Auto-Tuning of Downlink Power of LTE Femtocells Adaptive to Various Interference Conditions

Motoki Morita[1)], Yasuhiko Matsunaga[2)], Kojiro Hamabe[1)]
[1)]System Platforms Research Laboratories, [2)]Mobile Radio Access Network Division
NEC Corporation
Kawasaki, Japan
m-morita@bx.jp.nec.com, y-matsunaga@bl.jp.nec.com, k-hamabe@bq.jp.nec.com

Abstract— **Femtocell base stations are required to set proper downlink transmit power under various building environment. Conventional power setting techniques use a fixed power offset over received power level of the strongest macrocell base station to expand indoor femtocell coverage along with mitigating the interference leakage to the outdoors. However, the power offset has not been adequately optimized for various interference conditions, leading to degradation of macrocell or femtocell throughput. We propose an auto-tuning scheme of the power offset adaptive to the various interference conditions such as size of buildings where femtocell mobile stations exist, and distance to a street where macrocell mobile stations exist. The proposed scheme automatically tune the power offset so that the femtocell throughput can increase while maintaining the macrocell throughput based on macrocell mobile stations' interference detection reports and their totalization. According to the Long-Term Evolution system level simulations, the proposed scheme tuned the power offset to a proper level depending on various building conditions and can improve the throughput. If the power offset is commonly tuned among femtocells in macrocell, a newly deployed femtocell can employ a proper setting from the beginning of its operation.**

Keywords-component; femtocell; auto-tuning; interference mitigation; power setting

I. INTRODUCTION

Femtocell base stations (FBSs) are small, low-power wireless access points that are typically installed at a home or small office/home office (SOHO) and connected to a mobile operator's networks by using residential DSL or cable broadband connections [1]. Femtocells are expected to increase cellular network capacity, expand a macrocell's coverage, and introduce new services. On the other hand, only registered mobile stations (MSs) can connect to FBSs and the femtocells are often deployed in a co-channel with the macrocells. Therefore interference with existing macrocells or other FBSs is a major problem. Femto Forum, an industry consortium to promote femtocells, has published a whitepaper on the study of interference between femtocells and macrocells in various deployment scenarios in Universal Mobile Telecommunication System (UMTS) [2]. It is important for an FBS to set its own appropriate transmit power to mitigate the interference with macrocells. Furthermore, it is beneficial that an FBS set the transmit power automatically depending on the surrounding radio conditions because a large number of femtocells are expected to be deployed without any assistance from trained personnel by the network operator.

Self-configuration or self-optimization of the FBS transmit power has been investigated. We studied the adaptive power level setting by estimating penetration loss between a macrocell BS (MBS) and an FBS [3]. Standard bodies such as 3GPP TSG-RAN WG4 also investigated interference mitigation for UMTS and long-term evolution (LTE). Guidelines on how to control UMTS Home NodeB (HNB) and LTE Home eNodeB (HeNB) interference by transmit power level setting are given in refs. [4] and [5]. In these schemes an FBS estimates how much interference the macrocell MSs (MMSs) will have. On the other hand, instead of estimating this, the FBS can obtain interference information of the MMSs cooperatively via a network controller [6] or the MMS itself [7]. However, to initiate FBS operation at a proper setting, these techniques do not adequately optimize the power setting or collected the sufficient interference information of the MMSs. As a result, the difference between the radio environment, where the FBS is deployed, and the initial power setting will cause degradation of the macrocell or femtocell throughput.

We introduce an auto-tuning scheme of LTE FBS downlink power after an initial setting based on MMSs' interference detection. The proposed scheme automatically adjusts the power to a suitable value for size of buildings where an FBS should cover and distance to a street where MMSs exist. The performances of the proposed scheme are evaluated by system level simulations and the pros and cons are studied.

The paper is organized as follows. Section II gives details of the proposed auto-tuning scheme. Section III evaluates the performance of the scheme, including system level simulation assumptions and results. Section IV concludes this paper with a summary of results.

