A Novel Spectrum Arrangement Scheme for Femto Cell Deployment in LTE Macro Cells

Yi Wu, Dongmei Zhang, Hai Jiang, Ye Wu
Nokia Siemens Networks
Beijing, CHINA

Abstract—**Femto cells, also called home base stations, are small cellular access points installed by home users to get better indoor voice and data coverage with lower network operation cost. In this paper, the deployments of femto cells within LTE cellular networks are investigated. Based on the current partial co-channel deployment configuration for LTE Home evolved NodeB, a novel scheme of femtocell-aware spectrum arrangement is proposed for co-channel interference avoidance between macro and femto cells. The performance improvement of the proposed scheme has been validated by simulation results.**

Keywords—**Femto cell, Home eNB, Co-channel interference avoidance.**

I. Introduction

Femto cells are short-range low-cost low-power cellular radio systems which are plugged to residential DSL or cable broadband connections to provide improved indoor wireless coverage and increased throughput for mobile data services directly at home. The concept of femto cell [1] is quite simple: making a base station cheap enough to be deployed in high volume for residential use, connected to the core network via broadband. This would deliver an end-user the same service and benefit as a converged offering but, crucially, would use existing standard handsets, with no need to upgrade to expensive dual-mode devices. An example of femto cell access via broadband Internet is shown in Fig. 1. With the use of residential IP broadband connection behind the femto cell, an efficient fixed mobile convergence (FMC) solution is achieved. Correspondingly, the business analysis in [2], [3] show that the mobile operators could benefit from lower costs and increased fixed mobile substitution, leading to higher revenues and more profitable relationships with their newfound Internet and web partners.

From the customer perspective, the limited indoor coverage and poor performance of the typical cellular mobile networks usually lead to a bad experience for mobile users at home, which is mainly due to the wall attenuation of the radio signal. Furthermore, considering the practical use case that the in-house users would often have more requirements for high speed data services compared with those users on the way, how to provide a consecutive and stable wireless connection with high capacity becomes a critical issue for the mobile operators when competing with the other conventional home access approaches such as WLAN. Therefore, today almost all of the major mobile operator groups are undergoing trials and evaluations of femto cell products to add capacity and

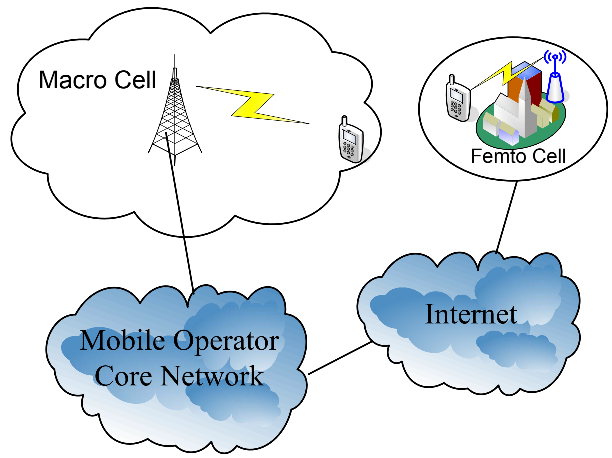

Fig. 1. Femto access via broadband Internet

coverage to their networks. The femto cell products have been developed to work with a range of different cellular standards including GSM, CDMA, UMTS, LTE and WiMAX. The ABI Research [4] has released a market prediction of 102 million world-wide users on more than 32 million femto cells by 2012. Toward this end, a collaborative organization called the Femto-Forum comprising operators and femto cell vendors was formed in 2007 with the objective of developing open standards for product interoperability [5].

The capacity improvement introduced by femto cell network has been studied in previous works mainly focusing on WCDMA system [6]-[8]. However, there are still many technical challenges and research topics open while facing femto cell networks [9]. One of them is the issue of radio frequency and interference management between the overlapped femto and macro cells. Once the femto cells are deployed in a large scale within the macro cell, the inter-cell interference will become increasingly dynamic and unpredictable. In 3GPP-LTE system [10], the requirements, architecture and deployment configurations of the on-going LTE Home eNodeB have also been widely designed and discussed for femto cell characterization [11], [12].

