# Pareto Optimal SINR Scheduling for Femto-cell Deployment in Wireless Networks

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***Abstract*—In this paper, Pareto Femto-Cell Scheduling (PFCS), a novel scheduling mechanism for randomly deployed femto-cells, is presented. Here, the signal-to-interference-plus-noise ratio (SINR) targets of femto-users are adapted such that the sufficient conditions for Pareto optimal power control (POPC) are fulfilled. Furthermore, interference from full bandwidth users is managed such that as many mobile stations (MSs) as possible can transmit. Due to the random nature of femto-base station (FBS) deployment, interference graphs are used to group femto-cells (and hence, users) such that target spectral efficiencies can be achieved at Pareto optimum power. Simulation results show that PFCS achieves significant system capacity gains over other SINR-target-based power allocation techniques, while maximising coverage in dense mobile environments. Furthermore, substantial power savings can be achieved.**

## I. Introduction

For future wireless networks, there is an increasing demand for higher user and system throughput, along with growing expectation for all MSs in a cell to be available to multimedia and Internet services. This is especially difficult to maintain at the cell-edge. Furthermore, the necessity for more energy efficient, or "green," technologies is growing. Increasing traffic load is expected to double network energy consumption within the next ten years [1]. Inter-cell interference coordination (ICIC) mechanisms attempt to manage interference in order to maintain sufficient spectral efficiency for the users in the network. In this paper, a scheduling and power control technique that produces large energy savings while maintaining system capacity is developed.

Studies indicate that a substantial portion of wireless traffic originates indoors [2]. Poor signal reception through walls severely inhibits the operation of indoor data services, attracting considerable interest in the concept of femto-cells [3]. FBSs are low-cost, low-power, short range, plug-and-play base stations (BSs) which aim to extend and enhance macro-cell indoor coverage. While abundant research on femto-to-macro interference has been carried out [4, 5], few techniques have been considered to manage the interference between several densely deployed FBSs. In this paper, a power control scheme for such interference coordination is developed.

Initial work on power control for orthogonal frequency division multiple access (OFDMA) networks is presented in [6], where fractional power control (FPC) offers a modification to conventional power control to control the tradeoff between system capacity and cell-edge rate. Due to this, however, many users will not achieve their SINR targets, and hence user throughput can suffer. An extension to FPC is developed in [7], where the power control mechanism takes interference caused to neighbouring cells into account. While this achieves a modest capacity increase, only the variance of interference to other cells, rather than the mean, is reduced. Finally, in [8] a computationally efficient power control technique is introduced, where minimisation of transmit power is the main goal. However, by splitting the joint subcarrier and power allocation into two stages, the dependence between the two is disregarded, yielding suboptimal performance.

In this paper, a novel technique combining scheduling and power control for densely deployed femto-cells is considered, to not only minimise power consumption but also satisfy MS throughput requirements through fair interference management. The rest of the paper is structured as follows, Section II describes the system environment for this paper, and Section III describes the analytic basis and implementation of PFCS. Sections IV describes the simulation and results, and Section V offers a conclusion.

## II. System Model

For this paper, a 5×5 apartment grid is considered for the femto-cell environment, where the probability $p_{\text{act}}$ describes the likelihood of a given apartment containing an active FBS. In each active femto-cell, both the MS and FBS are uniformly

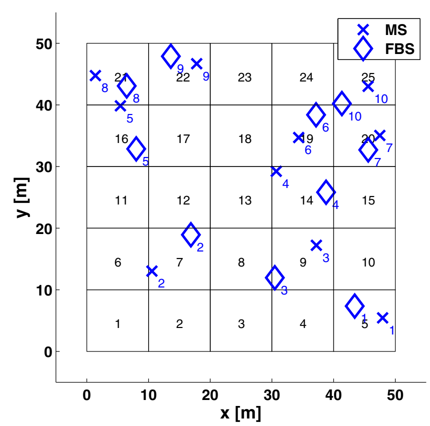


Fig. 1. Apartment block scenario with $p_{\text{act}} = 0.4$, where each apartment is $R = 10\,\text{m} \times 10\,\text{m}$.

distributed within the apartment. Due to the private deployment of femto-cells a closed-access system is assumed [9], and so each MS is assigned to the FBS in its apartment, even if a foreign femto-cell exhibits superior link conditions.

