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Research Article

On Uplink Interference Scenarios in Two-Tier Macro and Femto Co-Existing UMTS Networks

Zhenning Shi,[1] Mark C. Reed,[2,3] and Ming Zhao[2,3]

[1] *Alcatel Lucent-Shanghai Bell, China*
[2] *NICTA, Canberra Research Laboratory, Locked Bag 8001, Canberra ACT 2601, Australia*
[3] *The Australian National University, Australia*

Correspondence should be addressed to Mark C. Reed, mark.reed@nicta.com.au

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A two-tier UMTS network is considered where a large number of randomly deployed Wideband Code Division Multiple Access (WCDMA) femtocells are laid under macrocells where the spectrum is shared. The cochannel interference between the cells may be a potential limiting factor for the system. We study the uplink of this hybrid network and identify the critical scenarios that give rise to substantial interference. The mechanism for generating the interference is analyzed and guidelines for interference mitigation are provided. The impacts of the cross-tier interference especially caused by increased numbers of users and higher data rates are evaluated in the multicell simulation environment in terms of the noise rise at the base stations, the cell throughput, and the user transmit power consumption.

1. Introduction

Recent decades have witnessed an unprecedented growth in the achieved data rate and the quality of service (QoS) in wireless communications.

A coarse breakup on the increased capacity reveals that most cellular throughput improvement comes from better area spectrum efficiency. Mobile broadband communication solutions with high spectral efficiency are needed for indoors where demands for higher data rate services and better coverage are growing, for example, residential or office scenarios. It is difficult to provide this coverage and data throughput by macro-cellular networks. This forms the basic foundation that motivates the recent emerging femtocell architecture. Femtocells are essentially an indoor wireless access points for connectivity to the networks of wireless cellular standards. It serves home users with low-power, short-range base stations such as the 3GPP definition of a Home NodeBs (HNB). By enhancing the capacity and coverage indoors, where a majority of user traffic originates, HNBs also bring substantial benefits to the macronetwork as the macrocell resources can be redirected to outdoor subscribers. In addition, femtocell deployment can bring substantial cost savings to operators by reducing operational costs (OPEX) and capital costs (CAPEX) as well as the churn rate from subscribers.

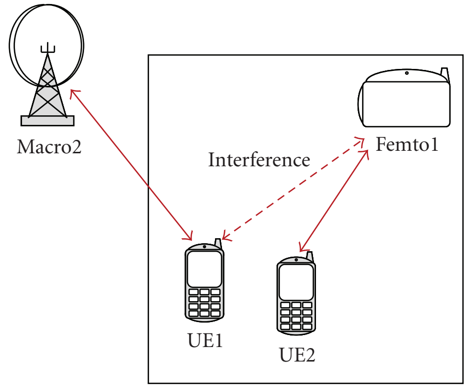
The introduction of femtocells gives rise to a number of technical challenges [1], for example, the IP interface to the backhaul network, closed or open access, synchronization and interference. Due to the scarcity of the radio spectrum resources, femtocells are likely to share the same carriers with the existing macrocells, which may cause interference across the two cellular layers. In particular, operators have concerns on the impact of femtocells onto the macrocells. To this end, an in-depth analysis on interference problems is needed. A comprehensive description of interference cases that exist in the uplink and downlink of the two-tier hybrid networks is given in [2]. These cases are conceptually illustrated through the simple models consisting of a couple of cells, and the analytical results of the basic scenarios are summarized together with the guidelines for interference mitigation. In the downlink, the deployment of femtocells may create multiple dead zones in the macrocell. The cochannel interference can be mitigated by using cognitive radio and adaptive power management techniques in the home base stations [2, 3].

In [4], a stochastic geometry model is employed to characterize the air interface statistics in large-scale hybrid networks, and Poisson-Gaussian sources are used to approximate the interference within and between the tiers. This approach allows the analysis to reflect the randomness of the network. However, it is assumed in [4] that users in both layers are under good coverage from their serving nodes, which may not always be the case in realistic scenarios. In [5] the femtocell capacity is shown in terms of the deployment of femtocells, user distribution in femtocells as well as the user excursion into neighbouring femtocells. In [6], the authors study the effect of access policy on a macro cellular network with embedded femtocells and suggest it should be adaptive to specific scenarios and the perspective of all participants in the system. It is found that by allowing a limited access to the femtocells, the similar QoS level to that of the macro-only scenario and much improved throughputs for all subscribers can be achieved.