II. AUTO-TUNING OF POWER SETTING

Proper setting of the FBS transmit power level depending on the environment is essential for controlling interference with macrocells. In this paper, transmit power means the transmit power of the reference signals of FBSs unless explicitly stated otherwise. The interference level can be controlled by the

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transmit power of the reference signal because it is proportional to the maximum transmit power.

We use the adaptive power level setting scheme proposed in our previous study [3] as a baseline. It is based on estimation of the penetration loss with downlink (DL) co-channel reception power of the reference signal of the strongest MBS and uplink (UL) reception power from neighboring MMSs. The FBS sets the transmit power of the reference signal $P_{\_tx}$ [dBm] as expressed in Equation (1).

$$P_{\_tx} = MEDIAN(P_{\_m} + P_{\_offset\_o} + L_E, P_{\_tx\_upp}, P_{\_tx\_low}), \quad (1)$$

where $P_{\_m}$ [dBm] is the reception power of the reference signal from the strongest MBS, $P_{\_tx\_upp}$ and $P_{\_tx\_low}$ [dBm] are the upper and the lower limit values of the transmit power, respectively, $P_{\_offset\_o}$ [dB] is an internally predetermined fixed power offset value compensating for the indoor path loss excluding the penetration loss, and L_E [dB] is the estimated value of the penetration loss described in detail in [3].

Because the $P_{\_offset\_o}$ is fixed, various interference conditions such as size of buildings where femtocell mobile stations (FMSs) exist and distance to a street where MMSs exist are not sufficiently considered. The macrocell or femtocell throughput may degrade if the initial value is too large and too small compared with the conditions. Therefore, we investigated an auto-tuning scheme of the $P_{\_offset\_o}$

A. *Requirements for the auto-tuning*

The auto-tuning scheme shall meet requirements as follows to clarify difference from a conventional no-tuning scheme.

R1: It shall maintain influence of the femtocell's interference to macrocells under various building environment.

R2: It shall increase femctocell throughput compared with a no-tuning scheme (the power offset is always fixed).

R3: It shall apply a proper power offset to initial self-configuration of FBSs.

If R1 and R2 are met, higher femtocell throughput is guaranteed with macrocell throughput maintained under different building environment. If R3 is met, a newly deployed FBS can immediately use the proper value already used at other existing FBSs at an initial setting.

Figure 1 shows the basic structure of the proposed auto-tuning scheme. The structure consists of the following three steps.

Step 1: The MMSs measure the DL interference from the FBSs and report the measurement to an operation & maintenance (OAM) server if a condition for interference detection is met.

Step 2: The OAM server for the FBSs collects the measurement reports and tunes the $P_{\_offset\_o}$ based on the totalization of the measurements at a certain interval.

Step 3: The OAM server notifies the FBSs of the tuned $P_{\_offset\_o}$.

We study three different auto-tuning schemes in detail based on the three steps. First scheme is using individual offset where the $P_{\_offset\_o}$ is tuned individually per FBS. Second or third one is using common offset where the $P_{\_offset\_o}$ is tuned commonly among FBSs in a macrocell with per-femtocell or per-macrocell measurement, respectively.

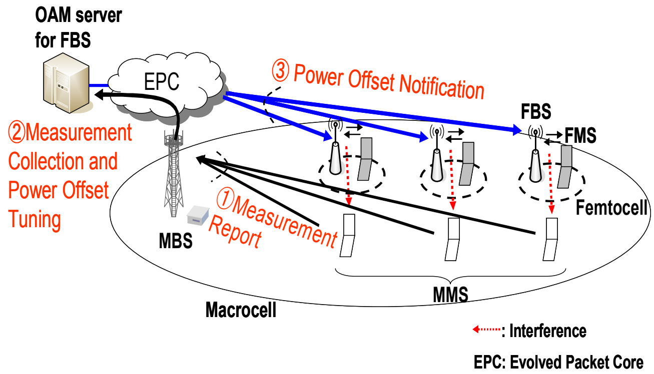

Figure 1. Basic structure of the auto-tuning of power offset

B. *Individual Offset*

In the tuning scheme using the individual offset (IO), the measurement reports are totalized individually per FBS and the $P_{\_offset\_o}$ is auto-tuned individually per FBS. This tuning scheme can adjust the $P_{\_offset\_o}$ to each building size. This tuning scheme is based on the transmit power control proposed in [6].