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### A. Channel Model

In general, the channel gain, $G_{k,l}$, between a transmitter $k$ and receiver $l$ separated by $d$ m is calculated as

$$G_{k,l} = |H_{k,l}|^2 \, 10^{\frac{-L(d)+X_\sigma}{10}}, \tag{1}$$

where $H_{k,l}$ describes the channel transfer function between transmitter $k$ and receiver $l$, $L(d)$ is the distance-dependent path loss (in dB) and $X_\sigma$ is the log-normal shadowing value (in dB) with standard deviation $\sigma$.

The path loss model used to calculate $L(d)$ is for a purely indoor link [10], *i.e.*, the link (desired or interfering) between a FBS and an indoor MS, and calculates the path loss as

$$L(d) = 127 + 30\log_{10}(d_{\mathrm{km}}) \quad [\mathrm{dB}]\,. \tag{2}$$

where $d_{\mathrm{km}}$ is the distance $d$ in km.

## III. Pareto Optimal SINR Scheduling

For future wireless networks, ICIC plays an important role in not only satisfying individual MS requirements, but also maintaining system performance. An interference coordination technique is introduced that schedules MSs based on path gains such that POPC can be applied, and co-channel users can achieve their SINR targets with minimum transmit power.

### A. Pareto Optimal Power Control

In POPC [11], given each link is assigned a SINR target, $\gamma_i^*$, the Pareto optimum transmit powers $\mathbf{P}^*{=}(P_1^*, \ldots, P_K^*)^T$ for a set of $K$ interfering users (*i.e.*, in OFDMA, on the same resource blocks (RBs) in $K$ different cells) are given by

$$\mathbf{P}^* = (\mathbf{I} - \mathbf{F})^{-1}\mathbf{u}, \qquad \text{iff} \quad \rho_F < 1\,, \tag{3}$$

where $\rho_F{=}\max_i |\lambda_i^{\mathbf{F}}|$ is the Perron-Frobenius eigenvalue of $\mathbf{F}$, $\mathbf{I}$ is the identity matrix,

$$\mathbf{u} = \left( \frac{(I_1+\eta)\gamma_1^*}{G_{1,v_1}}, \cdots, \frac{(I_K+\eta)\gamma_K^*}{G_{K,v_K}} \right)^T, \tag{4}$$

is the vector of interference ($I_i$) plus noise power scaled by the SINR targets and channel gains $G_{i,v_j}$ from $\mathrm{MS}_i$ to $\mathrm{FBS}_{v_j}$, and $\mathbf{F}$ is the interference matrix where

$$F_{ij} = \begin{cases} 0, & \text{if } i = j \\ \frac{\gamma_i^* G_{j,v_i}}{G_{i,v_i}}, & \text{if } i \neq j \end{cases} \tag{5}$$

with $i, j{=}1, \ldots, K$. $\mathbf{F}$ is non-negative and irreducible [11]. Hence, when POPC is applied, users can meet their $\gamma_i^*$ with minimal transmit power.

### B. Stepwise Removal (SR)

In POPC, if $\rho_F \not< 1$, no solution is available, and hence $\mathbf{P} \to \mathbf{0}$. A better way to address this problem is to successively remove single links from the group of interfering MSs, until an $\mathbf{F}$ is achieved with $\rho_F{<}1$. It makes sense to remove the link that is causing the most interference to the other users. It is clear, however, that turning off one of the links will harm the system spectral efficiency. Hence, for each link removal, the SINR target for the remaining links must be updated.

$$\gamma^*_{(1),\mathrm{up}} = \frac{\prod_j^K \left(1+\gamma_j^*\right)}{1+\gamma^*_{(2),\mathrm{up}}} - 1\,, \tag{6}$$

where $\gamma^*_{(i),\mathrm{up}}$ represents the updated SINR target of the $i^{\mathrm{th}}$ *remaining* link. Since (6) has infinite solutions, an additional condition on $\gamma^*_{(1),\mathrm{up}}$ and $\gamma^*_{(2),\mathrm{up}}$ such as a power minimisation

$$\text{Solve (6) s.t.} \qquad \min\left\{\gamma^*_{(1),\mathrm{up}} + \gamma^*_{(2),\mathrm{up}}\right\}\,, \tag{7}$$

or an equal absolute SINR increase

$$\text{Solve (6) s.t.} \qquad \gamma^*_{(1),\mathrm{up}} - \gamma^*_{(1)} = \gamma^*_{(2),\mathrm{up}} - \gamma^*_{(2)}\,, \tag{8}$$

is necessary.