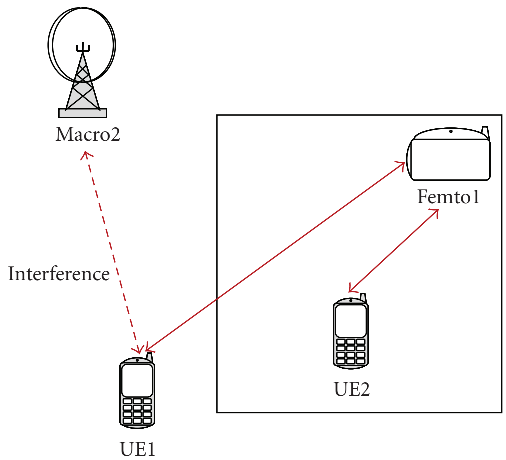
In [1], a femtocell configuration is shown to improve the spectral efficiency of the network by orders of magnitude. In [4], time hopping and directional antenna are proposed to interference and further increase the capacity. A utility-based power control method is proposed in [7] to mitigate the cross-tier interference at the expense of a reasonable degradation in the femtocell SINR. Nevertheless, it is based on the assumption that the user penetration between layers is not severe, that is, the users from one layer are not likely to come within the vicinity of the NodeBs in the other layer and cause substantial cross-tier interference. We note that if open access is not supported for femtocells, user penetration inevitably leads to an adverse condition for both femtocells and macrocells. This calls for more research efforts in this area.

In this paper, we consider the uplink (UL) interfering scenarios in the WCDMA femtocells with a macronetwork overlay. The motivation for focusing on the uplink is to better understand the noise-rise onto the macro base stations and to understand what improved sensitivity at the femtocell would mean to overall system performance. To be in line with the current approach, we consider the closed subscriber group (CSG) femtocell where the home network is only accessible by a limited number of subscribers. We assume a shared carrier for femto and macronetworks, whereby the options of frequency and time hopping [4] and dedicated carriers for femtocells are excluded. In particular, two interference scenarios that UE penetration triggers in the uplink, that is, what we refer to as the "Kitchen Table problem" and "Backyard problem", are studied to show the cases that may cause a service disruption in the system of interest. The analysis is conducted in a large-scale system and takes into account other interfering sources [2] in the network air interface. It also provides a comprehensive study on how different interfering causes are inextricably linked and take effects jointly. In this paper, the interference mitigation techniques are considered to enable the network operation even in the extreme cases.

The paper is organized as follows. In Section 2, two uplink interfering scenarios under consideration are described, together with, the system parameters used in the system analysis. In Section 3, the noise rise at macro NodeBs (MNB) is formulated and serves as a basis to separate the interfering sources in the uplink. A number of interference management techniques tackling the intercell and intracell interference are then presented. In Section 4, system simulation results are presented for suburban and urban scenarios to show the interference effect on both the macro and femto layers. Conclusions are summarized in Section 5.



(a) Kitchen Table UE



(b) Backyard UE

Figure 1: Illustrative examples of two interfering scenarios in the femtocell uplink.

2. System Model

2.1. Uplink Interfering Scenarios. Femtocells can support high data rate services since the transmitter and receiver are very close to each other and the resultant transmit power is very low. However, this is no longer the case when uncoordinated subscribers come to the vicinity of the femtocell HNB. Diagram in Figure 1(a) illustrates the scenario [2], where one macrocell and one femtocell coexist. Subscriber UE 1 is connected to the macrocell and termed as the MUE, while subscriber UE 2 camps on the femtocell and is referred to as the HUE. In this case, UE 1 enters into the household of the femtocell and causes strong interference at HNB. At the (macro-) cell-edge location, the interference becomes overwhelming as UE 1 transmit power is close to the maximum. This MUE causes the case, what we call the Kitchen Table user (KTU) problem, where on a kitchen table there could be both femto connected and macro connected terminals. The macroconnected terminals generate high interference due to the short distance between them and the affected HNB.

The other scenario that causes noticeable uplink interference takes place when the HUE, that is, the users on the femtocells, moves outside the household and continues the femtocell service. Since the femto-connected user's signal now penetrate through the home residence, the HUE has to transmit at a much higher power level than its indoor counterparts. Classified as Scenario D in [2], we name this user the Backyard User (BYU), and thus it generates the BYU problem discussed in the paper. In Figure 1(b), both users are connected to the femtocell, while UE 2 is inside the house where the HNB coverage is good, and the other user, UE 1, is on the edge of the HNB coverage. UE 2 introduces significant interference onto the Macro layer as well as to neighbouring femtocells. In the cases where the femtocell under consideration is close to the macrocell site, the noise rise from UE 1 at the macro NodeB can be significant.

The KTU and BYU problems are two extreme cases which may bring a disruption to the network service. Although the primary victims of BYU and KTU scenarios are the macro NodeB (MNB) and HNB, respectively, our analysis shows that they are not independent but rather inextricably linked, that is, one problem may enhance the other. To understand this, let us look at an example where the KTU and BYU problems happen simultaneously in the femtocell, that is, there is a KTU close to the HNB while an HUE outside of the house. In this case, the backyard HUE has to further increase the power to overcome the interference from the uncoordinated KTU. By doing so, it aggravates the resource constraint in the uplink by adding more interference at the macrobase station. Keeping this in mind, our study aims to reveal the joint effect of these two issues, rather than study them in separate scenarios.

