avoidance schemes are described and compared. Special attention is paid to the use of uplink and downlink power control and self-configuration and self-optimization techniques for the avoidance of interference. From the review, we conclude that frequency planning is suitable for interference avoidance schemes for unplanned location of femtocells deployment.

Key words: Femtocell, macrocell, cellular, orthogonal frequency division multiple access, interference avoidance.

INTRODUCTION

Femtocell is deployed to improve the indoor radio coverage of a given cellular standard and to enhance user's capacity (Chandrasekhar et al., 2008; Lopez-Perez et al., 2009; Claussen, 2008). The demand for the high data rate in wireless network has triggered the development of femtocell networks. Femtocell networks are considered as future cellular networks in order to remain competitive in wireless communication market (Roche et al., 2010). Femtocell is a low cost, low power of indoor base station which is user-installed connection via a fixed broadband connection backbone through digital subscriber line (DSL) to operator's radio access network. Femtocell is operated in a licensed frequency and managed by operators where it is contrast to a WiFi. They can be installed at anywhere and anytime. Femtocell which operates at the same frequency band with the existing macrocell system would induce the interferences between them. Moreover, the unplanned location and dynamic nature of femtocells make these problems seriously affected their performance. The interference avoidance schemes needs to avoid the interference and to provide a better quality of service (QoS) for both femtocell and macrocell users. Some previous researches on interference avoidance schemes in femtocell has been proposed by Sahin et al. (2009), Kwanghun et al. (2009), Chandrasekhar and Andrews (2009) and Su et al. (2009). In Sahin et al. (2009) an interference avoidance framework is proposed based on utilizing the resource block by closely locating macrocell mobile stations. The availability of scheduling information in conjunction with spectrum sensing is considered. However, it cannot be used for the strong inter-cell interference for spectrum opportunities detected.

Kwanghun et al. (2009) have proposed connectivity optimization of the femtocell network. The outdoor users have to be controlled with an appropriate strength in

*Corresponding author. sabarina@unimap.edu.my. Tel: +60135181375.

order not to interrupt the communication between macro BS and outdoor users and to avoid the interference. In Chandrasekhar and Andrews (2009), interference

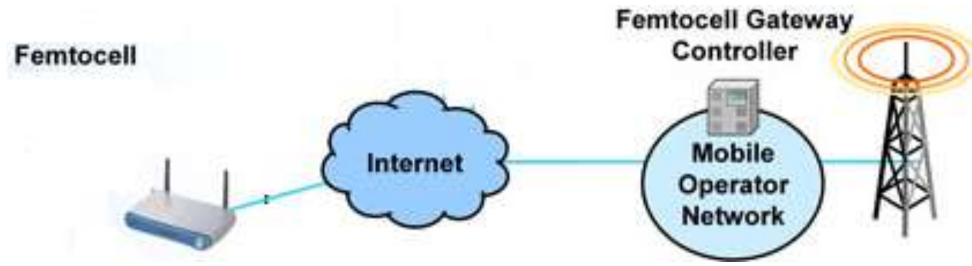

Figure 1. Femtocell architecture.

Table 1. Comparison between Wi-Fi and femtocell.

Parameter	Femtocell	Wi-Fi
Standard	3GPP, 3GPP2 femtocell standard	IEEE.802.11 a/b/g/n
Operating frequency	1.9 to 2.6 GHz (licensed)	2.4 and 5 GHz (unlicensed)
Data rates	7.2 to 14.4 Mbps	11 and 54 Mbps
Power	10 and 100 mW	100 and 200 mW
Distance (range)	20 to 30 m	100 to 200 m
Services	Voice and data	Voice and data
Handset	All ordinary phone devices	Dual mode devices
Service complexity	Relatively low	High
Signal robustness	Robust	Fades
Security protocols	Allow same security protocols based on cellular technology and standards	Own protocols such as wired equivalent protocol (WEP) universal access method (UAM)

avoidance help two-tier networks to achieve higher user capacity by using a network-wide area spectral efficiency metric called the network operating contours (OC) where higher spatial reuse through small sized enforcement on femtocells. Su et al. (2009) have proposed a synchronization scheme based on spectrum splitting. The distance and delay from macrocell is determined through the signaling. However, with scarcity of spectrum, it leads to the less efficiency of frequency utilization. In Chandrasekhar and Andrews (2009), the authors have focused on power control but it could not solve the interference problem very well when considering the complicated environment of femtocell. This paper deals with the literatures review of different interference avoidance schemes with accountability that influences the performance of spectral efficiency.

OVERVIEW OF FEMTOCELL

Femtocell is an inexpensive small-size base station that overlay an existing cellular network to improve capacity and coverage particularly to indoor users. Femtocell provides radio coverage of a cellular standard on the air interface. It uses DSL as the backbone connection to connect users with cellular service providers in the users' homes or business premises as shown in Figure 1. Femtocell can support four to six active users simultaneously and compatible with the cellular systems. The 'femto' in femtocell means one quadrillion (10^{-15}) where it is much smaller in size compared to the standard macrocellular wireless BS tower (Ortiz, 2008). Femtocell deployment promises fixed mobile convergence to access wireless networks services while conventional approaches require dual mode mobile devices. Table 1 demonstrates the comparison of the basic parameters between Wi-Fi based on IEEE 802.11 a/b/g standards and femtocell (Hasan et al., 2009). Femtocell can bring a lot of advantages for both operators and subscribers. Femtocell helps the operators to manage the exponential of growth traffic and increase the reliability of macrocell network. The increasing numbers of tower and other elements of cellular network infrastructure will increase the operator's operating expenditure (OPEX) and capital expenditure (CAPEX). Femtocell allows same security protocols as macrocell cellular service and share the licensed electromagnetic spectrum which is allocated to cellular service providers. It provides better indoor signal strength, high data rates and high QoS to users which are unattainable by macrocell coverage operating at higher frequency (Chandrasekhar et al., 2008).

