Pareto Optimal Power Control Scheduling for OFDMA Networks

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***Abstract*—In this paper, a novel scheduling mechanism that enhances both network spectral and energy efficiency is presented. In Pareto Optimal Scheduling (POS), mobile stations (MSs) are scheduled based on path gains such that the sufficient conditions for Pareto optimal power control (POPC) are fulfilled. This is performed in such a manner to maximise the number of concurrently transmitting MSs. Furthermore, a Stepwise Removal (SR) algorithm is introduced for the situation where links do not meet the sufficient conditions for power control. In this case, links are removed in order for other MSs to achieve their signal-to-interference-plus-noise ratio (SINR) targets. The targets of these remaining MSs are updated to prevent losses in system spectral efficiency caused by the link removals. Large network simulation results show that significant gains in spectral efficiency can be achieved over standard power control techniques, while additionally providing substantially improved energy efficiency.**

I. Introduction

With higher-speed wireless services becoming increasingly in-demand, there is a great need for increased throughput per bandwidth to accommodate higher data rates whilst guaranteeing quality of service. In addition, the necessity for more energy efficient, or "green," technologies is growing. Increasing traffic load is expected to double the network energy consumption within the next ten years [1]. Power control mechanisms attempt to minimise transmit power while maintaining sufficient spectral efficiency for the users in the network. In this paper, a scheduling and power control technique that benefits both the spectral and energy efficiency of future networks is developed.

In [2], a truncated closed-loop power control scheme is presented to cut off transmission of users when their short-term fading falls below a given threshold. While this leads to gains in both capacity and user availability, users are shown to suffer from large delays, a clearly undesirable result for wireless systems. Fractional power control (FPC) for orthogonal frequency division multiple access (OFDMA) networks is introduced in [3], which offers a slight adaptation to conventional power control to trade off spectral efficiency and cell-edge bit rate. Due to this, however, many users will not achieve their SINR targets, and hence user throughput suffers.

An extension to FPC is developed in [4], where the power control expression takes interference caused to neighbouring cells into account. While this achieves a modest capacity increase, the mean level of interference to other cells is not reduced, but rather only the variance. In [5] on the other hand, closed-loop power control offers significant gains in user throughput and transmit power. These are achieved, however, for very low SINRs, whereas almost no benefits are seen in the high SINR range. Finally, a computationally efficient power control mechanism is introduced in [6], where the problem of minimising transmit power is formulated. However, the joint subcarrier and power allocation is split into two stages, thus disregarding the dependence between the two.

This paper presents a novel technique to combine scheduling and power control, to not only minimise power consumption but also maximise system spectral efficiency through fair allocation of users. The rest of the paper is structured as follows, Section II presents POPC, and Section III describes the analytic basis and implementation of POS and the SR algorithm. Sections IV and V describe the simulation environment and results, respectively, and Section VI offers a conclusion.

II. Pareto Optimal Power Control

In a wireless system, the quality of each link is determined by the SINR at the intended receiver. In an uplink with K interferers, the SINR of the i^{th} user is denoted by:

$$\gamma_i = \frac{P_i G_{i,v_i}}{\phi \sum_{j \neq i}^{K-1} P_j G_{j,v_i} + \eta}\,, \quad i = 1, \ldots, K\,, \tag{1}$$

where P_i is the transmit power of MS_i, G_{j,v_i} the channel gain from MS_j to base station $(\text{BS})_{v_i}$ that serves MS_i, the thermal noise power is denoted by η, and ϕ is the interference reduction due to signal processing ($\phi = 1$ for OFDMA). Furthermore, since in OFDMA systems the interference between MSs can be broken down to interference between the resource blocks (RBs)[1] assigned to those MSs, K can be equated to the number of cells being considered. As a basis for this work, K=3.