2.2. System Simulation Assumptions. In this section, we introduce the cellular environments where the uplink of the hybrid network is studied. In Table 1, simulation parameters of macrocells and femtocells are specified for suburban and urban scenarios, respectively. The following assumptions are stipulated in the system model:

(i) A three-tier 37 macro-cell structure is considered for macronetwork where the macro NodeB of interest is in the center and the frequency reuse factor is one.

(ii) All mobiles terminals are uniformly distributed in the macrocells and femtocells, except that the outdoor HUEs are on the femtocell boarder and at the nearest side to the macrocell base station.

(iii) Directional antennas (sectorisation) are employed at the macro base stations to increase the capacity while omni-directional antennas are employed at the femto HNBs.

(iv) The residential home penetration loss is 10 dB.

(v) Outdoor HUE penetration, that is, the percentage of BYUs in the total population of HUEs, conforms to those in [8].

(vi) Indoor MUE penetration refers to the percentage of the KTUs in the total population of MUEs.

(vii) For macrocell service, only voice calls are used. While for femto cells, three types of services are specified in Table 2, ranging from the voice call to medium data rate services.

(viii) Perfect power control is assumed at both macro base stations and femtocell HNBs (Here HUE power is determined to guarantee the assigned data service under the power cap.).

3. Uplink Interference Management

As the uncoordinated UEs get close to nonserving NodeB, they typically introduce at these NodeBs interference that is significant w.r.t. the noise floor. Interference from a few such aggressors may cause service disruption in the affected cell. Even in cases where the services can be maintained, it is achieved at the cost of higher power consumption for UE. This in turn would deteriorate the services in other neighbouring NodeBs, that is, it forms a closed loop with positive feedback that makes the situation even worse. In this paper, the cost function to optimize is the Rise over Thermal (RoT) at macro base stations and HNB.

Assuming that the transmitted signals over the wireless link are primarily subject to the propagation loss, and that the downlink pathloss is the same as that in the uplink, the RoT at macro NodeB caused by a scheduled HUE is given by [9] as follows:

$$\mathrm{RoT}_{\mathrm{MNB}} = \Delta_P + \Delta_N + \rho_{\mathrm{HNB}} + \mathrm{RoT}_{\mathrm{HNB}} + \tau - \Delta, \quad (1)$$

where $\Delta_P = P_{\mathrm{HNB,max}} - P_{\mathrm{MNB,max}}$ is the difference between NodeB transmission power, $\Delta_N = N_{\mathrm{HNB}} - N_{\mathrm{MNB}}$ is the difference on the noise figures of NodeBs, ρ_{HNB} is the required carrier-interference-ratio (CIR) at HNB, $\mathrm{RoT}_{\mathrm{HNB}}$ is the receive interference (w.r.t. to noise floor) at HNB, τ is the average transmission power increase due to fast power control and Δ denotes the coverage difference at the position of HUEs between femto and macro cells. The RoT of HNB caused by an uncoordinated MUE (In this paper, we focus on the noise rise caused by femto-to-macro interference or vice versa, to highlight the impacts of femto deployment as well as simplify the analysis.) is given by

$$\mathrm{RoT}_{\mathrm{HNB}} = P_{\mathrm{MUE}} - L_{\mathrm{MUE\text{-}HNB}} - N_{\mathrm{HNB}}, \quad (2)$$

where P_{MUE} is the transmission power of the MUE and $L_{\mathrm{MUE-HNB}}$ is the pathloss between the MUE and the affected HNB. RoT leads to degradation in the receiver sensitivity, hence needs to be minimized. In the following, we present a number of techniques that mitigate the RoTs at NodeBs.

3.1. HNB Power Management. Typically good femtocell downlink coverage can be achieved more easily when

Table 1: System Parameter for Macro and Femtocells.

	Suburban scenario	Urban scenario
Macrocell parameters		
Macrocell Radius	1 km	500 m
Max. Macro NB Transmit Power	43 dBm	43 dBm
Maximum Indoor MUE (Kitchen Table User) Transmit Power	24 dBm	18 dBm
Maximum Outdoor MUE Transmit Power	14 dBm	8 dBm
Number of Sectors per Cell	3	6
Data Rate per MUE	15 kbps	15 kbps
Spreading Factor for MUE	128	128
Number of MUEs per km^2	26	229
Relative power of control channel	−6 dB	−6 dB
Asynchronous Uplink	Yes	Yes
Duty cycle for voice call	100%	100%
MUE Indoor Penetration	10%	10%
Femtocell parameters		
Femtocell Radius	15 m	10 m
Max. HNB Transmit Power	20 dBm	20 dBm
Shielding (Penetration) Loss	10 dB	10 dB
Area percentage occupied by HNB	2.4%	3%
Number of HUEs per HNB	2	2
Number of HUEs per km^2	68	190
Spreading factor for HUE	variant	variant
Duty cycle for data service	100%	100%
HUE Outdoor Penetration	20%	10%
HNB RoT threshold	12 dB	12 dB
Propagation loss model		
Macrocell	$133 + 35\log_{10}(d)$ dB	
Femtocell	$98.5 + 20\log_{10}(d)$ dB	
Voice	15 kbps	15 kbps
Low Rate Service	120 kbps	60 kbps
Medium Rate Service	360 kbps	120 kbps

femtocell location approaches the macrocell border. In these cases, a low transmit power by HNB suffices for the range of a normal residence. On the other hand, the HNB coverage is weak when the femtocell is close to the macro cell site due to the strong macro downlink interference. A fixed HNB power setup is suboptimal as it fails to provide constant femtocell coverage across the macrocell, and it may introduce excessive interference to the macrocell.