Femtocell can enable subscribers to use their mobile at home, where triple play services become available and enable users a seamless user experience across those

Table 2. Significant benefits of femtocell for cellular service provider and user.

Cellular service provider	User
Increase network capacity	Increase indoor coverage
Lower capital and operational cost (CAPEX/OPEX)	Higher performance data services
Expanded revenue opportunities	Higher quality voice
Lower backhaul cost	Lower cost home zone calling
Improved macro reliability	Improved multimedia experience
Reduce subscriber turnover	Continue using current handset
Offload of macrocell base station traffic	Reduce battery drain (prolong battery life)

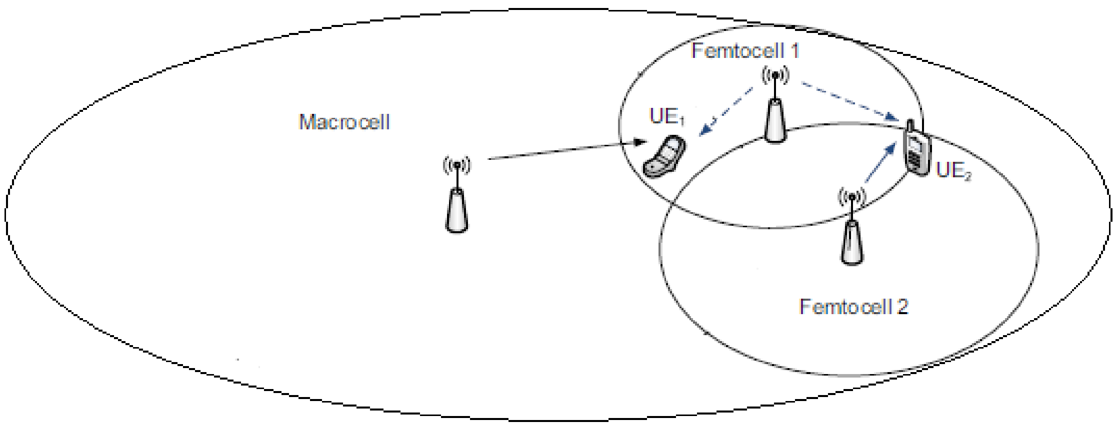

Figure 2. Inter-cell interference scenarios.

environment. Femtocell will save user equipment power. As the distance between user equipment and femtocell much shorter, the transmitting power can be much reduced. Therefore, the deployment of femtocells contributes significant benefit to cellular service providers and subscribers which are stated in Table 2. The femtocell forum which is promoting femtocell technology worldwide has agreed to develop and adopt a single standard for integration of femtocell through any cellular networks. Femtocell uses fully standard wireless protocols over air interface to communicate with standard mobile devices. The qualifying standard protocols including global system for mobile (GSM), universal mobile telecommunications service (UMTS), worldwide interoperability for microwave access (WiMAX), code division multiple access (CDMA) etc., which are current protocols standardized by third generation partnership project (3GPP), 3GPP 2 and WiMAX forum. The 3GPP standard is responsible to identify and create a standard set for UMTS terrestrial radio access network femtocell (Knisely et al., 2009). While the 3GPP2 standard is to prepare the industry standards which describe how femtocell can interoperate with cdma2000 cellular networks (Knisely and Favichia, 2009). Their advance capabilities is to breakout bearer traffic at femtocell device to allow end-users access through and also to supports the handling of voice call from macrocell networks and handoff between femtocells. The WiMAX forum has created a set of standard for WiMAX femtocell. The developments of WiMAX standard have two phases: phases 1 and 2.

Phase 1 is based on basic femtocell with limited network feature and no change in underlying air interface or system profile. It offers support for WiMAX Release 1 (IEEE 802.16e-2005) and Release 2 (IEEE 802.16 Rev.2) which will be expected to complete in first quarter (Q1) of 2010. Phase 2 is based on full femtocell function with advanced network features and air interface optimization which will include physical (PHY) and medium access control (MAC) layers enhancement in the IEEE 802.16 m standard.

INTERFERENCE SCENARIO IN FEMTOCELL

Interference is one of the outstanding issues when the femtocells are deployed at indoor environment and randomly distributed in large coverage area of macrocell.