In this paper, a novel scheme of femtocell-aware spectrum arrangement for co-channel interference avoidance between macro and femto cells is proposed. The scheme is applied to the partial co-channel configuration of the femto cell deployment settings in LTE system [12]. The basic concept of the proposal is to enable the coordination of the spectrum arrangement schemes between the overlapped macro and femto cells. The macro BS (Base Station) proactively makes usage of the configuration information of the femto cell spectrum within its coverage and impacts the scheduling algorithm of the macro cell so that the co-channel interference over the femto cell could be avoided. The performance improvement of the proposed scheme over the normal dynamic scheduling has been validated by simulations.

The rest of this paper is organized as follows. In Section II, the deployement configuration of LTE Home eNodeB is briefly introduced and the problem statements are presented. In Section III, the scheme of femtocell-aware spectrum arrangement for co-channel interference avoidance between macro and femto cells is proposed. In Section IV, the advantage of the proposed scheme over the uncoordinated dynamic scheduling is analyzed. In Section V, the results of performance evaluation by simulations are provided. Finally, concluding remarks are drawn in Section VI.

II. Technology Overview and Problem Statement

A. Deployment Configuration of LTE Femto Cells

Within the course of increasing cellular terminal penetration and fixed-mobile convergence, an upcoming demand for femto cells to provide attractive services and data rates in home environments has been observed. The femto cell deployment in LTE is referred to as Home eNodeB (HeNB).

There are a number of different deployment configurations which have been considered for femto cells. The femto BSs could be configured to operate in their own dedicated spectrum which is separated from that of the macro cells. In this type of configuration, there is no co-channel interference between the macro and femto cells. The disadvantage of the dedicated spectrum configuration is that the usage of radio spectrum is not efficient enough and the operator has to reserve a particular spectrum for the femto cells. Alternatively, the femto BSs could be configured to use the same spectrum as the macro cells. This is regarded as the worst case co-channel interference scenario and consequently the highest risk would be taken for this deployment configuration. Considering the tradeoff between the spectrum usage efficiency and the co-channel interference, the partial co-channel configuration is proposed, which works by limiting frequencies being shared by the macro cell and the femto cell.

Fig. 2 shows an example of spectrum sharing between the macro BS and femto BS for the LTE partial co-channel configuration [12]. Provided that the shared spectrum does not overlap the central 6 RBs (Resource Blocks) of the macro BS's downlink spectrum, then it will not prevent UEs (User Equipments) receiving the PBCH (Physical Broadcasting Channel) and the Synchronization signals [13]. Accordingly, the handover or cell entry process of the macro cell will not be influenced. In the partial co-channel configuration, the macro UEs in the shared part experiencing "pathological" interference are hoped to be dynamically scheduled to the macro dedicated part by frequency dependent scheduling.

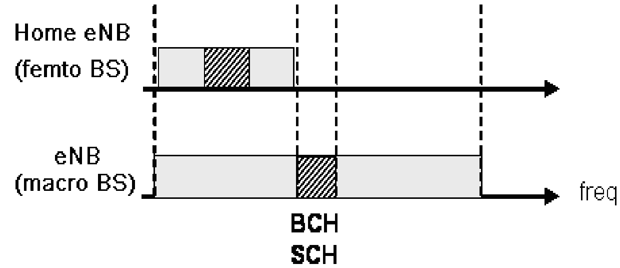

Fig. 2. Spectrum arrangement for LTE (partial co-channel)

B. Problem Statement

LTE ensures intra-cell orthogonality among macro users through OFDM technology and mitigate inter-cell interference through fractional frequency reuse (FFR). However, since the femto cells are located in the coverage of macro cell, the inter-cell interference is unavoidable due to the overlapping. If there is no coordination between the macro BS and femto BS, the inter-cell interference could be significant around the edge of the femto cells. How to arrange the radio spectrum among the macro and femto cells is an important issue especially in the partial co-channel configuration deployment.