Adaptive HNB power is an effective means to minimize the impact on the macrocell while keeping a satisfying coverage within the femtocell. To this end, common pilot channel can be used to measure the downlink channel and an appropriate HNB power is determined. In [3], a mobility event-based algorithm is used in managing HNB pilot power to minimize the unwanted handover events of UEs when HNB is in operation. Employment of the adaptive scheme substantially reduces the HNB power consumption, which corresponds to a reduction on Δ_P in (1) and leads to a decreasing RoT_{MNB} in turn.

Since femtocell deployment is not planned but rather random in nature, zero-touch self-configuration is preferred. To this end, a Network Listen Mode (NLM) is needed at HNB to scan the network air interface [10].

3.2. Handover Outdoor HUE to the Macrocells. Outdoor HUEs may generate severe inference at the macro base stations. This can be clearly seen in (1) where as the HUE moves to the femto cell border, the downlink coverage by the macro NodeB can be much better than that of the serving HNB, that is, Δ is small, while the resultant RoT at MNB increases. A viable solution is to handover the HUE to the macro layer. On one hand, this removes the outdoor HUEs from the serving HNB, and relieves the Backyard Problem. On the other hand, HUEs added onto the macro layer consume the system resources that would be otherwise allocated to MUEs. HUE handover techniques can be determined by evaluating the signal quality of the downlink CPICH channel of the serving HNB, w.r.t. that from nearby macro base stations.

3.3. Inter-Frequency Switch for MUEs in the Dead Zone. Femto deployment generates coverage holes called dead zones inside the macrocell. Macro UE in the dead zone undergoes tremendous cross-layer interference from the HNBs in the downlink and may experience a service disruption. On the other hand, macro UE inside the dead zone causes severe interference to the femtocell uplink transmission. This can be observed in (2) where RoT_{HNB} dramatically increases when $L_{\text{MUE-HNB}}$ is small. In this case, switching of the MUEs inside the dead zone, that is, Kitchen Table UEs, to another carrier or Radio Access Technique (RAT) can effectively mitigate the problem in both femtocells and macrocells, given that the operator has alternative carriers.

3.4. Adaptive Uplink Attenuation. On average, the transmission power of femto HUEs is below that of macro UEs, due to the much shorter transmission range. Nevertheless, the dynamic range of a receiver frontend (RF) is large at the HNB and can cope with strong interference from uncoordinated UEs in extreme cases. If the noise figure N_{HNB} is fixed, the interference caused by uncoordinated Kitchen Table MUE results in a substantial noise rise RoT_{HNB}. This in turn reduces the uplink throughput (number of users) that the HNB can support significantly [8, 11]. To resolve the problem, an additional UL attenuation gain is proposed for the receiver RF at the HNB to deal with the surging interference [8, 11].

We study the problem by assuming that the femtocells affected by Kitchen Table User can be anywhere, rather than

Table 2: Impact on macrocell throughput and range.

	Data rate	Receiver mode	Macro rate reduction in [%]		Increase in the number of macro-BS in [%]	
			Urban	Suburban	Urban	Suburban
Case 1	Medium	Conv.	3.3	3.7	0.4	0.2
Case 2	Medium	Conv.	40.0	25.9	50.9	15.9
Case 2	Medium	Adv.	10.0	3.7	0.4	0.2
Case 3	Voice	Conv.	3.3	3.7	0.4	0.2
Case 3	Low	Conv.	13.3	7.4	0.4	0.2
Case 3	Medium	Conv.	53.3	37.0	87.6	28.5
Case 4	Mix	Conv.	30.0	18.5	25.1	7.6
Case 4	Mix	Adv.	10.0	3.7	0.4	0.2

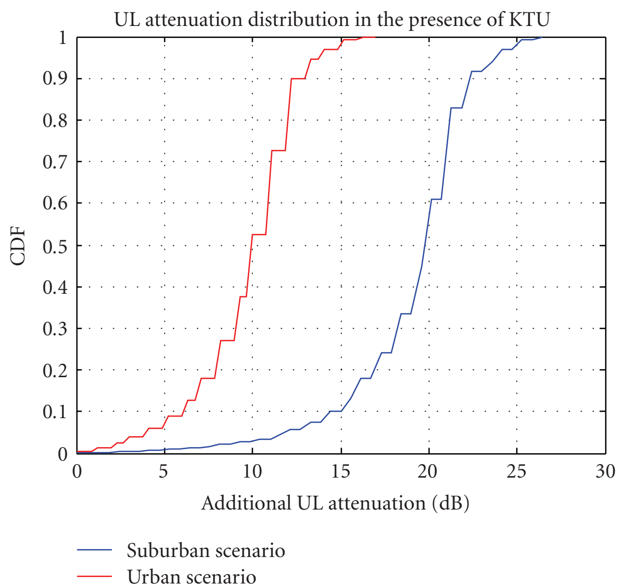


Figure 2: Distribution of adaptive UL attenuation gain when there is Kitchen Table MUE.