### C. Pareto Optimal Scheduling (POS)

As can be seen, POPC is dependent on $\rho_F{<}1$, *i.e.*, on $\mathbf{F}$, and hence on the positions/gains/SINRs of the interfering MSs. Therefore, by preemptively scheduling users specifically such that $\rho_F{<}1$, POPC can be applied to most, if not all, MSs in the system. This is the aim of Pareto Optimal Scheduling (POS).

Since for a particular grouping of MSs to be feasible $\rho_F{<}1$, it follows the modulus of all eigenvalues $\lambda_i$ of $\mathbf{F}$ must also be less than unity, *i.e.*, $|\lambda_i|{<}1$, $\forall i = 1, \ldots, K$. In other words, all eigenvalues must lie within the unit circle. In [12], Jury provides a simplified analytic test of stability of linear discrete systems, *i.e.*, the necessary and sufficient conditions for any real polynomial to have all its roots inside the unit circle. Hence, this test can be directly applied to the characteristic function $f_{\mathbf{F}}(\lambda)$ of the matrix $\mathbf{F}$, whose roots are the eigenvalues of $\mathbf{F}$. The characteristic function of $\mathbf{F}$ can be expressed as follows:

$$\begin{aligned} \text{Given} \qquad f_{\mathbf{F}_3}(\lambda) &= \det\left(\mathbf{F} - \lambda\mathbf{I}\right) \\ &= -\lambda^3 + \lambda(F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32}) \\ &\quad + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} \qquad (9) \\ &= \lambda^3 + c\lambda + d \qquad (10) \\ \text{Hence} \qquad c &= -F_{12}F_{21} - F_{13}F_{31} - F_{23}F_{32} \\ d &= -F_{12}F_{23}F_{31} - F_{13}F_{21}F_{32} \end{aligned}$$

In [12], the stability constraints for a polynomial of order $K{=}3$ are given[1]. Applying these to the characteristic function yields that for $f_{\mathbf{F}_3}(\lambda)$ to be "stable,"

$$\begin{aligned} & f_{\mathbf{F}_3}(\lambda) = \lambda^3 + c\lambda + d \\ & \quad a_3 = 1,\ a_2 = 0,\ a_1 = c,\ a_0 = d, \\ & \quad 1)\ \ |d| < 1 \\ & \quad 2)\ \ d^2 - 1 < c \ \rightarrow\ c > 1 - d^2 \\ & \quad 3)\ \ d + c + 1 > 0 \ \rightarrow\ c > -d - 1, \\ & \qquad\ \ d - c - 1 < 0 \ \rightarrow\ c > d - 1 \end{aligned} \tag{11}$$

which describes the ranges of $c$ and $d$ for which $\mathbf{F}$ is feasible. However, since from (5) $F_{ij}{\geq}0, \forall i, j$, it is clear that both $c, d{\leq}0$, and the constraints are reduced to only a single one, such that the **feasibility condition** becomes:

3) $\quad c > -d - 1$

**So,** $\rho_F{<}1$ **if**: (12)

$$F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32} + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} < 1\,.$$

[1] $K{=}3$ cells are chosen for complexity reasons. For $K{>}3$, the stability conditions and hence the derivation of POS become highly complex, and is practically intractable.

So, a group of MSs, one in each cell (in the three-cell scenario), is feasible iff the condition in (12) is fulfilled. This is clearly dependent on the individual desired and interfering path gains, along with the SINR targets of the users.

*1) Feasibility for $K-1=2$:* In the case that the scheduler is unable to find feasible groups for particular MSs (due to *e.g.*, location at cell-edge), the SR algorithm from Section III-B would turn off one of the links in a group of MSs, resulting in a feasibility matrix $\mathbf{F}$ of size $K-1 \times K-1$, in the three-cell case $2\times2$. Using the stability conditions from [12], the **feasibility condition** for two links is given by

$$\rho_F < 1 \quad \text{if} \quad F_{12}F_{21} < 1\,. \tag{13}$$

### D. Pareto Femto-Cell Scheduling (PFCS)

POS is dependent on many users per cell to be able to iterate over multiple path gain combinations and, hence, find feasible MS-groups in these cells. In the femto-cell environment considered here, however, each cell contains only a single user, and hence in any grouping of three cells the users in these cells will directly form a MS-group. Now if this group is infeasible, then there is no possibility of a different (feasible) group being formed, and at least one link must be removed. Therefore, the SINR targets of the individual users must be varied such that $\mathbf{F}$ becomes feasible.