In spectrum sharing environments where the same frequency resource (co-channel) used would be result interference and can limit the users to achieve the better signal strength and voice quality. Figure 2 shows an illustration of inter-cell interference scenarios where femtocells are added, located close and distributed over

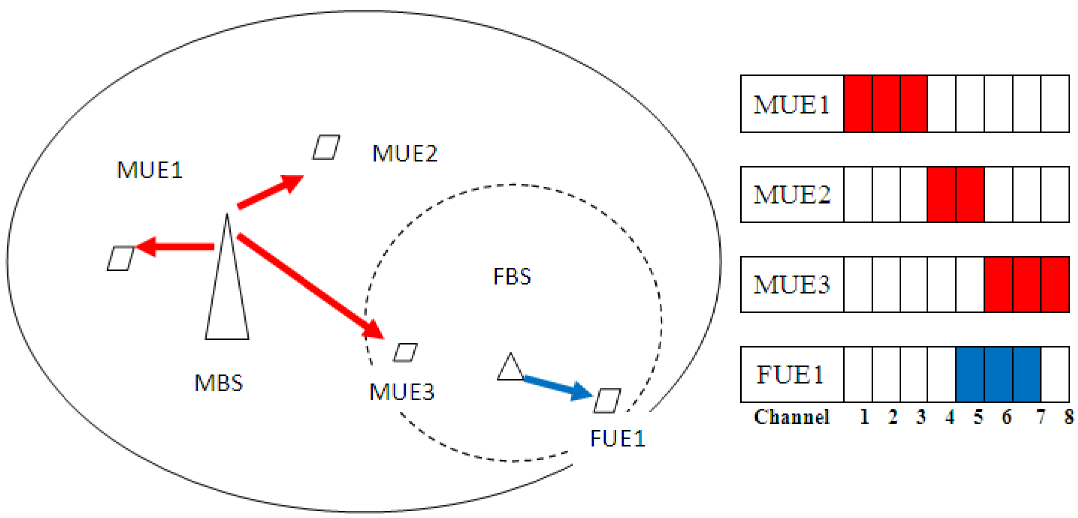

Figure 3. Co-channel interference of frequency allocation.

a macrocell area. Dead zone is created by the femtocell radiated power. It will degrade the macrocell performance which is leading to non-uniform coverage and resources with low quality. The femtocell users which were located far from femtocell base station (FBS) will raise their power level and it might produce high level of interference to neighbouring femtocells. The same phenomenon happened when a macrocell user (Mms) is located close to femtocell base station (FBS). The interference between macrocell and femtocell layers which is using the same spectrum overlap in an affected area can be classified into two types: co-layer interference and cross-layer interference. Co-layer interference occurs between neighbouring femtocells, while cross-layer interference occurs between macrocell and femtocells. Figure 3 represents the frequency allocation scenario where a loaded macrocell base station (MBS) uses the entire available sub channels to transmit information to the three macrocell users (MUE1, MUE2 and MUE3). However, when MUE3 is located closed to FBS, the heavy interference occurs where the femtocell also uses the sub channels that are allocated to MUE3 to femtocell user (FUE1).

The interference at FBS is the aggregation of interference from the uplink mobile users and is typically dominated by a small number of mobile users transmitting at relatively high power the main base station (Chandrasekhar and Andrews, 2009).

Frequency scheduling scheme

The interference avoidance scheme through the frequency scheduling has also been suggested in Sahin et al. (2009) and Akbudak and Czylwik (2010). It is an interference handling method from close-by macrocell mobile stations. It is required to handle the received interference by avoiding the use of their frequency resources at the femtocell network and utilized the spectrum resources efficiently. This scheme utilizes the result of spectrum sensing in terms of energy detection with respect to the distance as availability of scheduling information. The femtocell base station has received the macrocell mobile stations scheduling information from macrocell base station through the backhaul connection. Then it performs spectrum sensing to find the occupied resource blocks of nearby macrocell mobile stations. Then the received subcarrier power is compared to the energy detection threshold as shown in Figure 4a for the delay shorter and longer than cyclical prefix (CP) of a femtocell signal. Figure 4b show the scheduling information for multiple MBSs (such as mMS1, mMS2, mMS3 and mMS4). Then the FBS will compare subcarrier received power with MBSs scheduling information and matched as energy detection results with missed detections and false alarms due to the interference and noise shown in Figure 4c. The detected energy sign as occupied and spectrum opportunities have been found. Figure 4d indicates that the received signal power for mMS2 is relatively weak causes the resource blocks associated with mMS2 may be utilized by femtocell and the subcarrier index at 170 is available but it cannot be used due to strong interference from mMS3 and mMS4 subcarriers.

The spectrum opportunities of FBS are determined by comparing the result with the scheduling information. Then, FBS can avoid the use of resource blocks of the close-by user and schedule their femtocell mobile stations over the air interface without causing any interference. The FBS with the jointly utilizing spectrum sensing and scheduling information has shown that interference is avoided by identifying the spectrum of nearby users and not using their belonging resource blocks. However, this strategy cannot be use in open