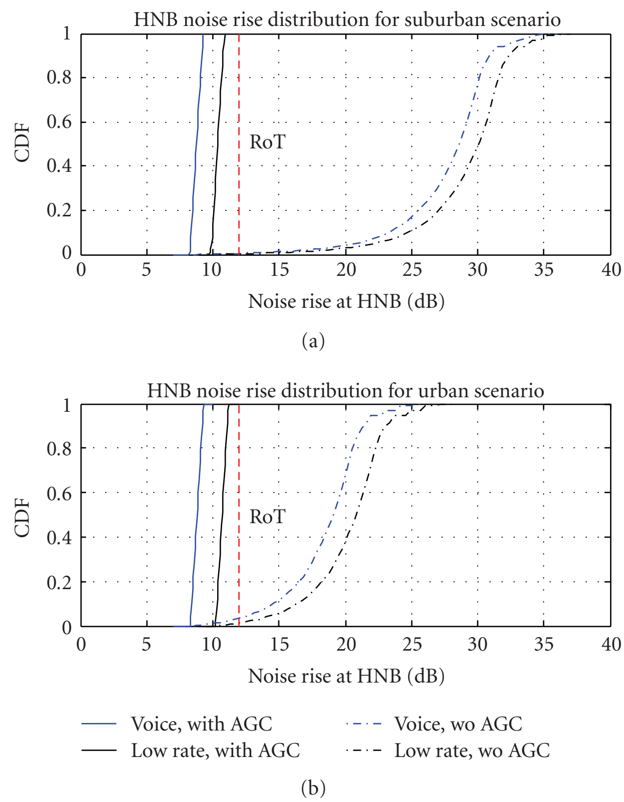


Figure 3: Distribution of rise over thermal (RoT) in a femtocell with nonconnected UE penetration.

on a few isolated points in the macro cell [2]. Depending on their positions in the macrocell, the effect of Kitchen Table MUEs on the femto cell is different, reflected by the distribution of the UL attenuation gain over a wide range. Figure 2 shows the distribution of the UL attenuation gain employed at the home NodeB RF frontend. It is observed that in suburban scenarios the attenuation gain can be as high as 30 dB, while in more than 90% of the cases the HNB receiver needs to attenuate the incoming signals by more than 15 dB. This number drastically decreases in urban areas, where only a marginal percentage of HNBs need to execute an additional attenuation gain of 15 dB. By doing so, the extravagant noise rise caused by the nonconnected UEs can be effectively controlled within the system-defined RoT threshold, which is marked as the red dashline in Figure 3.

It should be noted that using a large attenuation gain may increase the battery drain of the femto-connected terminals, reduce femtocell range, and cause additional interference onto neighboring femtocell HNBs and macro base stations. Therefore, it should be adaptive to the interference in the radio environment and applied only when it is necessary.

3.5. Downgrade Service of HUE. Under the strong interference from the Kitchen Table MUEs, the HUE can reduce the data rates of its services to relax the power requirements. This mechanism eliminates the unnecessary interference to other cochannel users but will compromise data throughput. In this paper, we let HUEs tune to the service of the highest supportable data rate if they can not achieve the target data rate. Moreover, HUE transmission power is capped at a maximum power of 21 dBm to avoid creating excessive interference.

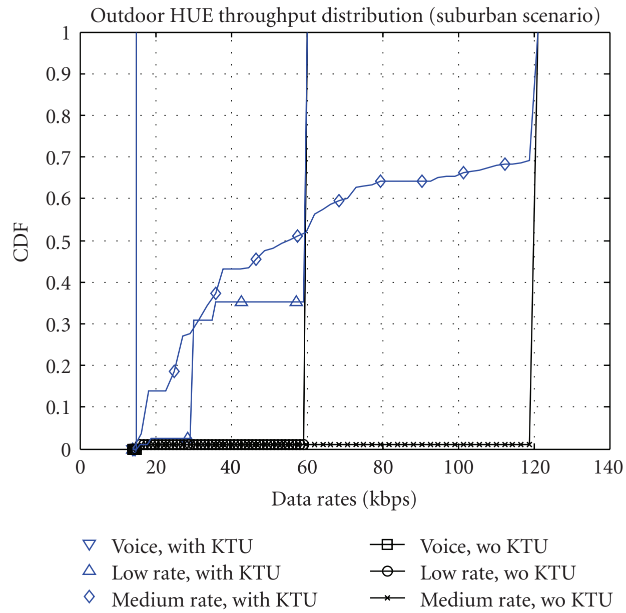


Figure 4: Distribution of outdoor HUE throughput in the presence of Kitchen Table MUEs.