Given each link is assigned a minimum SINR target, γ_i^*, this constraint can be represented in matrix form [7] with component-wise inequalities

$$(\mathbf{I} - \mathbf{F})\mathbf{P} \geq \mathbf{u}\,, \quad \mathbf{P} > \mathbf{0}\,, \tag{2}$$

where $\mathbf{I}$ is the identity matrix and $\mathbf{P} = (P_1, \ldots, P_K)^T$ is the vector of transmit powers,

$$\mathbf{u} = \left(\frac{(I_1 + \eta)\gamma_1^*}{G_{1,v_1}}, \cdots, \frac{(I_K + \eta)\gamma_K^*}{G_{K,v_K}} \right)^T\,, \tag{3}$$

is the vector of interference (I_i) plus noise power scaled by the SINR targets and channel gains, and $\mathbf{F}$ is the interference matrix where

$$F_{ij} = \begin{cases} 0, & \text{if } i = j \\ \frac{\gamma_i^* G_{j,v_i} \phi}{G_{i,v_i}}, & \text{if } i \neq j \end{cases} \tag{4}$$

[1]Due to the orthogonality of subcarriers and, hence, also RBs.

with $i, j = 1, \ldots, K$. $\mathbf{F}$ is non-negative and irreducible [7].

Given $\rho_F = \max_i |\lambda_i|$ as the Perron-Frobenius eigenvalue of $\mathbf{F}$, if $\rho_F < 1$, then there exists a vector $\mathbf{P} > \mathbf{0}$ such that the SINR requirements of all interfering users are satisfied, and $\mathbf{P}^* = (\mathbf{I} - \mathbf{F})^{-1}\mathbf{u}$ is the Pareto optimal solution (*i.e.*, if there is any other solution $\mathbf{P}$ to (2), then $\mathbf{P} > \mathbf{P}^*$ component-wise) [7]. Hence, if all the SINR requirements can be met simultaneously, the optimal power vector $\mathbf{P}^*$ minimises the transmit power of the users.

III. Pareto Optimal Scheduling (POS)

In Pareto optimal power allocation, given a feasible link allocation, *i.e.*, $\rho_F < 1$, a vector $\mathbf{P}^* = (\mathbf{I} - \mathbf{F})^{-1}\mathbf{u}$ can be found such that all users achieve their SINR requirements with minimal power. This is of course a highly desirable result which, depending on the location and service requirements of the interfering MSs, is clearly not always possible. Hence, by scheduling users in such a manner to maximise the number of feasible $\mathbf{F}$ matrices (in principle, there can be as many $\mathbf{F}$ matrices as there are RBs in the system), the system spectral efficiency can be maximised. Such a scheduling algorithm is developed here.

A. Analytical Basis

Since for a particular grouping of MSs (on the same RB(s) in different cells) to be feasible $\rho_F < 1$, it follows the modulus of all eigenvalues λ_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 [8], 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 $\mathbf{F}$, and thus need to lie within the unit circle. The characteristic function $f_{\mathbf{F}_3}(\lambda)$ is expressed as follows:

$$\text{Given} \qquad \mathbf{F} = \begin{bmatrix} 0 & F_{12} & F_{13} \\ F_{21} & 0 & F_{23} \\ F_{31} & F_{32} & 0 \end{bmatrix}$$

$$\begin{aligned} f_{\mathbf{F}_3}(\lambda) &= \det(\mathbf{F} - \lambda\mathbf{I}) \\ &= -\lambda^3 + \lambda(F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32}) \\ &\quad + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} \qquad (5) \\ &= \lambda^3 + c\lambda + d \qquad (6) \end{aligned}$$

$$\begin{aligned} \text{Hence} \qquad c &= -F_{12}F_{21} - F_{13}F_{31} - F_{23}F_{32} \\ d &= -F_{12}F_{23}F_{31} - F_{13}F_{21}F_{32} \end{aligned}$$

In [8], the stability constraints for a polynomial of order K=3 are given as[2]

$$\begin{aligned} & f(z) = a_3z^3 + a_2z^2 + a_1z + a_0, \quad a_3 > 0 \\ & 1) \;\; |a_0| < a_3 \\ & 2) \;\; a_0^2 - a_3^2 < a_0a_2 - a_1a_3 \\ & 3) \;\; a_0 + a_1 + a_2 + a_3 > 0, \; a_0 - a_1 + a_2 - a_3 < 0 \end{aligned} \quad . \qquad (7)$$

[2] K=3 cells are chosen for complexity reasons. For K >3, the stability conditions in (7) and hence the derivation of POS becomes highly complex, and is practically intractable.