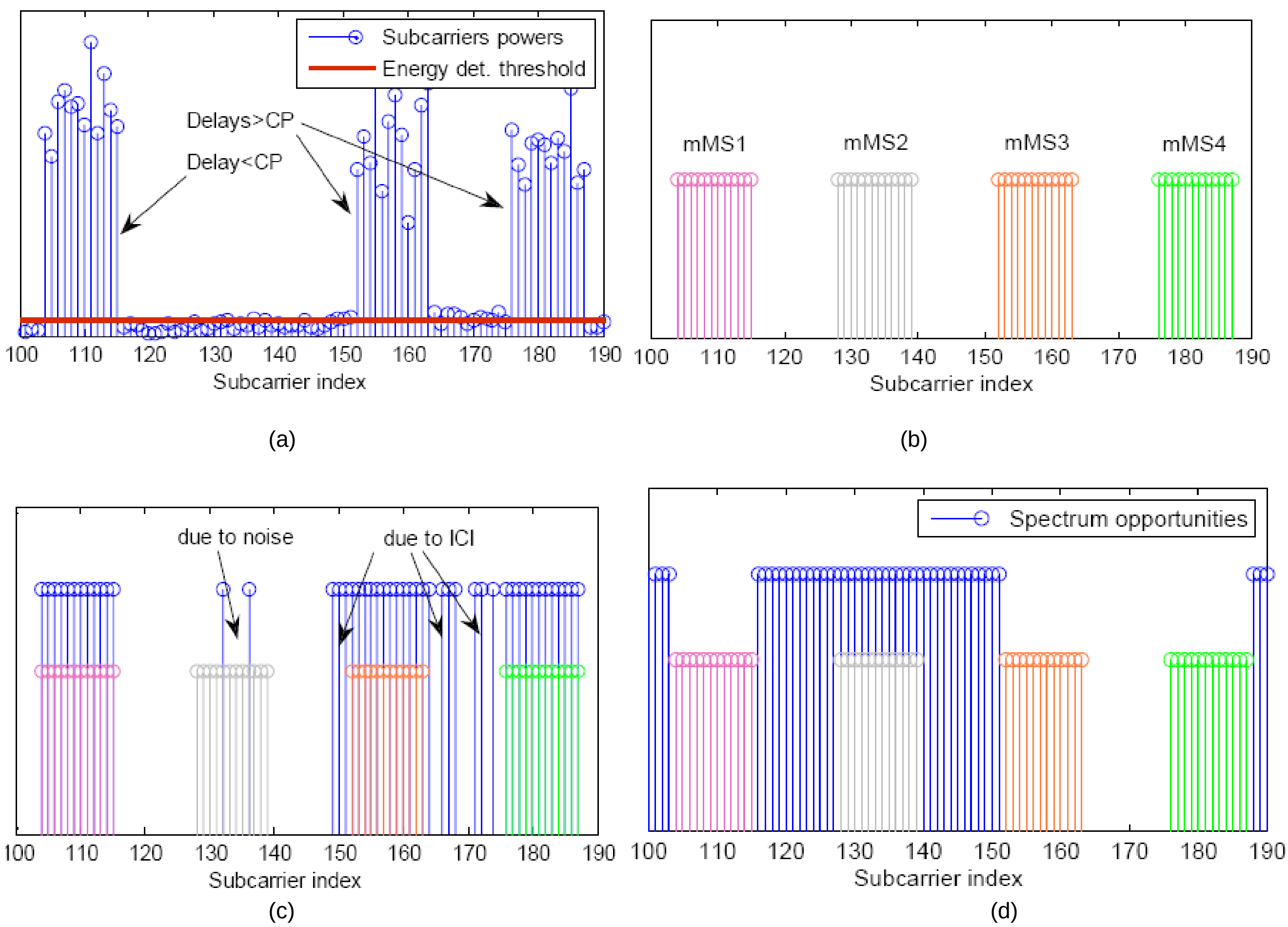

Figure 4. a) Received subcarrier power and detection threshold; b) Scheduling information for multiple users; c) Power detection matched to scheduling information and, d) Spectrum opportunities detected.

access but successfully operated in closed subscriber group access environment.

Synchronization scheme

Su et al. (2009) has been proposed synchronization scheme where femtocell needs to be synchronized for multiple accesses to align the received signals to avoid interference and tolerate with the carrier offset. The strongest signal from femtocell must be synchronous with desired macrocell signal based on the scenario shown in Figure 5 and by assuming FBS and MBS transmit signal to macrocell mobile station at the same time. Each of FBS must determine their distance, *d* from the MBS through signalling and delay the transmission by a *d/c* relative to MBS time base. This scheduling period is adjusted accordingly based on their location from the MBS's distance. The MBS is free from the strongest femtocell interference if synchronization range is less than the difference between the length of cyclic prefix (CP) and the maximum multipath delay spread.

$$Delay, D = \frac{d}{c}\frac{1}{T_s} \quad (1)$$

User delays *(D)* are directly proportional to *d* through Equation 1, where *c* is the speed of light and T_s is the sampling time.

$$Energy, \quad E = \frac{P_T \lambda^2}{(4\pi)^2 d^\gamma} \quad (2)$$

Equation 2 also shows that the transmitted energy *E* depends on *d*, where λ is the wavelength of the transmitted signal and γ is the path loss exponent. Figure

6 has illustrated the signal transmission arrival time is in advanced *(d_2-d_3)/c* from FBS compared from MBS. If the signal transmission arrival times are within or less than the different of CP size and maximum multipath delay spread (CP to τ_{max}), no interference will occur. Also if femtocells delay their transmission corresponding to their

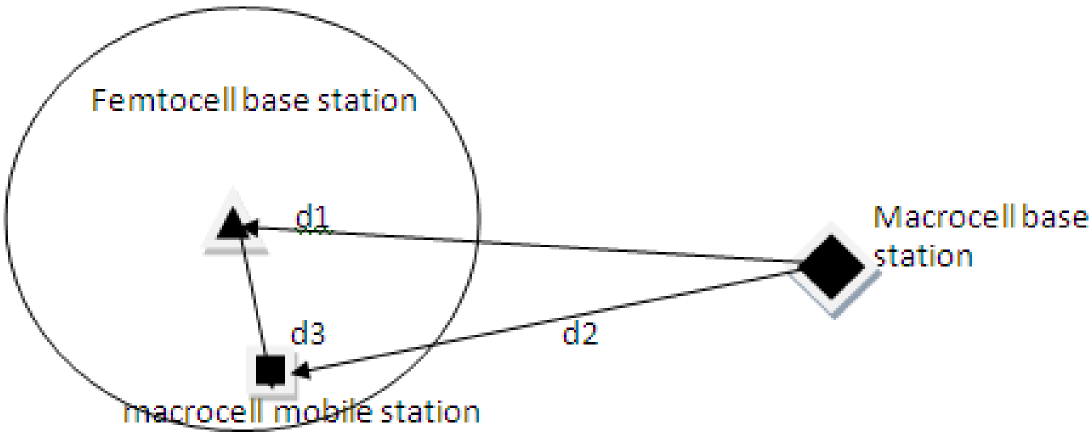

Figure 5. A macrocell mobile stations at femtocell.