In Step 1, the MMS measures the reference signal received power (RSRP) of a serving MBS and interfering FBSs. The OAM server or the serving MBS sends a measurement control message to the MMS. If the interfering FBS is registered in a neighbor cell list in the MBS, the MMS can measure the RSRP of the FBS as in a normal handover procedure. If not, the MMS can measure the RSRP of the FBS as in a detected cell reporting procedure. After measurement, if the RSRP [dBm] of FBS minus the RSRP [dBm] of the MBS is greater than a threshold (Th1 [dB]), then the MMS reports the interference detection result to the OAM server via the MBS. This report is event-triggering.

In Step 2, the OAM server collects the interference detection reports triggered in Step 1 at a certain interval. Then it totalizes the reports per FBS and calculates an interference detection ratio (IDR1). The IDR1 is the ratio of the number of interference detection reports to the number of MMSs that receive the measurement control message from the serving MBS. If the IDR1 is greater than a target value Ta1, then the $P_{\_offset\_o}$ is decreased by a step size $\triangle$. This condition corresponds to high interference from the FBS to the MMS. On the other hand, if the IDR1 is smaller than Ta1-Hy1 (Hy1 is a hysteresis value), then the $P_{\_offset\_o}$ is increased by the same step size $\triangle$. This condition corresponds to low interference from the FBS to the MMS. The $P_{\_offset\_o}$ has a range between its minimum and maximum values. The OAM server updates the $P_{\_offset\_o}$ per FBS.

In Step 3, the OAM server notifies each FBS in the same macrocell of each tuned $P_{\_offset\_o}$ per FBS in Step 2.

C. Commen Offset with Per-Femtocell Measurement

In the tuning scheme using common offset with per-femtocell measurement (CO-F), the measurement reports are totalized individually per FBS in the 1st step and collectively among FBSs in the macrocell in the 2nd step, and the $P_{\_offset\_o}$ is auto-tuned collectively among FBSs in the same macrocell. This tuning scheme can suppress the number of FBSs that cause a large amount of interference detection at MMSs.

Detail actions in Step 1 are the same as the IO scheme. In Step 2, the OAM server collects the interference detection reports triggered in Step 1 at a certain interval. First it totalizes the reports per FBS and calculates the interference detection ratio IDR1. Second it totalizes the reports among FBSs by calculating an over-interference FBS ratio (OFR). The OFR is the ratio of the number of FBSs, IDR1 of which exceeds a threshold Th2, to the total number of FBSs in the macrocell. If the OFR is greater than a target value Ta2, then the $P_{\_offset\_o}$ is decreased by a step size $\triangle$. On the other hand, if the OFR is smaller than Ta2-Hy2 (Hy2 is a hysteresis value), then the $P_{\_offset\_o}$ is increased by the same step size $\triangle$. The $P_{\_offset\_o}$ also has a range between its minimum and maximum values. The OAM server updates the $P_{\_offset\_o}$ per macrocell.

In Step 3, the OAM server notifies all FBSs in the same macrocell of one $P_{\_offset\_o}$ tuned per macrocell in Step 2. This auto-tuning scheme can maintain the number of interfering FBSs at a target value because it uses the OFR instead of the IDR1 directly.

D. Common Offset with Per-Macrocell Measurement

In the tuning scheme using common offset with per-macrocell measurement (CO-M), the measurement reports are totalized collectively among FBSs in the macrocell, and the $P_{\_offset\_o}$ is auto-tuned collectively among FBSs in the same macrocell. This tuning scheme can suppress average interference detection at MMSs in the macrocell.