These conditions can now be applied to $f_{\mathbf{F}_3}(\lambda)$

$$\begin{aligned} & f_{\mathbf{F}_3}(\lambda) = \lambda^3 + c\lambda + d \\ & \quad a_3 = 1, \; a_2 = 0, \; a_1 = c, \; a_0 = d, \\ & \quad 1) \;\; |d| < 1 \\ & \quad 2) \;\; d^2 - 1 < c \;\rightarrow\; c > 1 - d^2 \\ & \quad 3) \;\; d + c + 1 > 0 \;\rightarrow\; c > -d - 1, \\ & \quad\quad\; d - c - 1 < 0 \;\rightarrow\; c > d - 1 \end{aligned} \qquad (8)$$

which describes the ranges of c and d for which $\mathbf{F}$ is feasible. However, since from (4) $F_{ij} \geq 0$, $\forall i, j$, 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:

$$\begin{aligned} & 3) \quad c > -d - 1 \\ & -F_{12}F_{21} - F_{13}F_{31} - F_{23}F_{32} > F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} - 1 \end{aligned}$$

So, $\rho_F < 1$ **if**: (9)

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

So, a group of MSs, one in each cell (in the three-cell scenario), is feasible if and only if the condition in (9) is fulfilled. This is clearly dependent on the individual desired and interfering path gains, along with the SINR targets of the users. Therefore, a scheduler might make use of this condition to schedule users such that the number of feasible groups of MSs is maximised, hence also maximising the spectral efficiency of the system.

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 turns 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 2×2:

$$\mathbf{F} = \begin{bmatrix} 0 & F_{12} \\ F_{21} & 0 \end{bmatrix} \qquad (10)$$

And hence, the characteristic function is given by

$$\begin{aligned} f_{\mathbf{F}_2}(\lambda) &= \det(\mathbf{F} - \lambda\mathbf{I}) \\ &= \lambda^2 - F_{12}F_{21} \\ &= \lambda^2 + c \\ c &= -F_{12}F_{21} \end{aligned} \qquad (11)$$

Stability constraints [8] for polynomials of order $K-1$=2 are applied to $f_{\mathbf{F}_2}(\lambda)$, yielding the **feasibility condition** given by

$$2) \;\; \begin{aligned} 1 &> -c \\ 1 &> F_{12}F_{21} \end{aligned} \qquad \textbf{So, } \rho_F < 1 \textbf{ if:} \quad F_{12}F_{21} < 1\,. \qquad (12)$$

B. Stepwise Removal

In POPC, if $\rho_F \not< 1$, no solution is available, and hence $\mathbf{P} \rightarrow \mathbf{0}$. In this case, none of the links will transmit, hence this solution is highly suboptimal. 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, at each step, remove the link that is causing the largest interference to the other users. It is clear, however, that turning off one of the links will harm the system spectral efficiency, and hence for each link removal, the SINR target for the remaining links (assuming link 3 has been switched off) must be updated as follows

$$\gamma^*_{(1),\mathrm{up}} = \frac{\prod_j^K \left(1+\gamma^*_j\right)}{1+\gamma^*_{(2),\mathrm{up}}} - 1\,, \tag{13}$$

where $\gamma^*_{(i),\mathrm{up}}$ represents the updated SINR target of the i^{th} *remaining* link. Since (13) has infinite solutions, an additional condition on $\gamma^*_{(1),\mathrm{up}}$ and $\gamma^*_{(2),\mathrm{up}}$ such as a power minimisation