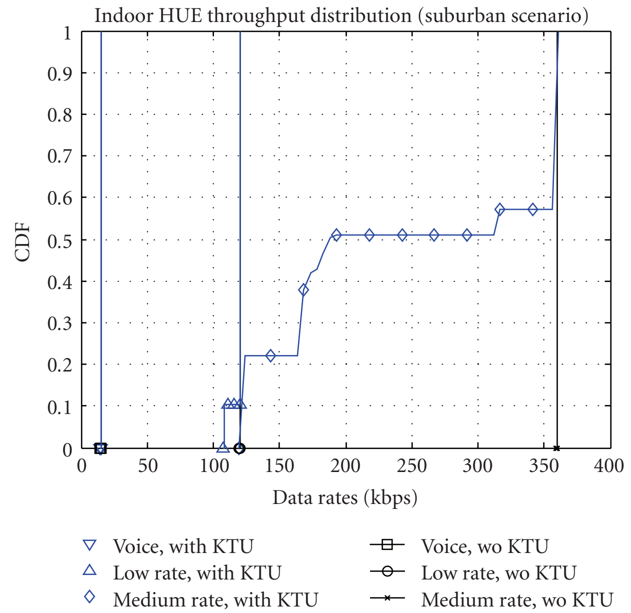


Figure 5: Distribution of indoor HUE throughput in the presence of Kitchen Table MUEs.

3.6. Improved Femtocell Receiver Sensitivity. Application of advanced methods to improve the femtocell sensitivity will reduce the transmit power from Femto-connected UEs. Different techniques can be used to achieve this including antenna diversity, interference cancellation, enhanced signal processing in synchronization, and channel estimation and equalization [12–14]. This not only enhances the performance in the femtocell, but also reduces the interference introduced to the macro layer as will be seen in the presented results.

4. Simulation Results

In this section, simulations are conducted in a femto-macro hybrid network specified in Section 2 to show the impacts of the femtocell deployment. The direct consequence of the Kitchen Table problem is to generate substantial noise rise at the affected HNBs and degradation in the HUE throughput. The increase in the HUE transmit power is shown as a result of the desensitized HNB receiver. The impact in the macro layer is studied by observing the noise rise and data throughputs in the macrocell. Unless specified otherwise, we use the parameters in Table 1 in all simulations. Adaptive power management is assumed at the home NodeBs such that a constant coverage is maintained for femtocells. The uplink attenuation technique in Section 3.4 is employed to mitigate the impact of the severe cross-tier interference.

Due to the strong interference of a macro-connected user, the Kitchen Table problem deteriorates the femtocell user performance significantly. Figures 4 and 5 show the rate distribution of three types of HUE services when there is Kitchen Table MUE against that in the absence of Kitchen Table MUEs. In suburban areas, it can be seen that for low data rate, around 35% of outdoor HUEs are served below the target rate of 60 kbps, while the ratio jumps to 68%

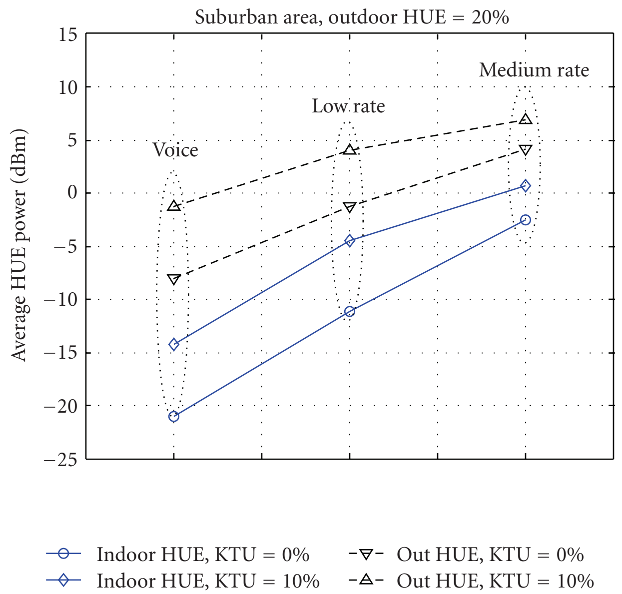


Figure 6: Average transmit power of HUEs in suburban scenario.

for medium data rate, reflecting a drastic degeneration in the uplink throughput. On the other hand, target rates can be easily achieved in cases where there is no Kitchen Table User. For indoor HUEs, the relative reduction is smaller in the presence of Kitchen Table UE. Nevertheless, the ratio of services staying below the target rate is still 57% for the medium rate service.