Detail actions in Step 1 are the same as the previously mentioned auto tuning schemes. In Step 2, the OAM server collects the interference detection reports triggered in Step 1 at a certain interval. Then it totalizes the reports among FBSs in the macrocell and calculates the interference detection ratio IDR2. The IDR2 is the ratio of the total number of interference detection reports in the macrocell to the multiplication of the number of MMSs that receive the measurement control message from the serving MBS by the total number of FBSs in the macrocell. If the IDR2 is greater than a target value Ta3, then the $P_{\_offset\_o}$ is decreased by a step size $\triangle$. On the other hand, if the IDR2 is smaller than Ta3-Hy3 (Hy3 is a hysteresis value), then the $P_{\_offset\_o}$ is increased by the same step size $\triangle$. The $P_{\_offset\_o}$ also has a range between its minimum and maximum values. The OAM server updates the $P_{\_offset\_o}$ per macrocell.

In Step 3, the OAM server notifies all FBSs in the same macrocell of one $P_{\_offset\_o}$ tuned per macrocell in Step 2. This auto-tuning scheme can suppress the number of interfered MMSs in the macrocell because it uses the IDR2 instead of the IDR1 or OFR.

III. Performance Evaluation

We evaluated the performances of the three proposed auto-tuning schemes with system level simulations based on the DL LTE system in several scenarios and studied their pros and cons in terms of the requirements stated in Section II A.

A. Simulation Assumptions

Figure 2 shows a suburban (residential) deployment scenario considered in the evaluation. FBSs and MMSs are dropped within each macrocell with a random uniform distribution. In each single-floor femtocell, an FBS is located at the center and an FMS is located randomly. The cell radius of the femtocell (this value is the minimum distance between an MMS and an FBS) and the number of internal walls are adjustable.

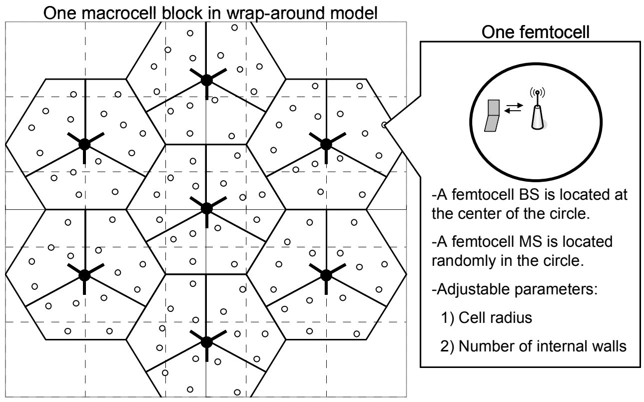

Figure 2. Macrocell and Femtocell Deployment Scenario

Tables I and II summarize the simulation assumptions and parameters of a macrocell and femtocell respectively [8].

TABLE I. MACROCELL SIMULATION ASSUMPTIONS

Parameter	Assumption
Cellular Layout	Hexagonal grid, 3 sectors per site
Cell Radius	1 km
Number sites	7 (=21 cells) with wrap-around
Carrier Frequency	2000 MHz
Carrier Bandwidth	5 MHz
Path loss from MBS to MMS	15.3+37.6log10(R) [dB] R [m]: Distance
Path loss from MBS to FMS/FBS	15.3 + 37.6log10(R) + Low [dB] Low [dB] : Penetration Loss
Log-normal shadowing standard deviation	8 dB
BS antenna gain after cable loss	14 dBi
BS noise figure	5 dB
MS Antenna gain	0 dBi
MS Noise Figure	9 dB
Total BS TX power	43 dBm
Traffic model	FTP (File size: 2 Mbytes, User arrival rate: 2.5 per hour per user)
Number of MMSs	100 per macrocell
Min. distance between MBS and MMS or MBS and FBS	35 m
MS speeds of interest	3 km/h