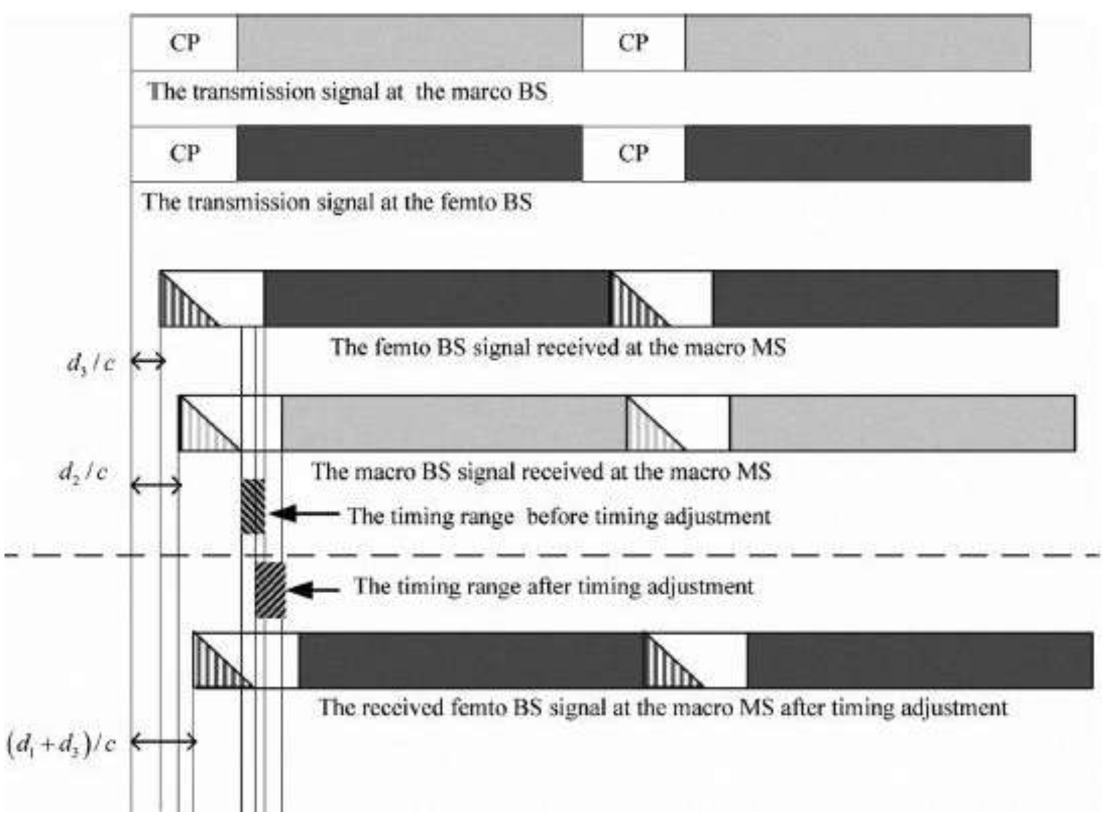

Figure 6. The signal transmission arrives at macrocell mobile station (Su et al., 2009).

distance from macrocell mobile station, the performance of carrier to interference ratio can be improved without changing their timing. Therefore, the strongest interference from FBS can be avoided and macrocell mobile station needs not to change their timing procedure in existing macrocell network. A longer distance leads to a larger delay but weaker interference should be observed at large distances. Therefore, interference power is expected to be maximized at a certain distance and then will start decreasing with *d* and hence a stronger interference.

Access control mechanism scheme

Mechanism of access control scheme plays an important position in avoiding cross-tier interference. Lopez-Perez et al. (2008) have demonstrated the computed probability