$$\text{Solve (13) s.t.} \qquad \min\left\{\gamma^*_{(1),\mathrm{up}} + \gamma^*_{(2),\mathrm{up}}\right\}\,, \tag{14}$$

or an equal absolute SINR increase

$$\text{Solve (13) s.t.} \qquad \gamma^*_{(1),\mathrm{up}} - \gamma^*_{(1)} = \gamma^*_{(2),\mathrm{up}} - \gamma^*_{(2)}\,, \tag{15}$$

is necessary[3]. Finally, when two links have been removed and only a single link remains, $\gamma^*_{(1),\mathrm{up}} = \prod_j^K \left(1+\gamma^*_j\right) - 1$, and $\mathbf{F} = 0$, $\rho_F = 0$, and $\mathbf{P} = \mathbf{u} = \frac{n\gamma^*_{(1),\mathrm{up}}}{G_{1,v_1}}$.

Through this form of link removal, system spectral efficiency is maintained while maximising the number of transmitting users according to the feasibility constraint ρ_F. Furthermore, it prevents the annihilation of links caused in POPC.

C. Scheduling

The goal is to maximise the number of "MS-groups" for which (9) is satisfied and POPC can be applied. This is opposed to a random scheduler where the assignment of RBs, and hence also MS-groups, is performed arbitrarily.

The scheduler is split into three stages, corresponding to the number of cells considered and hence one more than the number of stepwise removals possible. In the first round of grouping, the scheduler searches through all combinations of MSs (*i.e.*, one in each cell) that fulfil the feasibility condition (9). Clearly, it is possible for an MS to be part of multiple feasible groups, but also part of none. Hence, to maximise the number of feasible combinations, those MSs with the fewest feasible combinations (*i.e.*, "least feasible" MSs) should be scheduled first along with the two least feasible partners. This is done until all MSs have been scheduled/grouped.

In the second round, the MSs that have not been scheduled cannot form groups of three, and hence groups will be allocated with one link deactivated. Furthermore, through the SR algorithm the SINR targets are raised according to (13) to maintain system spectral efficiency. Thus, all "MS-pairs" that satisfy (12) can be allocated. Again, the least feasible MSs are scheduled first, and to complete each group, the least feasible MS is selected from the unscheduled cell.

Finally, in the third round, MS-groups with two deactivated links are scheduled. Here, the activated link in each group should have the best path gain to minimise the necessary transmit power. Therefore, each of the remaining groups is constructed by the MS with the best path gain and the MSs in the two other cells with the worst path gains. This is done until all MSs have been scheduled. The SINR target is again updated to maintain system spectral efficiency.

In the power allocation stage, $\mathbf{F}$ and $\mathbf{u}$ (sized appropriately for groups with three or two links) are constructed for each MS-group, and POPC is performed. The MS transmit power is limited by the maximum power $P_{\max}$, which may reduce the optimality of some solutions. This is, however, unavoidable.

Lastly, over multiple time slots the deactivated MSs are scheduled in later slots, such that they too can achieve their target spectral efficiency. Here, this is done over three slots, such that when only a single link in a group can be active, each mobile has its own slot to transmit. Through this scheduler, all MSs in the system should attain the desired spectral efficiency, and if not, reduce the losses incurred.

D. Three-Cell Simulation Results

Fig. 1 shows the spectral efficiency results for varying SINR targets and inter-site distances (ISDs) in a three-cell scenario. The max. power spectral efficiency is independent of MS SINR targets and thus constant over all SINRs, while POPC suffers significantly from the random grouping (all benchmarks are randomly scheduled), as the number of feasible groups disappears very rapidly with increasing SINR. The upper bound in Fig. 1 denotes the Shannon capacity of the given SINR target, *i.e.*, the attainable spectral efficiency if *all* MSs can be optimally scheduled.