If the macro BS and femto BS employ their own frequency dependent scheduling without coordination, there are two critical problems which may lead to high interference:

1) **Dead zone due to the asymmetry level of uplink transmission power**

   Since the femto cell is small enough, the transmission power of the UEs in femto cell should not be as large as that of the UEs in macro cell. If the distance between femto cell and the macro BS is large enough, the co-channel interference caused by the femto UE's uplink transmission will not be detected by the macro BS. Contrarily, when the macro UE is close to the femto cell, the co-channel interference caused by the macro UE's uplink transmission will be quite high considering the small radius of the femto cell. Therefore, because the macro BS does not detect the co-channel interference from the femto cell in the uplink, the macro UE who is close to the femto cell will generate a "dead zone" to the femto uplink transmission.

2) **Incoordination of dynamic scheduling processes**

   Practically, the mechanism of frequency dependent scheduling works based on the assumption that the wireless fading is continuous in time scale and therefore, it can be evaluated and predicted. If the interference comes from the femto cell co-channel, the normal scheduling could not work successfully since the co-channel interference varies unpredictably due to the dynamic scheduling of the femto BS and the dynamic characteristics of the femto traffic. Without cooperation of the macro BS and femto BS, the independent scheduling will not be optimal in the presence of the femto cell deployments with the partial co-channel configuration.

III. Proposed Scheme

In this section we propose a novel scheme of femtocell-aware spectrum arrangement for co-channel interference reduction between macro and femto cells. The scheme is applied to the partial co-channel configuration as described previously.

Since the spectrum allocated to the femto cell is configured by the mobile operator, the macro BS could have knowledge of the shared frequency resource for femto cells within its coverage. Accordingly, the macro BS divides its available spectrum into different part: the macro dedicated spectrum part and the femto sharing spectrum part. When managing UEs, the macro BS is proposed to maintain a femto-interference pool. The UEs which have potential threat of co-channel interference on the femto cells are categorized into the femto-interference pool, and therefore their arranged frequency will be limited to the macro dedicated spectrum part during scheduling. All the other UEs outside the femto-interference pool could be freely scheduled spanning the whole spectrum. An example of the proposed scheme is illustrated in Fig. 3. Explanatorily, the mechanism of categorizing UEs into the femto-interference pool is approached by the following methods:

A) Detecting UE's moving speed

The macro BS is proposed to use the knowledge of UE moving speed as one criterion for estimating if the UE is a potential threat over the femto cells. The UE moving speed could be evaluated by Doppler frequency estimation of the received reference signals. Generally, some other mechanisms such as handover may also need the information of the UE moving speed as an assistant and therefore, this should not be an increased burden for the BS functionality. By roughly estimating the moving speed of the UE, the BS could exclude those UEs with high speed from the femto-interference pool because they are supposed not to be in or around the femto cells for non-negligible time considering the fact that the femto cell is always located inside a building (home) and the size is quite small.

B) Femto-aware CQI reporting and calculation

In our proposal, when configuring the macro cell subbands for CQI (Channel Quality Indicator) reporting [14], the macro BS needs to ensure that the femto spectrum part are not spanning over any subband boundary in order to enable an easy mapping of the femto spectrum to a subset of the subbands. Then there are several alternative ways for the macro BS to distinguish the connected UEs from being located in the so-called interference area with femto cells:

1) If the macro UE supports CQI reporting of all subbands, the macro BS will categorize the reporting UE into the predefined femto interference pool if the CQI values of the subbands belonging to the macro dedicated spectrum are all comparably higher than those belonging to the femto sharing spectrum.
2) If the UE supports CQI reporting of part of subbands, the UE should select a set of M subbands corresponding to the femto sharing spectrum and report one CQI value reflecting transmission only over the M selected subbands. Additionally, the UE shall also report the wideband CQI value. Therefore, the macro BS could easily detect that if the CQI value over the femto sharing spectrum is comparably lower than the widerband CQI value and make the decision of putting the UE into the femto interference pool. The UE-selected subband feedback could be done in two alternative ways:
   a) The BS involves the mapping of the subbands to the femto sharing spectrum and the macro dedicated spectrum in the broadcast system message and therefore, the UE could store the mapping in its own memory and selectively report the M subbands automatically. In this way the UE is also aware of the proposed method and needs to have algorithm upgrade in implementation.
   b) The BS notifies the UE to select the required M subbands by sending higher layer message and the UE reports the CQI of the subbands according to the notified subband index. In this way the UE is not aware of the proposed method and the algorithm upgrade is only required at the BS side.

For all the above comparisons between the CQI values of the femto sharing spectrum and the macro dedicated spectrum or the wideband spectrum, there should be a threshold predefined by the system as the criterion of detected interference between femto and macro cells. Whenever the CQI difference between the femto sharing spectrum and the macro dedicated spectrum or the wideband spectrum goes below the predefined threshold, the macro BS should exclude the reporting UE from the femto interference pool immediately.

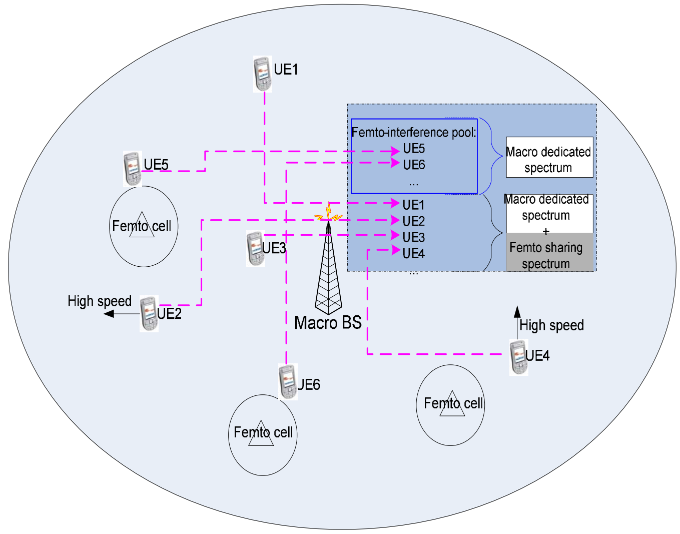

Fig. 3. Illustration of the proposed scheme

IV. Advantage Analysis over the Uncoordinated Dynamic Scheduling

In this section, we analyze the advantage of the proposed scheme over the normal uncoordinated dynamic scheduling. To

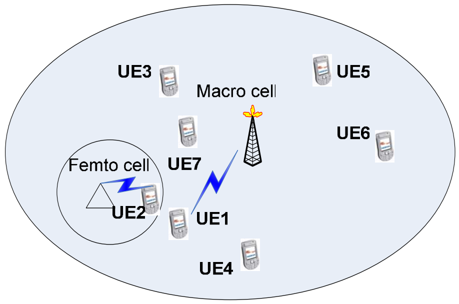

Fig. 4. An example of co-channel interference scenario

illustrate the advantage of the proposed scheme over that of the normal frequency dependent scheduling, we take an example of LTE FDD cellular network with femto cell overlapping as shown in Fig. 4. The macro UE1 is assumed to be close to the femto cell, being a potential co-channel threat on the performance of the femto UE2.