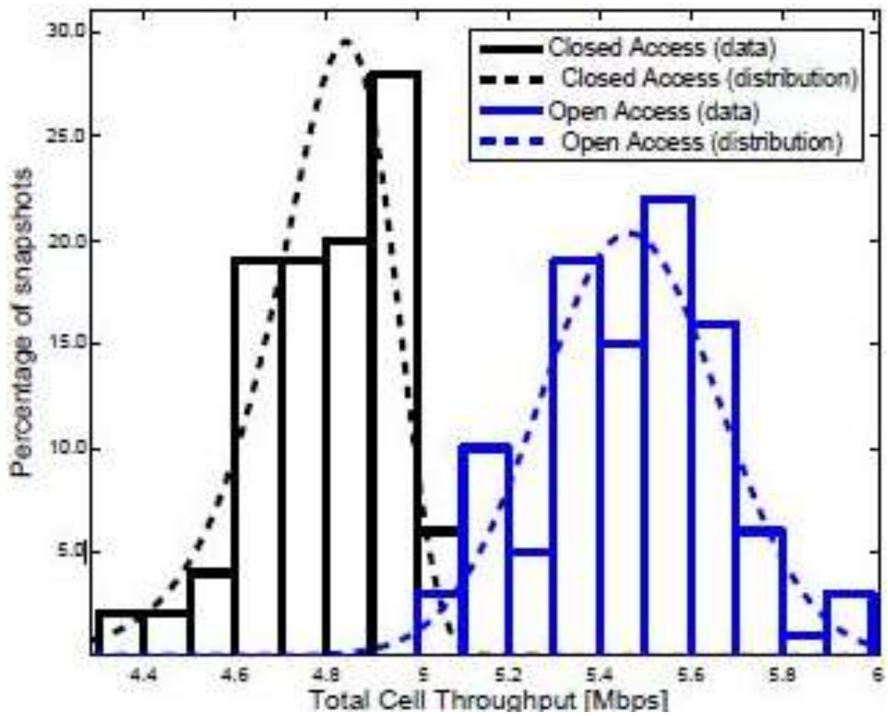

Figure 7. The probability density function of total cell throughput (Lopez-Perez et al., 2008).

density function of total cell throughput for closed and open access using a Montecarlo snapshot at a residential area where a large deployment of femtocells and a macrocell have been considered (Figure 7). Due to the destructive interference produce by femtocell to users which are connected to the macrocell, the figure have shown that the open access is outperforms than the closed access. The closed access method tends to drive the total cell throughput to 15% lower than open access method. With the hybrid access, the level of accesses femtocell can be controlled and its connection can be configured to guarantee a minimum performance. The unable user located at the weak coverage still can connect to femtocell by using sub-channels which are reserved for access to non-subscriber users. Moreover, the sharing of femtocell resources between subscribers and non-subscribers needs to be finely tuned. Therefore, the studies of hybrid access approach needed for adaptation to the femtocell deployment scenarios.

Self-organization scheme

In the previous literature, different self-organization strategies for femtocell have been introduced. Holger (2008) have been introduced a power control method for pilot and data channels in UMTS networks that ensures a constant coverage femtocell radius. Each femtocell sets its power to a value that is equal to the power received from the nearest macrocell at a target femtocell radius. Holger (2008) have been presented a method for a coverage adaptation for UMTS networks that uses information on mobility events of passing and indoor users. Each femtocell sets its power to a value that minimizes the total number of attempts of passing users to connect to such femtocell. Young et al. (2009) have been proposed a new preamble structure based on power control scheme in closed access to enable a macrocell mobile station to detect an MBS when it is located very near to FBS. They have used self-organized preamble selection algorithm in FBS to extend the coverage of the femtocell outside the building. But the performance of scheme in Lopez-Perez et al. (2010) depends on the transmission activity of macrocell and femtocell. Pantisano et al. (2010) have proposed scheduling information exchange to schedule transmission for clustered femtocell in order to avoid interference with macrocell users and among neighboring femtocells. When a femtocell is on the self-configuration will provide initial setting while self-organization will update the configuration in order to adapt their parameters to the environments (Lopez-Perez et al., 2009). It is used for sensing the nearby available frequency channels and power to avoid collision and interference.

It is capable to sense air interface by using a network listening mode, identify the active cells between them and sub-channels within their range. This is done by the

Table 3. Performance of resource allocation algorithms.

Performance	FRS1	FRS3	FRS4	Distributed DFP	Centralized DFP
Successful users (%)	94.10	95.43	87.49	96.32	97.92
Users in outage (%)	5.4	3.94	11.24	2.73	2.35
Macrocell throughput (Mbps)	3.93	4.32	4.06	4.54	4.81
Femtocells throughput (Mbps)	123.47	123.32	113.67	123.60	123.64
Total throughput (Mbps)	127.40	127.64	117.73	128.14	128.45

forward of measuring report from user which has received signal strength and active sub channels of serving. By using this information, they configure, tune their optimization power and select sub-channels according to the networks changes. This approach provides a higher versatile design for the interference avoidance technique. It is possible to use measurement reports from mobile users in order to choose intelligently the most appropriate sub-channel and time slot to perform transmission. Femtocell must be capable to sense air interface and optimize their parameters based on tuning. A user is considered successful if it has achieved the minimum requested throughput. If the received power coming from BS is smaller than user's terminal sensitivity, no coverage is provided. During allocation process user also cannot achieve the minimum throughput if there are no resources available. There is also no radio access bearer if the signal to noise ratio (SNR) on channel state information (CSI) is smaller than the requirement SNR level. The essential idea of cellular radio is to transmit at power levels sufficiently low such that to not interfere with the nearest location at which the same channel is reused. The lower the power levels used in cells sharing a common channel, the lower the probability of interference. Thus, a combination of power control and frequency planning is used in cellular systems to prevent interference.

Lopez-Perez et al. (2009) has used measurement reports in distributed dynamic frequency planning (D-DFP) to sense environment. The requested slot for ith user is as follows:

$$slot_i = \frac{requested\ throughput}{slot\ throughput} \quad (3)$$

With Equation 3, the requested sub channel for ith sector is:

$$C_{sj} = \sum_{i \in s_j} slots_i \frac{slots}{subchannels} \quad (4)$$

With this information from Equation 4, each femtocell can configure their sub-channel priority list independently and update periodically. In this approach, a random time counter is used to wake-up femtocell and achieve stable solution and also avoid changes make at the same time. Based on the result shown in Table 3, D-DFP is the better strategy according to the network throughput performance where the behaviour of traffic and channel can be optimized and able to adapt to the system resources.