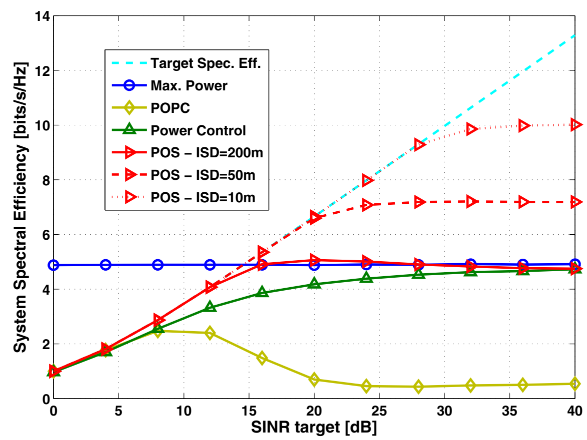

Fig. 1. System spectral efficiency (calculated using Shannon's equation) results for the various power control techniques over a range of SINR targets. Three-cell scenario with a single omni-directional antenna per cell.

The ISD is a significant factor in the performance of POS. Here, the smaller the ISDs, the better the performance; a key factor for shrinking cell sizes in future networks. When links are deactivated, the larger transmit powers needed to meet γ^*_{up} are bounded by $P_{\max}$. Reducing the ISDs is equivalent to increasing $P_{\max}$ due to greater desired link gains. Lastly, it is evident that POS outperforms all other techniques investigated, and has significant potential for future wireless networks.

E. Extension to Macro-cellular Network

Since POS is developed for a three-cell system, on its own it is very ineffective for more realistic scenarios where there are clearly more than three cells. One option would be to derive the feasibility condition(s) for a larger number of cells, to henceforth be able to apply POS to a larger network. From [8][4],

[3] In this paper, a system wide SINR target γ^* is used, in which case (14) and (15) yield equivalent results for (13).

[4] In [8] the sufficient conditions for stability of n^{th} order polynomials are presented, which were used to derive the feasibility condition in (9).

however, we can infer that the feasibility conditions for even a four-cell scenario are excessively complex, and hence such extension to larger networks is highly impractical.

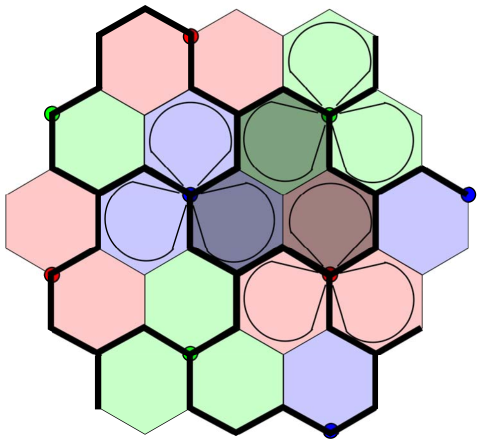

Fig. 2. Extension of three-cell POS to larger multi-cellular networks. Universal frequency reuse is applied, and the differing colouration of the cells simply demarks which BS is serving them.

A more pragmatic approach is to find a way to tessellate the three-cell POS over a network of any dimensions. This is shown in Fig. 2, where the structure of a typical sectorised cellular network can help the extension of POS to multiple cells. By grouping three cells with coinciding beam patterns (see shaded cells in Fig. 2), POS can be applied to these three cells, and the cluster will be relatively shielded from neighbouring sectors' interference due to the nature of the beam patterns. This clustering is then tessellated over the network, such that POS can be applied separately in each of these clusters without overly excessive co-channel interference (CCI) from the surrounding cells, allowing the MSs to achieve their transmission requirements.

IV. Simulation

Monte Carlo simulations are used to provide mean performance statistics for a system using various power allocation techniques, including POS.

A. System Setup

The simulation area comprises 19 cells, where each cell is served by a sector of its BS (see Fig. 2 for an example). Furthermore, an antenna downtilt is considered to mitigate interference between cells. In each cell the N users per cell are uniformly distributed. The assignment of MSs to each cell is done on path loss alone. The general simulation parameters utilised for the simulation are shown in Table I.