*1) SINR Variation:* In PFCS, the same feasibility conditions for $\mathbf{F}$ still apply, *i.e.*, (12) and (13). Hence, an intelligent mechanism for the variation of the individual SINRs must be formulated. This is done using the feasibility condition (12) for the case where all three MSs (*i.e.*, one in each cell) transmit:

$$\begin{aligned}
f(\mathbf{F}) =& F_{12}F_{21}+F_{13}F_{31}+F_{23}F_{32}+F_{12}F_{23}F_{31}+F_{13}F_{21}F_{32}\\
=& \gamma_1^*\gamma_2^*\left(\rho^2\frac{G_{1,v_2}G_{2,v_1}}{G_{1,v_1}G_{2,v_2}}\right)+\gamma_1^*\gamma_3^*\left(\rho^2\frac{G_{1,v_3}G_{3,v_1}}{G_{1,v_1}G_{3,v_3}}\right)+\\
&+\ \gamma_2^*\gamma_3^*\left(\rho^2\frac{G_{2,v_3}G_{3,v_2}}{G_{2,v_2}G_{3,v_3}}\right)+\\
&+\ \gamma_1^*\gamma_2^*\gamma_3^*\left(\rho^3\frac{G_{1,v_2}G_{2,v_3}G_{3,v_1}+G_{1,v_3}G_{2,v_1}G_{3,v_2}}{G_{1,v_1}G_{2,v_2}G_{3,v_3}}\right)\\
=& \gamma_1^*\gamma_2^*A_{12}+\gamma_1^*\gamma_3^*A_{13}+\gamma_2^*\gamma_3^*A_{23}+\gamma_1^*\gamma_2^*\gamma_3^*A_{123}
\end{aligned} \tag{14}$$

where $\mathcal{A}=\{A_{12},A_{13},A_{23},A_{123}\}$ is the set of coefficients of $f$ that are constant throughout the SINR variation. Therefore if $f(\mathbf{F})>1$, by finding $\max\{\mathcal{A}\}$ the largest coefficient can be found, and hence the SINR targets preceding the coefficient can be reduced to ultimately decrease $f(\mathbf{F})$.

Given $f(\mathbf{F})>1$ and $\max\{\mathcal{A}\}=A_{ij}$, it is clear that $\gamma_i^*$ and $\gamma_j^*$ need to be reduced such that $f(\mathbf{F})<1$. The reduction is performed as follows:

$$\begin{aligned}
r &= \frac{1}{10n_r}\left\lceil 10\left(1-\frac{1}{f(\mathbf{F})}\right)\right\rceil\\
\gamma_i^* &\leftarrow \gamma_i^*(1-r)\\
\gamma_j^* &\leftarrow \gamma_j^*(1-r)
\end{aligned} \tag{15}$$

where $r$ in (15) represents the SINR reduction factor rounded[2] up to a factor of .1, and $n_r$ denotes the number of MSs whose SINR targets are being reduced (in the above case, $n_r$=2). To maintain the desired system spectral efficiency however, the remaining user's SINR target must be increased

$$\gamma^*_{k\neq\{i,j\}} = \frac{(1+\gamma_1^*)(1+\gamma_2^*)(1+\gamma_3^*)}{(1+\gamma_i^*(1-r))(1+\gamma_j^*(1-r))}-1\,. \tag{16}$$

Hence, the system spectral efficiency is maintained while the value of $f(\mathbf{F})$ is decreased. Although this procedure may achieve the desired SINR target constellation in the first step, is repeated until either $\gamma_i^*,\gamma_j^*<\gamma_{\min}$, or $f(\mathbf{F})<1$.