1) Asymmetry problem of uplink transmission power

As discussed in the previous section of problem statement, the dead zone problem due to asymmetry level of UEs' uplink transmission power happens when the distance between the femto cell and the macro BS is large enough. In such a case, the macro BS's uplink scheduler will not detect the co-channel interference when the same frequencies are used by the femto uplink transmission in parallel. Correspondingly, the macro UE will not be "moved" to the macro dedicated spectrum and the co-channel interference caused by the macro UE's uplink on the femto cell would be serious because of the small radius.

In the proposed scheme, since the macro BS employs the femto-aware CQI reporting which is measured in the downlink direction, the femto co-channel interference could be easily detected due to the comparatively small distance between the macro UE1 and the femto BS. Whenever the femto co-channel interference is detected in the downlink measurement, the UE is categorized into the femto interference pool and therefore, both the downlink and uplink scheduler will only allocate the macro dedicated spectrum to the related UE with higher priority. Correspondingly, the co-channel interference is avoided and the problem of asymmetric uplink transmission power is solved.

2) Incoordination problem of parallel scheduling processes

As for the incoordination scheduling problem, we take the example in Fig. 4 to compare the difference between the normal dynamic scheduling method and the proposed scheme. Assuming that the available frequency resource in the macro cell is not saturated, we only consider the resource allocation to the interested UEs (i.e. UE1 in macro cell and UE2 in femto cell). The wireless channel variances of the UEs are considered in scheduling and the traffic of UE2 is assumed to be arriving in burst dynamically.

Fig. 5 shows that if the macro BS has no knowledge about the femto BS, the co-channel interference is hard to be avoided because the resource allocation of the femto cell is unpredictable by the macro BS. As shown in Fig. 6 when the

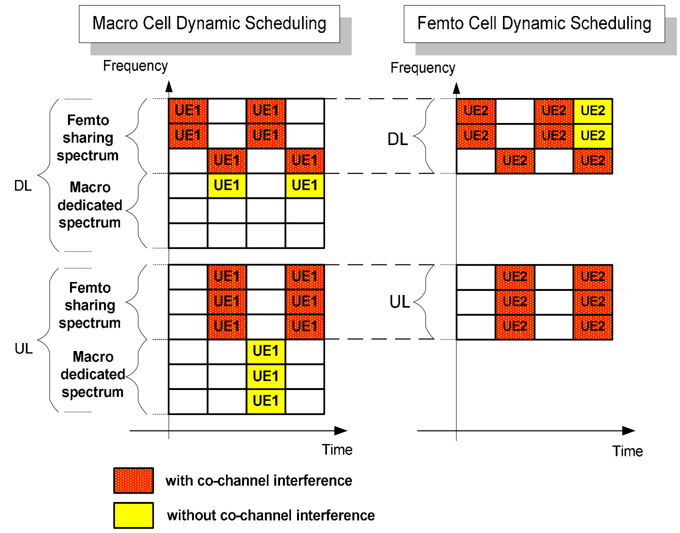

Fig. 5. Snapshot of frequency dependent scheduling for the Macro BS without awareness of femto cell