TABLE II. FEMTOCELL SIMULATION ASSUMPTIONS

Parameter	Assumption
Cell Radius	5 or 20 m
Femtocell Frequency Channel	Same frequency and same bandwidth as macrocell layer
Number of FBSs	24 per macrocell
Antenna gain	0 dBi
Number of internal walls s (q)	0 or 4
Penetration loss of exterior (Low) /internal (Liw) wall	10/5 dB
Path loss from FBS to FMS	38.46+ 20 log10(R) + 0.7*d + q*Liw[dB] d [m]: distance inside house
Path loss from FBS to MMS	max(15.3 + 37.6log10(R), 38.46 + 20log10(R)) + 0.7*d + q*Liw + Low [dB]
Path loss from FBS to FMS in another femtocell	max(15.3 + 37.6log10(R), 38.46 + 20log10(R)) + 0.7*d + q*Liw + 2*Low [dB]
Log-normal shadowing standard deviation	4 dB
BS Noise figure	8 dB
Upper/Lower limit value of the Max Tx power	20/-10 dBm
Traffic model	FTP (File size: 10 Mbytes, User arrival rate: 20 per hour per user)
Initial / Min / Max $P_{\_offset\_o}$	70/30/130 dB
Threshold value	(Th1, Th2) = (-8 dB, 0.2)
Target value	(Ta1, Ta2, Ta3)=(0.04, 0.1, 0.1)
Hysteresis value	(Hy1, Hy2, Hy3)=(0.02, 0.05, 0.05)
Update interval of $P_{\_offset\_o}$	5 sec (Simulation duration is 900 sec)
Step size △	1 dB
Min distance between FBS and FMS	10 cm

B. Simulation Results

The proposed auto-tuning schemes were evaluated in three scenarios which had different cell radii (CR [m]) of the femtocell and number of internal walls (q). In all scenarios, the initial value of the $P_{\_offset\_o}$ was 70dB which can cover about 10m of the cell radius. Scenario 1 consisted of small residences ((CR, q) = (5, 0)), where the $P_{\_offset\_o}$ is expected to converge to a smaller value. Scenario 2 consisted of very large residences or offices ((CR, q) = (20, 4)), where it is expected to converge to a larger value. Scenario 3 consisted of both small and very large residences equally mixed to differentiate the individual and common offset.

Figure 3 shows the probability distribution functions (PDFs) of the $P_{\_offset\_o}$ of three proposed auto-tuning schemes in each scenario. In scenario 1, the $P_{\_offset\_o}$ of the CO-F and CO-M schemes had a peak around 60 dB, which is a suitable value for small residences. On the other hand, the $P_{\_offset\_o}$ of the IO scheme often reached the maximum value (130 dB). In scenario 2, the $P_{\_offset\_o}$ of all auto-tuning schemes reached the maximum value, which is a suitable for very large buildings. In scenario 3, the $P_{\_offset\_o}$ of the CO-F only had a smaller peak than the initial value. Note that the maximum FBS transmit power is limited by its upper value of 20dBm even if the $P_{\_offset\_o}$ reaches the maximum value. In scenario 2, the $P_{\_offset\_o}$ reached the maximum value because all FBSs did not interfere with MMSs even if the maximum FBS transmit power was set to the upper value. In scenarios 1 and 3, the $P_{\_offset\_o}$ of the IO often reached the maximum value because several FBSs which were near MBS did not interfere with MMSs. On the other hand, the $P_{\_offset\_o}$ of the CO-F and CO-M was commonly tuned among all FBSs in a macrocell and reached a certain value where a frequency of the interference from FBSs as a whole was close to a target one. The difference in the $P_{\_offset\_o}$ peaks of the CO-F and CO-M in scenario 3 was due to setting that the $P_{\_offset\_o}$ of the CO-F was more sensitive to the interference from FBSs in especially small residences.

Figure 4 shows the cumulative distribution functions (CDFs) of the maximum FBS transmit power. The no tuning scheme (the $P_{\_offset\_o}$ was always fixed to 70dB) is also described along with the three auto-tuning schemes. The maximum FBS transmit power was set as in the Equation (1) to be larger or smaller than that of the no-tuning scheme, depending on the $P_{\_offset\_o}$ tuned as in Figure 3.