For the (rather unlikely) case that $\max\{\mathcal{A}\}=A_{123}$, the strongest interferer $\text{MS}_i$ is found, and the same reduction is performed except $n_r$=1 in (15). The SINR target increase of the remaining MSs is

$$\gamma^*_{\{j,k\}\neq i} = \sqrt{\frac{(1+\gamma_1^*)(1+\gamma_2^*)(1+\gamma_3^*)}{(1+\gamma_i^*(1-r))}}-1\,. \tag{17}$$

*a) Feasibility for $K-1=2$:* For the occasion that the scheduler is unable to find a set of $\{\gamma_1^*,\gamma_2^*,\gamma_3^*\}\geq\gamma_{\min}$ such that $\mathbf{F}$ becomes feasible (*i.e.*, $f(\mathbf{F})<1$), the link causing the most interference is removed, and the SINR targets of the two remaining users are updated according to the SR algorithm.

If, now, the feasibility condition (13) is not satisfied, the SINR target of the $\text{MS}_i$ with the weaker desired channel gain must be reduced according to (15) with $n_r$=1, while $\text{MS}_j$ with the stronger desired link receives a SINR target boost according to

$$\gamma_j^* = \frac{(1+\gamma_i^*)(1+\gamma_j^*)}{1+\gamma_i^*(1-r)}-1\,, \tag{18}$$

to maintain the system spectral efficiency[3]. This is again repeated until either $\gamma_i^*<\gamma_{\min}$, or $f(\mathbf{F})<1$.

Finally, if the scheduler is unable to find $\{\gamma_i^*,\gamma_j^*\}\geq\gamma_{\min}$ such that $\mathbf{F}$ is feasible, the MS with the weaker desired link is removed, and the target of the remaining user is again updated.

*2) Scheduling:* While it is clear from Section III-D1 how an infeasible grouping of MSs can be made feasible, these groups must still be found. In a randomly deployed femto-cell environment, this can be a challenging task as there is no pre-existing infrastructure to guide grouping mechanisms. Here, the cell-grouping part of PFCS is described.

*a) Interference Graphs:* To find groups of femto-cells suitable for POPC, an interference graph [13] for the network instance is constructed, through which the strongest interfering cells can be grouped together. An interference graph is constructed by evaluating the interference users in the system cause to each other. For each MS, the strongest interferers are removed (and consequently considered as interfering neighbours) until the minimum signal-to-interference ratio (SIR), $\gamma^*$, at the MS is achieved.

Assuming each MS will transmit at maximum power, $P=P_{\max}$, each user will achieve a certain SIR. If the SIR

[2]The need for this rounding is two-fold; first, since $f(\mathbf{F})$ must be $<1$, without the rounding it would be steered towards 1 and not below, and second, because the SINR boost of the third MS will again slightly increase $f(\mathbf{F})$.

[3]The MS with the stronger desired link is chosen for the SINR target boost as it will require less power than the weaker MS to achieve it due to its enhanced desired channel gain, and hence cause less interference. This slightly reduces the fairness over a single slot, however through scheduling over multiple slots this is equalised

of $\text{MS}_k$, $\gamma_k < \gamma_k^*$, the strongest interferers are removed until

$$\gamma_k = \frac{S_k}{\sum_{l \in \mathcal{I}_k \setminus \mathcal{W}_k} I_{l,k}} \geq \gamma_k^* \,, \tag{19}$$

where $S_k$ is the desired received signal strength of $\text{MS}_k$, $I_{l,k}$ the interference caused by $\text{MS}_l$ at $\text{MS}_k$'s BS, $\mathcal{I}_k$ all its interferers, and $\mathcal{W}_k$ the removed interferers, *i.e.*, neighbours. Hence, each user will have a list of strongly interfering neighbours based on its interference environment, and if $\text{MS}_l$ is a neighbour of $\text{MS}_k$, the vice versa is also true.

Once this procedure has been done for all MSs in the system, the interference graph can be constructed, an example of which is shown in Fig. 2. From this, groups of (up to) three femto-cells (and hence the three MSs in these cells) are formed by collecting the three strongest interfering and neighbouring cells together, and then the next, and so on. For cells with fewer than two neighbours, smaller groups are formed.