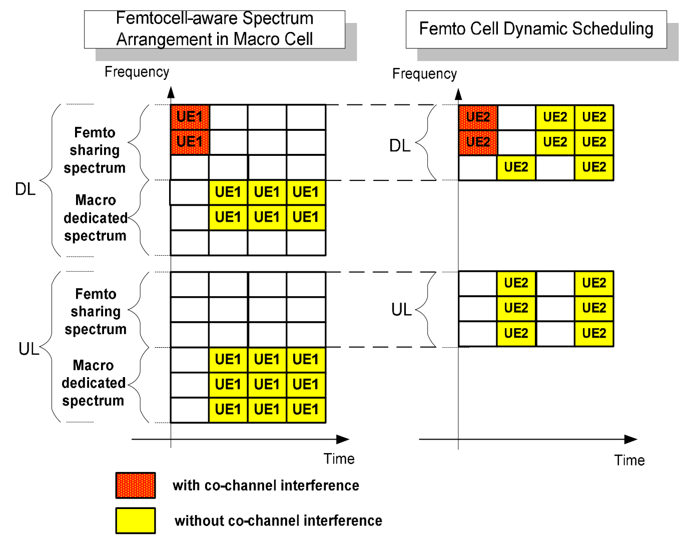

Fig. 6. Snapshot of femtocell-aware spectrum arrangement for the Macro BS

proposed method of femtocell-aware spectrum arrangement is employed, as long as UE1 is detected to be a potential threat for femto co-channel interference in CQI reporting, the allocated spectrum for UE1 is moved to the macro dedicated part both in downlink and uplink scheduling. Therefore, the performance of the macro UE is improved efficiently and also the potential threat on the femto cell is avoided.

V. Numerical Examples

To evaluate the performance of the proposed method, a mixed macro and femto scenario as shown in Fig. 4 is considered in simulation. For simplicity of simulation, the intra-cell orthogonality among macro users is assumed for the LTE system. Since this paper focuses on the partial co-channel configuration, we assume that the femto cell occupies half of the spectrum of the macro cell as pre-negotiated

TABLE I
SYSTEM PARAMETERS

Parameter	Value
Max Tx power for macro/femto BS	43dBm/15dBm
Max Tx power for macro/femto UE	25dBm/10dBm
Distance from femto cell to macro BS	1km
Femto cell radius	200m
Thermal noise density	-174dBm/Hz
Antenna configuration	SISO, Omni
Macro propagation model	$L[\text{dB}] = 128.1 + 37.6\lg(R)$, where R is in km.
Indoor propagation model	$L[\text{dB}] = 37 + 32\lg(R) + nL_w$, where R is in meter, n is the number of indoor walls and L_w=6.9dB is the attenuation of an indoor wall.
Shadow fading	Lognormal distributed, std. 8.0dB
Multipath fading: power [dB]	EVA:[0,-1.5,-1.4,-3.6,-0.6,-9.1, -7.0,-12.0,-16.9]; EPA:[0,-1.0,-2.0,-3.0,-8.0, -17.2,-20.8]
Multipath fading: delay [ns]	EVA:[0,30,150,310,370,710,1090, 1730,2510]; EPA:[0,30,70,90,110,190,410]
Direction	Uplink
Scheduler	Proportional fairness

by the operator and the inter-cell interference between the adjacent femto cells is not considered. Most of the important parameters used in simulation are shown in Table I. A modified Okumura-Hata model as presented in [15] is used for the macro propagation channel and a modified COST 231 multi-wall model as presented in [16] without the effect of floor attenuation is used for the indoor propagation channel. As for the shadow fading, a general lognormal distribution with a standard deviation of 8 dB is used. For the multi-path fading, the EPA channel model and EVA channel model [17] are used for pedestrian users and vehicular users, respectively.

In this example, we focus on the impact of co-channel interference due to the uplink transmission and the uplink traffic of each UE is assumed to be saturated. To simplify the scheduling process, each UE is assumed to be allocated by 1MHz while being scheduled both in the macro and femto cells. In the simulated scenario, one UE is assumed to be staying in the femto cell and six UEs are located in the macro cell. In the macro cell, the two pedestrian UEs are located around the edge of the femto cell, which have the potential threat of co-channel interference on the femto cell. The other four macro UEs are assumed to be far away from the femto cell, two pedestrian and two vehicular. The proposed femtocell-aware spectrum arrangement scheme is applied in the macro BS so that the scheduler could proactively avoid the potential uplink co-channel interference on the femto cell based on the results of CQI reporting and UE speed estimation.

Fig. 7 presents the CDF (cumulative distribution function) of the instantaneous throughput for the femto user. To evaluate the performance improvement, the results of the typical frequency dependent scheduling scheme are also presented, which does not involve any coordination between the macro and femto BSs. The results show that the proposed coordination scheme provides clearly higher throughput for the femto users than the typical uncoordinated scheme. In our simulation, we have also increased the number of pedestrian macro UEs around the edge of the femto cell and evaluate the performance improvement of the proposed scheme. The results in Fig. 8 show that with the increased macro UEs near the femto cell, the performance of the femto UE under the typical uncoordinated scheduling scheme deteriorates quickly due to the co-channel interference, while the proposed coordination scheme successfully survives from that.