B. Channel Model

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

$$G_{k,l} = |H_{k,l}|^2 \, 10^{\frac{-L(d)+X_\sigma}{10}}, \tag{16}$$

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_σ is the log-normal shadowing value (in dB) with standard deviation σ.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
ISD	$200\,\mathrm{m}$
Number of cells	19
Antenna tilt	$5°$
Users per cell, N	10
Number of available RBs, M	50
RB bandwidth, B_{RB}	$180\,\mathrm{kHz}$
Subcarriers per RB, k_{sc}	12
Symbol rate per subcarrier, ϱ_{s}	$15\,\mathrm{ksps}$
Time slots	6
Noise spectral density, η_0	$-174\,\mathrm{dBm/Hz}$
Total MS transmit power	$10\,\mathrm{dBm}$
Shadowing Std. Dev., σ	$4\,\mathrm{dB}$
Auto-correlation distance	$50\,\mathrm{m}$

The path loss model used to calculate $L(d)$ is for a purely outdoor link [9], *i.e.*, the link (desired or interfering) between a BS and an outdoor MS, and calculates the path loss as

$$L(d) = 15.3 + 37.6 \log_{10}(d) \quad [\mathrm{dB}]\,. \tag{17}$$

C. Scheduling and Power Allocation

For this study, MSs in a cell are assigned a contiguous equal-sized block of RBs, where each block contains $M/N = 50/10 = 5$ RBs. The scheduler assigns a block to each user in the cell. For POS, the scheduling and allocation of power to the users is performed as described in Section III-C. Furthermore, multiple time slots are utilised such that removed links can be scheduled in the next slot. For the benchmarks, a random resource allocation is utilised.

D. Performance Statistics

After the transmit powers adjustment in each cell, the performance statistics can be gathered. These are composed of two values: the uplink system spectral efficiency and energy efficiency. Given the SINR as calculated in (1), the throughput C_u of MS_u using adaptive modulation and coding (AMC) is calculated

$$C_u(\gamma_u) = n_u^{\mathrm{RB}} k_{\mathrm{sc}} \varrho_{\mathrm{s}} \varepsilon_{\mathrm{s}}(\gamma_u)\ , \tag{18}$$

where n_u^{RB} is the number of RBs assigned to MS_u, k_{sc} the number of subcarriers per RB, ϱ_{s} the symbol rate per subcarrier, and $\varepsilon_{\mathrm{s}}(\gamma_u)$ the symbol efficiency[5].

The energy efficiency β_u measures the the data sent per unit of energy (or, alternatively, data rate per unit of transmit power) of MS_u. This is defined as follows:

$$\beta_u = \frac{C_u}{P_u} = \frac{n_u^{\mathrm{RB}} k_{\mathrm{sc}} \varrho_{\mathrm{s}} \varepsilon_{\mathrm{s}}}{P_u} \quad \left[\frac{\mathrm{bits/s}}{\mathrm{W}}\right] \equiv \left[\frac{\mathrm{bits}}{\mathrm{J}}\right], \tag{19}$$

where P_u is the total transmit power of MS_u, and C_u the throughput from (18).

V. Results

Fig. 3 shows the spectral efficiency results for POS and the two benchmarks in a macro-cellular network. As expected, the antenna downtilt and sectorisation decrease the spectral efficiency of all three systems (in comparison to Fig. 1) due

[5]The modulation and coding is taken from Long-Term Evolution (LTE) [10], and the SINR ranges from [11]. The downlink is used because no uplink implementation was found, as these values are operator specific.

to the increased interference among the cells and diminished desired path gains, respectively (the use of AMC is also significant). However, it is evident that POS benefits from this additional interference, as it is more able to mitigate it than the benchmark systems. In general, POS has a performance