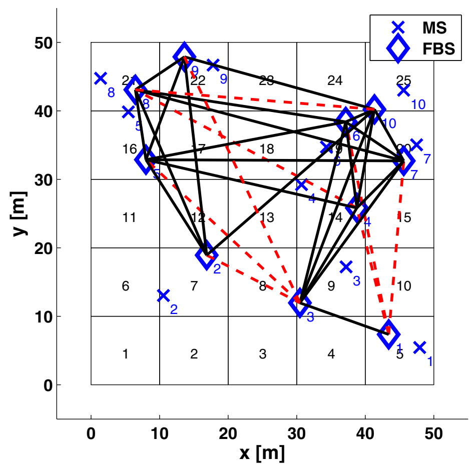


Fig. 2. Interference graphs for the (in Fig. 1) given $5 \times 5$ grid femto-cell scenario for various SINR targets. The solid lines indicate neighbours for $\gamma^*{=}0\,\text{dB}$, the dashed lines indicate the additional neighbours when $\gamma^*{=}8\,\text{dB}$.

*b) SINR and Power Allocation:* As a result of the interference graph grouping, each MS will be able to remove two of its strongest interferers through POPC and SINR variation, if necessary. The SINR target and transmit power allocation for each group is performed as follows:

1) If (12) is satisfied, then (3) (POPC) can be performed and each MS should achieve its SINR target.
2) If (12) fails, then $\max\{\mathcal{A}\}$ is found, and the $\gamma_k^*$ are modified by (15) and (16) (or (17) if $\max\{\mathcal{A}\} = A_{123}$) until (12) is satisfied and (3) can be used.
3) If this is not possible, the strongest interfering link is removed, and (13) must be satisfied (with updated $\gamma_k^*$ due to SR) in order for (3) to be applied.
4) If (13) fails, then the $\gamma_k^*$ are adjusted through (15) and (18) until (13) is satisfied and (3) can be utilised.
5) If this is again not possible, then a second link is removed, and (3) (which converges to conventional power control for a single user) is performed for updated $\gamma_k^*$.

Through this power allocation, the number of simultaneously serviced (*i.e.*, $\gamma_k \geq \gamma_k^*$) MSs in the system will be maximised, along with the achievable throughput.

## IV. Simulation and Results

Monte Carlo simulations are used to provide mean performance statistics of the achieved capacities of the system with and without the use of PFCS.

### A. Simulation

The system and channel model for the simulation are detailed in Section II; multiple randomly deployed femto-cell networks are generated such that precise performance statistics can be acquired.

*1) Scheduling and Power Allocation:* For this study, each MS in a cell is assigned the full bandwidth (*i.e.*, all RBs), as only a single MS per cell is considered. For PFCS, the cell-grouping and allocation of power to the users is performed as described in Section III-D2. Furthermore, the simulation is run over multiple time slots, such that removed links can be scheduled in later slots and achieve capacity.

*2) Performance Statistics:* After the power allocation in each cell, the performance statistics can be gathered. These are composed of two values: the system throughput and power usage. First, the SINR, $\gamma_u$, of $\text{MS}_u$ is calculated as

$$\gamma_u = \frac{P_u G_{u,v_u}}{\sum_k P_k G_{k,v_u} + \eta} \,, \tag{20}$$

where $P_u$ and $P_k$ are the transmit powers of $\text{MS}_u$ and interfering MSs, respectively. Given the SINR, the throughput $C_u$ of $\text{MS}_u$, using adaptive modulation and coding, is calculated

$$C_u(\gamma_u) = n_u^{\text{RB}} k_{\text{sc}} \varrho_{\text{s}} \varepsilon_{\text{s}}(\gamma_u) \,, \tag{21}$$

where $n_u^{\text{RB}}$ is the number of RBs assigned to $\text{MS}_u$, $k_{\text{sc}}$ the number of subcarriers per RB, $\varrho_{\text{s}}$ the symbol rate per subcarrier, and $\varepsilon_{\text{s}}(\gamma_u)$ the symbol efficiency[4].

The total system transmit power is calculated as a sum of the individual MS transmit powers.

### B. Results and Discussion

The general simulation parameters are shown in Table I. In Fig. 3, the system throughputs for maximum power, PFCS, and LTE FPC [6] are shown. Here PFCS produces large gains over conventional power control ($\alpha = 1$), but does not achieve quite the system capacities of the other systems. It should be

TABLE I
Simulation Parameters

| Parameter | Value |
|---|---|
| Apartment width, $R$ | 10 m |
| FBS probability, $p_{\text{act}}$ | 0.5 |
| Number of available RBs, $M$ | 50 |
| RB bandwidth, $B_{\text{RB}}$ | 180 kHz |
| Subcarriers per RB, $k_{\text{sc}}$ | 12 |
| Symbol rate per subcarrier, $\varrho_{\text{s}}$ | 15 ksps |
| Time slots | 6 |
| Minimum SINR, $\gamma_{\text{min}}$ | -6 dB |
| Thermal noise, $\eta$ | $-174\,\text{dBm/Hz}$ |
| Total MS transmit power | 10 dBm |
| Shadowing Std. Dev., $\sigma$ | 10 dB |
| Auto-correlation distance | 50 m |

[4]The modulation and coding is taken from Long-Term Evolution (LTE) [14], and the SINR ranges from [15]. The downlink is used because no uplink implementation was found, as these values are operator specific.