Figure 5 shows the MMS's lower 5-percentile (5%) user throughput and the FMS's mean user throughput of the three auto-tuning schemes and the no-tuning scheme. In scenario 1, the largest MMS 5% user throughput was achieved at the CO-F scheme (by 18% over the no-tuning scheme) without degrading the FMS mean user throughput because the maximum FBS transmit power was decreased largest. In scenario 2, the FMS mean user throughput was improved at the all auto-tuning schemes (by 65% over the no-tuning scheme in the CO-F, for example) because the maximum FBS transmit power was expectedly increased to the upper limit. In scenario 3, the FMS mean user throughput of the IO scheme was increased by 13% over the no-tuning scheme. This was due to increase of the FMS mean user throughput in especially very large residences because the maximum FBS transmit power of the IO was independently set to be larger.

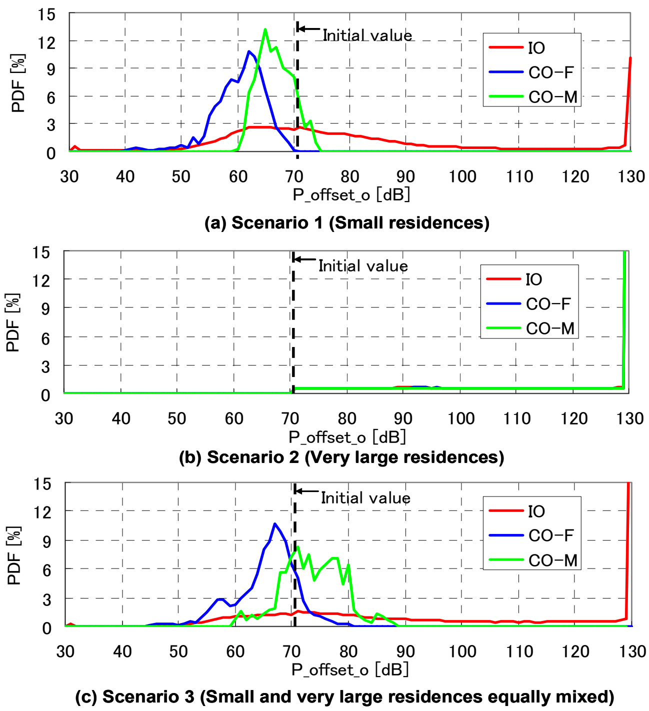

Figure 3. PDFs of the $P_{\_offset\_o}$

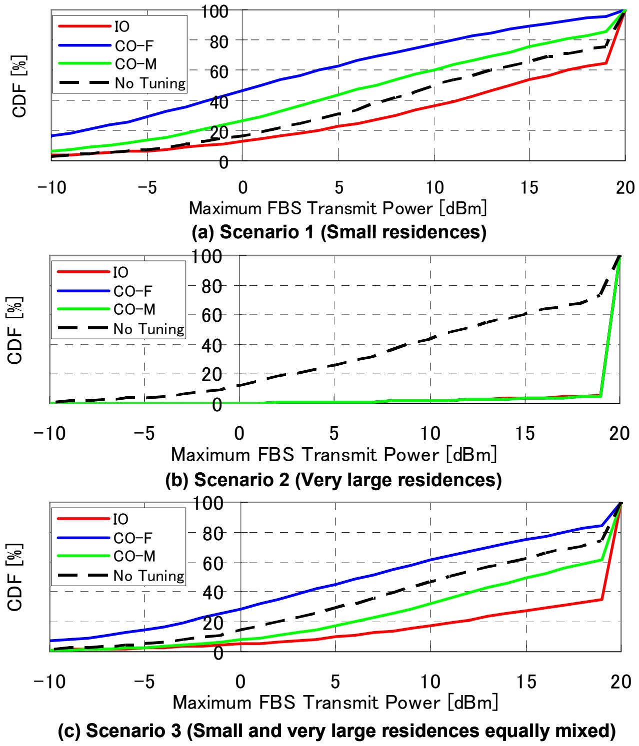

Figure 4. CDFs of the maximum FBS transmit power

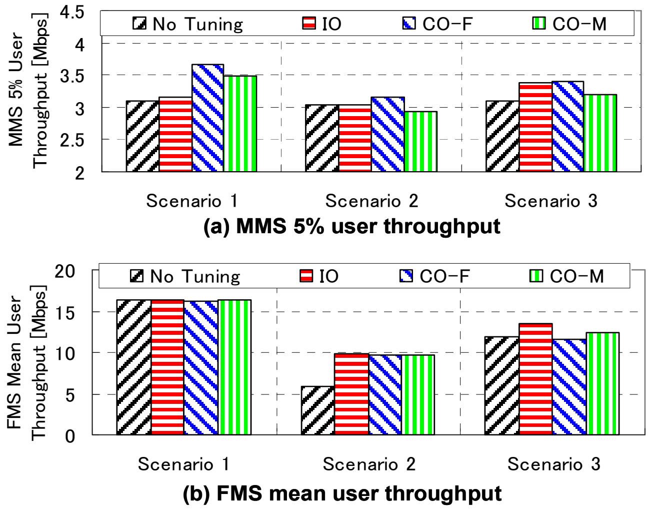

Figure 5. (a) MMS 5% and (b) FMS mean user throughput

C. Pros and Cons of the Proposed Auto-Tuning Schemes

Table Ⅲ summarizes the pros and cons of the proposed auto-tuning schemes in terms of the requirements stated in the Section II (A). In the requirement 1 (R1), MMS 5% user throughput increased in the all auto-tuning schemes compared with the no-tuning. This means the femtocell's interference to macrocells was suppressed. Especially in the scenario 1, MMS 5% user throughput of the CO-F scheme was rather excellent because the transmit power tends to be smaller than that of the no-tuning. In the requirement 2 (R2), FMS mean user throughput of the all schemes also increased compared with the no-tuning. Especially in the scenario 3, FMS user throughput of the IO scheme was rather excellent because the