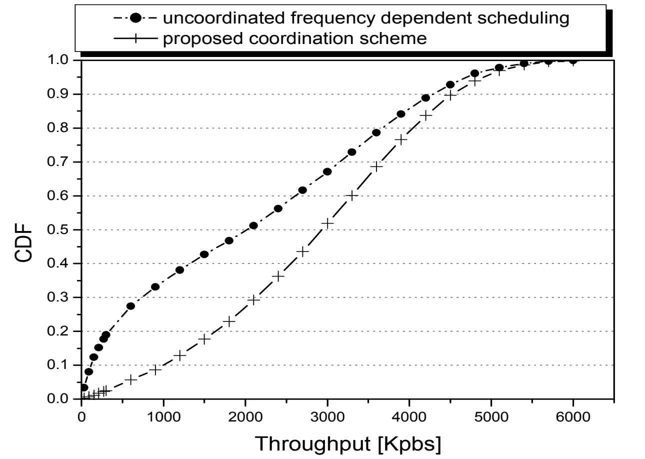

Fig. 7. Cumulative distribution function of the instantaneous throughput of the femto UE

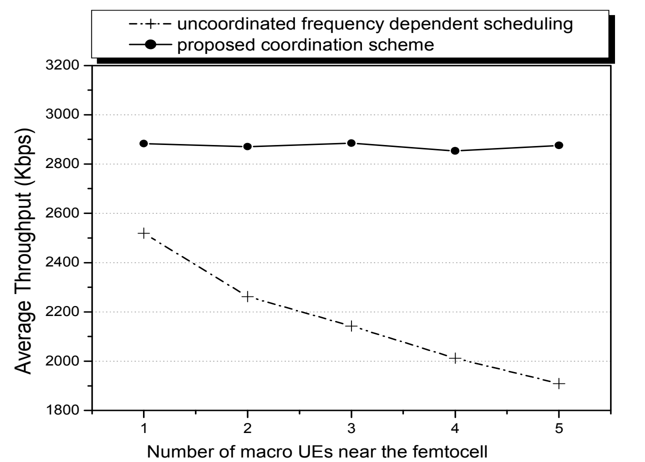

Fig. 8. Average throughput of the femto UE while increasing the number of macro UEs near the femto cell

On the other hand, when the macro UE is detected to have a potential threat of co-channel interference on the femto cell, its available spectrum in scheduling would be limited to the macro dedicated part. Correspondingly, the resource allocation for the particular macro UE may not be so optimized as the typical frequency dependent scheduling. Fig. 9 presents the CDF of the instantaneous throughput of one selected

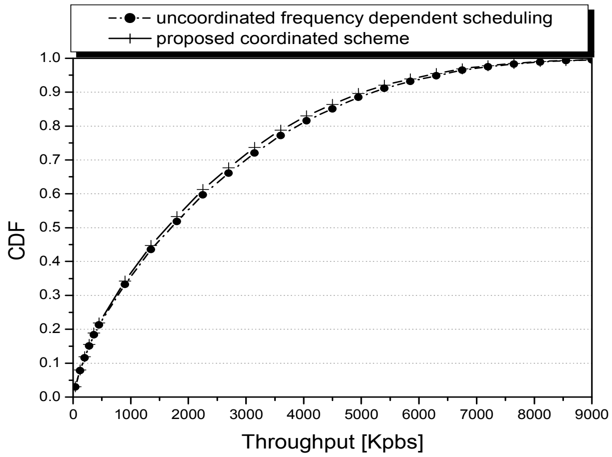

Fig. 9. Cumulative distribution function of the instantaneous throughput of the selected macro UE