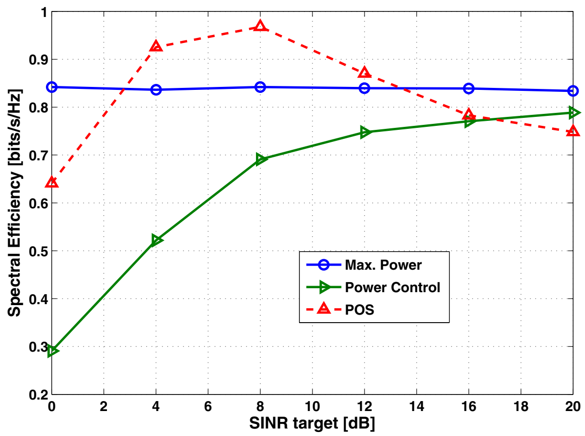

Fig. 3. System spectral efficiency results for the various power control techniques.

advantage over power control over all SINR targets (except $\gamma^{*}{=}20\,\mathrm{dB}$), whereas also substantial gains over $13\,\%$ are seen over max. power transmission in the mid-SINR (typically the operational) range. The POS performance begins to suffer for higher SINRs as too many users are switched off each time slot by the SR protocol. However, on average the POS spectral efficiency is equivalent to that of max. power transmission.

This becomes even more significant when considered together with the energy efficiency results shown in Fig. 4. As expected, maximum power transmission is the least energy efficient of the three considered techniques. POS, on the other hand, provides massive energy efficiency benefits for the system, even when compared to power control, with gains

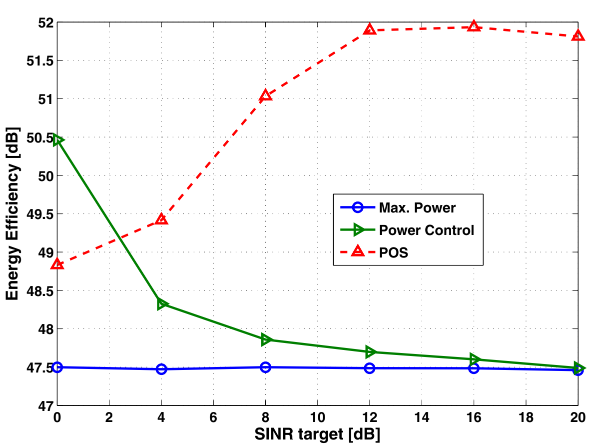

Fig. 4. System energy efficiency results for the various power control techniques. Decibel (dB), *i.e.*, $10\log_{10}\left(^{\mathrm{bits}}/_{\mathrm{J}}\right)$, are utilised as the energy efficiency unit for ease of comparison.

of up to $5\,\mathrm{dB}$ for higher SINRs. Hence, it is quite clear that POS drastically reduces the transmit power consumption in a macro-cellular network. Considering this together with the spectral efficiency results, it is evident that POS provides overall superior system performance over the standard power allocation techniques.

VI. Conclusion

In this paper, POS, a scheduling technique designed to maximise the application of POPC, was introduced. By expressing the necessary conditions for power control in a simple feasibility condition of path gains and SINR targets, users are scheduled such that the Pareto optimal power control can be applied. The addition of the SR algorithm in collaboration with SINR target updates allow the scheduler to achieve the target system spectral efficiency, while providing a Pareto optimal power allocation. Therefore, no significant losses in spectral efficiency are incurred while the total transmit power of the network is minimised, hence resulting in a more energy efficient system.

It is quite clear from the simulation results that POS provides close to optimal spectral efficiency over a wide range of SINR targets, and can significantly outperform standard power control techniques. Furthermore, since the necessary calculations are performed at the BS-side, only minimal additional signalling between neighbouring BSs is required, while no extra information other than the resource and power allocation is sent to the MSs. Finally, POS provides large energy efficiency boosts over both power control and maximum power transmission, providing a low-power solution, and hence "greener" wireless systems.

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