transmit power tends to be adjusted per each different size of residences. In the requirement 3 (R3), whether a tuned power offset was usable or not from the beginning of FBS operation was compared. The CO-F and CO-M schemes were good in the initial setting because when an FBS is newly set, the $P_{\_offset\_o}$ has already been tuned with the accuracy of about 10dB around the peak value. However, in the IO scheme, the initial setting is difficult because the $P_{\_offset\_o}$ has a large range and enough dedicated interference detection for its convergence is required.

In conclusion, it is possible for the proposed scheme using common offset to improve the throughput irrespective of interference scenarios and to use a proper power setting from the beginning.

TABLE Ⅲ Summary of Pros and Cons of Auto-Tunnig Schemes

Requirement	Individual Offset	Common Offset Per-Femtocell	Common Offset Per-Macrocell
Gain of MMS 5% user throughput	1.6 - 9.4 %	4.0 - 18.1 %	0 - 12.6 %
Gain of FMS mean user throughput	0 – 66.7 %	0 – 64.7 %	0 – 66.0 %
Use of a tuned offset from the beginning	No	Yes	Yes

IV. CONCLUSION

We proposed an auto-tuning scheme of the FBS transmit power offset adaptive to the various interference conditions such as size of buildings where FMSs exist, and distance to a street where MMSs exist. The proposed scheme automatically tune the power offset so that femtocell throughput can increase while maintaining macrocell throughput based on MMSs' interference detection reports and their totalization. According to the LTE system level simulations, it is possible for the proposed scheme using common offset among FBSs in a macrocell to improve the throughput by tuning the power offset to a proper level depending on various building conditions. By using the common offset, a newly deployed femtocell can employ a proper setting from the beginning of its operation.

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