Time-hopped CDMA (TH-CDMA) scheme

Chandrasekhar and Andrews (2009) have evaluated interference avoidance based on network-wide area spectral efficiency or operating contour which combine the numbers of active users and femtocell base station per site. They reveal the worst case of interference at the edge of femtocell through time-hopped code division multiple access (TH-CDMA). TH-CDMA has been proposed as a feasible means of reducing cross-layer uplink interference. The avoidance of mutual interference between femtocell users and nearby macrocell users was done through slow hopping and the probability of collision within neighbouring femtocells can be decreased. Macrocell and femtocell will each transmit independently over one time slot and remain silent over other slots. However it is in fact equivalent to splitting the resources in the time domain instead of splitting them in the frequency domain. There is a major drawback for the spectrum splitting because the loss of resource efficiency in an environment where radio resource is scarce. In TH-CDMA, the CDMA duration is based on its processing gain and the period is divided into *N* numbers of hopping slot. Each user can randomly select a hopping slot for transmission and remains silent during the remaining slots. Random time-hopping has reduced the average number of interfering users by a factor of N_{hop}, while femtocells are accommodated by changing the operation on an existing CDMA macrocell network. Moreover, the authors have been modelling the random spatial distribution of users and femtocells by using a stochastic geometry framework. A Poisson-Gaussian model for macrocell interference and alpha stable distribution for cross-layer femtocell interference result accurately capture statistics. The use of antennas with N_{sec} sectors in femtocell also suggested as a way of reducing the interference caused by closed macrocell users in the uplink.

The combinations of average number of active

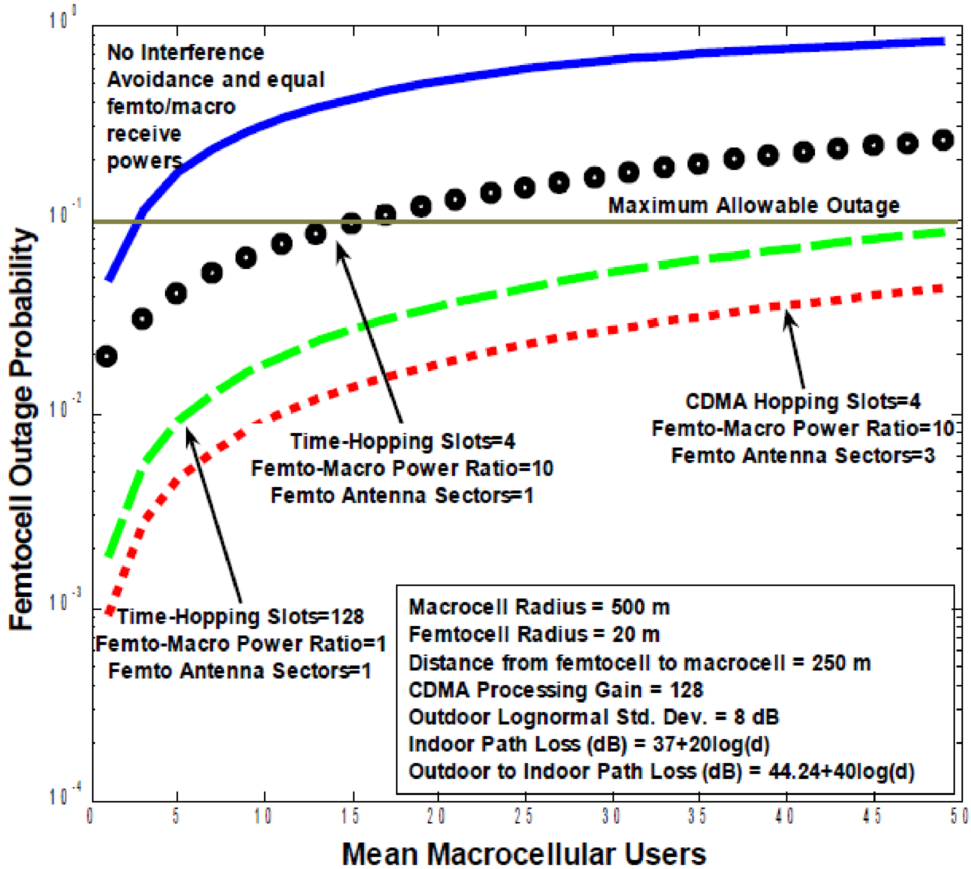

Figure 8. The outage probability for a femtocell user (Chandrasekhar and Andrews, 2009).

macrocell users and FBSs per cell site as an operating contour make an outage constraint target satisfied. There are the reductions in the outage probability for a femtocell user which the femto-macro receive power ratios are 1 and 10 in conjunction with interference avoidance using CDMA time hopping and antenna sectoring as shown in Figure 8. These femtocells had to be configured for requiring higher reception powers in the uplink compared with inner femtocells. However, by equipping femtocell with sectoring antennas would imply a price increase.