There is typically enough headroom in the femtocell UE transmit power due to the short transmission range. However, this is no longer the case when the Kitchen Table problem or Backyard problem occurs. Figure 6 shows the average transmission power of indoor and outdoor HUEs

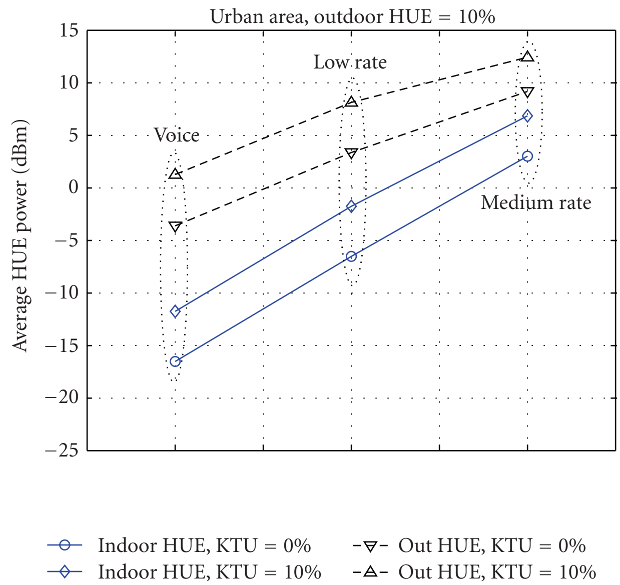


Figure 7: Average transmit power of HUEs in urban scenario.

in the suburban scenario. It can be seen that even though the outdoor HUEs are on services of lower data rates, their power consumption is typically 5∼15 dBm higher than that of the indoor counterparts. This can be explained by noting that outdoor HUEs have to use extra transmit power to compensate for the more significant pathloss, including the building penetration loss. It is also observed that the presence of Kitchen Table MUEs leads to a drastic increase on the power consumption for affected femtocell users. Figure 7 shows the average power for HUEs in urban scenario, which has a similar trend to that in suburban scenario.

The Kitchen Table problem is considered as the worst scenario for the HNB where the uncoordinated MUEs introduce significant interference into the femtocell uplink. Nevertheless, from (1) it can be seen that a noise rise in the femtocell can also affect the macro-NodeB, since HUEs in the femto cells need to boost up their transmission power to improve the received signal quality at the HNB. In [2], this is classified as an undesired UE noise rise at non-serving NodeBs. To clearly show the impacts of HUEs, jointly with Kitchen Table and Backyard problems on the macrocell, four test cases are defined as follows.

(i) *Case* 1. *No Kitchen Table or Backyard Problem*. All HUEs stay inside their homes and are under good coverage of the serving HNB, while all MUEs are outside the femtocell households.

(ii) *Case* 2. *Backyard Problem Only.* A number of HUEs are on the femtocell edge (specified for suburban and urban scenarios), while macro UEs stay clear of the femtocell households.

(iii) *Case* 3. *Joint Kitchen Table and Backyard Problems.* A number of HUEs are at the femtocell edge and some MUEs are inside the units with femtocells. The percentage of outdoor HUEs and indoor MUEs is specified in Table 1.

(iv) *Case* 4. *Mixed Service.* The break up of indoor and outdoor HUE services is 70%, 20%, and 10% for voice calls, low rate services, and medium-rate services, respectivlely.

In the simulations, a baseline system equipped with conventional receiver techniques is considered. Table 2 includes the reduction in macrocell throughput due to the introduction of femtocells. It can be seen from that in Case 1, with neither Kitchen Table nor Backyard problems, interference from femtocells is tolerable and causes a marginal loss in the macrocell. The rate loss is below 5% in both urban and suburban scenarios.

In Case 2, which embodies the Backyard User problem only, the macro throughput loss increases substantially, especially for services of higher data rates. The rate reduction caused by medium rate femtocell services is 40% and 26% for urban and suburban scenarios, respectively. Results for voice and low data rates show marginal performance degradation in Cases 1 and 2, and hence omitted from the table.

Case 3 takes into account both Kitchen Table and Backyard problems, hence represents the worst scenario for the hybrid radio network. While a rate loss of no more than 15% is observed in macrocell for low rate femtocell services, the throughput compromise jumps to 53% and 37% for medium rate services, in suburban and urban scenarios. It indicates that the capacity increase in femtocells may trigger substantial macrocell performance degradation if severe Kitchen Table and Backyard problems exist.

Case 4 represents a service portfolio that is akin to the realistic traffic in the femtocell. In this case, macrocell throughput reduction can be up to 30% and 18% in urban and suburban scenarios, while improvements in receiver sensitivity are able to mitigate the problem by a great extent. We consider advanced techniques that can improve the sensitivity of the single user decoding chain by a couple of dBs and are able to cancel 80% of the intracell interference (In [14], it is shown that around 2 dB improvement in receiver sensitivity can be achieved for a moderately loaded UMTS by employing data-aided channel estimation. Using the soft interference cancellation (SIC), 80% of interfering power can be removed if the BER in the previous decoding iteration is below 0.05).