macro UE who is set around the edge of the femto cell. The results show that the performance degradation due to the spectrum limitation of the proposed coordination scheme is not obvious which is mainly because we have assumed that the available frequency resource of the macro cell is large enough. Actually, the adverse impact of the proposed scheme is that the available frequency resources of the macro UEs in the femto-interference pool are limited within the macro dedicated part while being scheduled. If the load of the macro BS is heavy enough and the number of the macro UEs categorized into the femto interference pool is too large, the macro dedicated part spectrum may be exhausted and then the femto dedicated part has to be used for capacity issue of the macro cell. In this case, the co-channel interference would be increased and the throughput performance of both femto and macro cells would be degraded to a certain extent.

VI. Conclusion

Femto cell is an attractive proposition for mobile consumers and operators alike. With the trend towards in-home femto cell deployment, the overlapping of the femto cells and the macro cell would be a usual scenario. This paper presented a novel scheme of femtocell-aware spectrum arrangement for femto cell deployment in macro LTE network. With the proposed scheme, the macro BS takes the knowledge of the shared frequency resource for femto cells within its coverage and proactively detects those UEs having potential threat of co-channel interference with femto cells. By the efficient spectrum arranging method, the detected UEs which have potential threat to femto cells are allocated to the "clear" part of the spectrum which has no frequency overlapping with the femto cells. The advantage of the proposed scheme over the normal uncoordinated scheduling method has been analyzed and validated by simulations.

References

[1] Picochip White Paper, "The Case for Home Base Stations," April 2007.

[2] Airvana White Paper, "Femtocells: Transforming the Indoor Experience," Femto Forum, 2007.

[3] Andy Tiller, "The Case for Femtocells," The Basestation e-Newsletter, June 2007.

[4] ABI Research, "Femtocell Access Points Market Research Report," www.abiresearch.com/products/market research/Femtocell Access Points, 3rd Quarter, 2007.

[5] Femto Forum, http://www.femtoforum.org/.

[6] V. Chandrasekhar, J. Andrews, "Uplink Capacity and Interference Avoidance for Two-Tier Cellular Networks," IEEE GLOBECOM, Nov. 2007.

[7] T. Nihtila, "Capacity improvement by employing femto cells in a macro cell HSDPA network," IEEE Symposium on Computers and Communications, June 2008.

[8] H. Andersson, R.S. Karlsson, P. Larsson, P. Wikstrom, "Improving system performance in a WCDMA FDD network using indoor pico base stations," IEEE VTC2002-fall, Sept. 2002.

[9] V. Chandrasekhar, J. Andrews, A. Gatherer, "Femtocell Networks: a Survey," IEEE Communications Magazine, Sept. 2008.

[10] 3GPP-LTE: http://www.3gpp.org/Highlights/LTE/LTE.htm

[11] 3GPP TS 22.220, "Service requirements for Home NodeBs and Home eNodeBs (Release 9)," Sept. 2008.

[12] 3GPP TR 25.820, "3G Home NodeB Study Item Technical Report (Release 8)," Sept. 2008.

[13] 3GPP TS 36.211 v8.5.0, "Evolved Universal Terrestrial Radio Access (E-UTRA): Physical Channels and Modulation," Dec. 2008.

[14] 3GPP TS 36.213 v8.5.0, "Evolved Universal Terrestrial Radio Access (E-UTRA): Physical Layer Procedures," Dec. 2008.

[15] 3GPP TR 25.848, "Physical Layer Aspects of UTRA High Speed Downlink Packet Access," April 2001.

[16] D.J. Cichon and T. Kurner, "EURO-COST 231 Final Report," 1998.

[17] 3GPP TS 36.104 v8.4.0, "Evolved Universal Terrestrial Radio Access (E-UTRA): Base Station (BS) radio transmission and reception," Dec. 2008.