COMPARISON OF INTERFERENCE AVOIDANCE SCHEMES

As described previously, there are many strategies which have been proposed, frequency scheduling (Sahin et al., 2009), self-configuration and self-organization (Lopez-Perez et al., 2009), control access mechanism (Roche et al., 2010) and CDMA time-hopping (Chandrasekhar et al., 2009). These techniques also can be used to improve performance of femtocell coverage and macrocell capacity. Sahin et al. (2009) have proposed frequency scheduling and time synchronization for minimizing co-channel interference. They have ensured that femtocell can avoid interference by using macrocell resource blocks which belong to nearby mobile macro station (mMS) and do the transmission at the difference time base. The delay has to be synchronizing based on the distance and the size of cyclic prefix. However, this operation only considers using closed access mode. Regarding to Roche et al. (2010) and Lopez-Perez et al. (2008, 2009), open access is more efficient than closed access in terms of spectral efficiency for frequency (sub channel) allocation. However, it will increase the number of handoffs and signalling, thus these activities become challenging for the operator. The power of the interference is much larger than the one of the carrier signal, whereas in dense deployments femtocells in random positions severely jammed by neighboring femtocells. Therefore, frequency allocation scheme which was introduced by Roche et al. (2010) is most efficient where co-channel deployment is combined with open access. There are no separate carriers that must be reserved and the available carriers not limited to macrocell but can be used by the operators.

It can be considered by defining the right user to use femtocell through hybrid access algorithm and the use of FDTD prediction model. The poor indoor coverage and system capacity can be improved but it also depending

Table 4. Different of interference avoidance strategies.

Interference avoidance	Challenge	Solution	Improvement
Frequency scheduling (Sahin et al., 2009)	Serious interference at mMS at cell edge.	Using closed-subscriber-group (CSG) mode with availability of macrocell frequency scheduling information utilized in conjunction with spectrum sensing.	No collision. Enforce higher spatial reuse for higher user capacity shared spectrum network.
Synchronization (Su et al., 2009)	Co-channel interference	Each femtocell base station delays its transmission time by a period relative to the macro BS transmission time base according to its distance from the macrocell base station.	The co-channel interference ratio performance of macro mobile stations greatly improved.
Access control mechanism (Roche et al., 2010; Lopez-Perez et al., 2008)	Poor indoor coverage and system capacity	Define the right user to use femtocell through radio coverage prediction by propagation model.	Hybrid access can control femtocell access and their connection.
Self-organization (Lopez-Perez et al., 2009)	Change rapidly due to shadowing and multipath fading.	Collect the data, generate the plan and distribute the information and then adapt RF parameter to user environment and channel condition.	Larger spectrum availability.
Time-hopped CDMA (Chandrasekhar et al., 2009)	Cross-tier interference and shadowing effects.	Poisson-Gaussian model for macrocell interference and alpha-stable distribution for cross-tier femtocell interference.	Time hopping and antenna sectoring offer the largest gains in user capacity for shared spectrum two-tier networks.

profile and the scenario under consideration. Unlike Roche et al. (2010) and Lopez-Perez et al. (2008) has proposed femtocell interference avoidance through self-organization technique which applies distributed frequency planning (DFP). Each cell manages its own sub-channel by sensing and tuning their parameter according to network changes. The number of sub-channels required can be estimated based on a regular basis to satisfy the user's bandwidth demand per sector since each sector knows the number of connected user and their requirements in terms of capacity and throughput at each time. If the femtocell can be configured correctly, the collisions between the same frequencies used in neighbour cells can be avoided. The probability of slot collision can be reduced by using frequency reuse factor (FRF) to mitigate the co-channel interference by a factor of the number of fragments in each channel is divided. However, network load user traffic vary quickly base on location and time. Spectrum reuse of frequency reuse scheme (FRS) which is based on fix pattern cannot cope with uneven distribution and dynamic behaviour of traffic throughput. Therefore, the dynamic-distributed frequency planning (D-DFP) needs to adapt the radio frequency parameter to the user environment and channel condition. Chandrasekhar et al. (2009) has enforced on higher spatial reuse for higher user capacity shared spectrum network by case interference at a corner of femtocell. A Poisson-Gaussian model was used for macrocell interference and alpha-stable distribution for cross-tier femtocell interference. There are modest improvements in the network operating contours through a combination of femtocell exclusion and tier selection.

The brief comparison of different interference avoidance strategies for femtocells on the existing macrocell and using difference access technology have been presented in Table 4. The interference avoidance schemes are necessary to avoid the impact of femtocells interference especially for co-channel interference in two layer networks. These are an effective solution for the scarce and the expensive licensed spectrum. With these schemes, femtocells and macrocell can cooperate to improve spectrum resource utilization, enhance the performance of throughput and also improve the quality of the signals. Physically, most of the involved schemes are based on power control and spectrum allocation management. The Interference avoidance strategy needs to deploy a femtocell tier over existing macrocell network successfully. It depends on the techniques used for allocating the spectral resources, the method used to access the femtocells and the use of self-organization techniques.

CONCLUSIONS

We have shown that although a femtocell can cause interference to other users in macrocell the system, the interference can be well controlled on both the downlink and uplink if proper interference avoidance schemes are used. The schemes based on interference avoidance represent efficient alternatives (for example, power and sub-channel management). Power control algorithms and radio resource management are tools often used in cellular systems to avoid interference. If they are not applied, users located far from a base station will be jammed by users in much closer positions. More efficient management of sub-channels is necessary. Such an approach would help to enhance frequency reuse in the femtocells layer and maximize the overall cell throughput. With orthogonal frequency division multiple access (OFDMA), and since the number and positions of the femtocells are unknown, traditional network planning needs to be replaced with efficient spectrum allocation algorithms for the purpose of interference avoidance, since novel algorithms are still needed to perform such allocation in realistic scenarios.

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