To better understand the consequence of the femtocell coexistence onto the macrocell, the increase in the MNB number is included in the right-most columns in Table 2. It can be seen that for Case 4 traffic, much more operator infrastructure is needed to maintain sufficient QoS with conventional receiver techniques. While the degradation becomes negligible if advanced signal processing is employed.

It is also observed that compared to the macrocells in suburban areas, macrocells deployed in the urban scenario are more subjected to the interference from the femtocells. This is because the urban macrocells have a much smaller range and the base station is closer to the femtocells. Moreover, due to the higher density of femtocell populations and the fact that the HUEs are more likely to be at the cell edge (refer to Table 1), urban macro base stations are interfered by more users in the femto layer, especially those causing strong interference.

5. Conclusion

The new wireless configuration using femtocells is an appealing application to enhance the indoor service in residential areas, hot spots, and macro cellular environments, while reducing operator costs. Due to the randomness of femtocell deployments, it is crucial to understand the impacts of femtocells on the existing networks and try to minimize these effects. In this paper, we consider a hybrid network with coexisting femto and macrocells, and provide a comprehensive study on the impacts of deploying a large number of femtocells in the shared spectrum with macro cells. In particular, two severe interference scenarios caused by penetration of nonconnected UE to the other layer are analyzed. Our analysis considers a large cellular network and discusses a number of interference management schemes to improve the situation. We show through simulation that the Kitchen Table problem is the worst case scenario and on average 57% of indoor and 68% of outdoor HUEs cannot achieve the target throughput. Due to such strong interference from uncoordinated MUE, the HUE consumes 5∼10 dB more power than it normally needs. Such HUE power boosting also produces undesired noise rise at macro BS. Our results show that up to 53% and 37% macrocell throughput reductions are observed at macro BS in suburban and urban scenarios, respectively. Together with these simulation results, guidelines for minimizing the impacts of embedded femtocells on the underlying macrocells are presented.

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References

[1] V. Chandrasekhar, J. G. Andrews, and A. Gatherer, "Femtocell networks: a survey," *IEEE Communications Magazine*, vol. 46, no. 9, pp. 59–67, 2008.

[2] "Interference management in UMTS femtocells," *Femto Forum White Paper*, December 2008.

[3] H. Claussen, L. T. W. Ho, and L. G. Samuel, "Self-optimization of coverage for femtocell deployments," in *Proceedings of the 7th Wireless Telecommunications Symposium (WTS '08)*, pp. 278–285, Pomana, Calif, USA, April 2008.

[4] V. Chandrasekhar and J. G. Andrews, "Uplink capacity and interference avoidance for two-tier cellular networks," in *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM '07)*, pp. 3322–3326, Washington, DC, USA, November 2007.

[5] D. Das and V. Ramaswamy, "On the reverse link capacity of a CDMA network of femto-cells," in *Proceedings of the IEEE Sarnoff Symposium*, pp. 1–5, Princeton, NJ, USA, April 2008.

[6] D. Choi, P. Monajemi, S. Kang, and J. Villasenor, "Dealing with loud neighbors: the benefits and tradeoffs of adaptive femtocell access," in *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM '08)*, pp. 1–5, New Orleans, La, USA, December 2008.

[7] V. Chandrasekhar, J. G. Andrews, T. Muharemovic, Z. Shen, and A. Gatherer, "Power control in two-tier femtocell networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 8, pp. 4316–4328, 2009.

[8] R4-082309, "Text proposal for HNB TR25.9xx: guidance on UL interference testing," *picoChip Designs, Airvana, AT&T, ip.access and Vodafone*.

[9] R4-080154, "Simulation results for Home NodeB to Macro NodeB uplink interference within the block of flats scenario," *Ercisson*.

[10] J. Edwards, "Implementation of network listen modem for WCDMA femtocell," in *Proceedings of the IET Seminar on Cognitive Radio and Software Defined Radios: Technologies and Techniques*, pp. 1–4, London , UK, September 2008.

[11] R4-080154, "HNB and macro uplink performance with adaptive attenuation at HNB," *Qualcomm Europe*.

[12] A. Lampe, "Iterative multiuser detection with integrated channel estimation for coded DS-CDMA," *IEEE Transactions on Communications*, vol. 50, no. 8, pp. 1217–1223, 2002.

[13] R. Otnes and M. Tuchler, "Iterative channel estimation for turbo equalization of time-varying frequency-selective channels," *IEEE Transactions on Wireless Communications*, vol. 3, no. 6, pp. 1918–1923, 2004.

[14] Z. Shi and M. C. Reed, "Iterative maximal ratio combining channel estimation for multiuser detection on a time frequency selective wireless CDMA channel," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC '07)*, pp. 1002–1007, Hong Kong, March 2007.