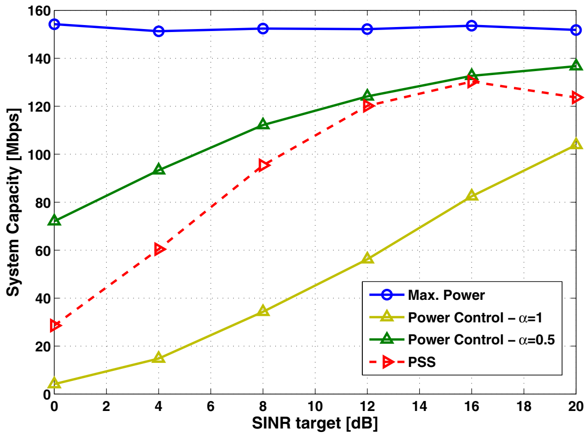


Fig. 3. System capacity results for the various power control techniques over a range of SINR targets.

mentioned here that the comparisons to both maximum power transmission and $\text{FPC}_{\alpha=0.5}$ are rather unfair, as these are based much less on the actual SINR targets of the users (in the case of max. power not at all), and hence use significantly more power to achieve their larger system throughputs.

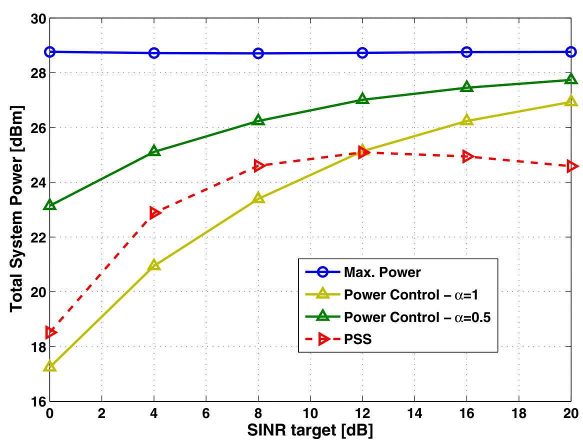


Fig. 4. System power results for the various power control techniques.

This is very clear in Fig. 4, where both maximum power and $\text{FPC}_{\alpha=0.5}$ consume considerably more power in the network than PFCS. Furthermore, while for low SINRs $\text{FPC}_{\alpha=1}$ shows some power savings (which is expected due to the low capacity achieved), for the higher SINR targets PFCS utilises the least amount of system power. This is mainly because less links are transmitting in each time slot (due to SR), and hence less power is spent while still achieving respectable system throughputs, an encouraging result. For the other systems, it is clear that $\text{FPC}_{\alpha=0.5}$ achieves a balance between max. power and $\text{FPC}_{\alpha=1}$ in all of the performance statistics. All in all, PFCS provides significant throughputs for almost all MSs in the system while minimising the necessary transmit power.

## V. Conclusion

In this paper, PFCS, a scheduling technique designed to maximise the application of POPC in femto-cells, is developed. POS, the basis of PFCS, schedules users according to path gains such that POPC can be directly applied. As only a single MS per femto-cell is assumed, the path gains cannot be modified, and hence a technique to adapt the SINR targets of the users was developed to make infeasible groupings feasible. Through this, MSs are allocated Pareto optimal transmit powers while limited losses in spectral efficiency are incurred.

It is quite clear from the simulation results that PFCS provides substantial throughputs over a wide range of SINR targets, and significantly outperforms the purely target-based power control technique. Both max. power transmission and $\text{FPC}_{\alpha=0.5}$ are not strictly bound by SINR targets, and hence are able to transmit with higher power and achieve larger throughputs. On the other hand, it is evident that PFCS provides a low-power solution, significantly reducing the necessary MS transmit powers, creating a "greener" system.

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