# Coordination of Clusters for Inter-cell Scheduling

Ki Won Sung and Jens Zander
Wireless@KTH, Royal Institute of Technology (KTH)
Electrum 229, 164 40 Kista, Sweden
Email: sungkw@kth.se and jenz@kth.se

***Abstract*—Coordination of base stations is essential in the mitigation of inter-cell interference in cellular communication systems. One of practical solutions is a cluster-based inter-cell scheduling where base stations in each cluster determine their transmissions in cooperative fashion. In spite of potential performance improvement, the inter-cell scheduling may result in conflict between clusters. However, a dynamic coordination in the cluster level is difficult due to the prohibitive burden of inter-cluster communication. In this paper, we address the coordination of clusters in the downlink of cellular networks. We propose a rule of inter-cluster coordination, namely nominal scheduling order with penalty (NSOP) which does not require communication between the clusters. Dynamic system level simulations are performed to examine the performance of the NSOP in various interference scenarios. It is observed that the proposed NSOP effectively strikes a balance between the inter-cluster interference avoidance and the intra-cluster multi-user diversity by means of a simple penalty factor.**

***Index Terms*—Inter-cluster coordination, inter-cell scheduling, nominal scheduling order with penalty (NSOP), proportional fair (PF) scheduler**

## I. Introduction

Mitigation of inter-cell interference is a key issue in the design and the operation of cellular communication systems. Frequency reuse has been used in conventional systems for decades as a way of achieving an acceptable level of signal to interference ratio (SIR). During the past few years, attentions have been paid to advanced methods of the interference mitigation due to the lack of spectral efficiency caused by the frequency reuse.

The authors of [1] showed that coordinated scheduling among base stations (BSs) has a huge potential to increase the spectral efficiency of the system by effectively avoiding the inter-cell interference. In [2], [3], hierarchical resource allocation for OFDMA system was proposed where a radio network controller (RNC) coordinates multiple BSs on a super-frame level and each BS schedules its mobile stations (MSs) at each scheduling instance. In [4], [5], dynamic adaptation of fractional frequency reuse was addressed for 3GPP long-term evolution (LTE) system as a means of enhancing cell-edge performance. In [6], an opportunistic scheduling was extended to multi-cell environments to achieve network-wide fairness. Network coordination in signal level was proposed in [7] where BSs act as multiple antennas of a transmission unit. Although significant gain in the system capacity can be obtained by the proposed methods, they require a knowledge of channel state information (CSI) for own and neighboring BSs. The burden of real time inter-BS communication prevents these methods from being implemented in existing cellular systems.

In [8], a cluster-based inter-cell scheduling was proposed as a practical alternative to the frequency reuse. In the inter-cell scheduling, a group of BSs establish a cluster and make a collective decision on the scheduling so that only one BS in the cluster transmits at each scheduling instance. The inter-cell scheduling scheme is analogous to the selection diversity in distributed antenna systems (DAS) [9], [10]. Note that the duty cycle of a BS in the inter-cell scheduling is comparable to that in frequency reuse because only one BS can transmit in a cluster at any moment. On the other hand, additional multi-user diversity can be obtained by the flexibility of the inter-cell scheduling. It is shown in [8] that the inter-cell scheduling outperforms the conventional frequency reuse when the opportunistic scheduler is employed. However, the performance of the inter-cell scheduling has not been examined with practical scheduling algorithms such as proportional fair (PF) scheduler. In spite of the apparent performance improvement within a cluster, the inter-cell scheduling may result in conflict between clusters. This necessitates the coordination in the cluster level.

In this paper, we address the coordination of clusters for the inter-cell scheduling in the downlink of cellular networks. Since a frequent information exchange between clusters would not be practical in existing systems, we particularly aim at devising a rule of inter-cluster coordination which can be implemented autonomously in each cluster without requiring inter-cluster communication. The autonomous implementation of network coordination by a static rule was discussed in [11], [12]. In this study, we propose a coordination scheme, namely *nominal scheduling order with penalty* (NSOP) which is a scheduling rule combined with a simple penalty factor. The NSOP tackles the tradeoff between the freedom of scheduling within a cluster and the interference avoidance among the clusters by adjusting the penalty value. We examine the performance of the proposed scheme by dynamic system level simulations in various interference scenarios. A practical PF scheduling algorithm is considered in the experiments.

The rest of the paper is organized as follows: In Section II, the system model and the basic idea of the NSOP are explained and the practical implementation is discussed. The simulation model is provided in Section III. Then, the simulation results are shown in Section IV. Finally, conclusions are drawn in SectionV.

## II. Nominal Scheduling Order with Penalty

### A. System Model

Let us consider the downlink of a cellular network which consists of $N_b$ BSs. The BSs are grouped into $N_c$ clusters. We assume universal frequency reuse, i.e. a single radio channel is shared by all BSs. The system employs the cluster-based inter-cell scheduling [8]. At each scheduling instance, BSs in a cluster collectively choose a MS which has the best scheduling metric. Then, the BS that serves the MS is entitled to transmit. This means that only one BS in the cluster may transmit at any given moment. The inter-cell scheduling has the comparable duty cycle to the frequency reuse. However, flexibility of the inter-cell scheduling gives additional multi-user diversity to the system. On the other hand, the inter-cell scheduling may lead to higher fluctuation in the inter-cell interference compared to the frequency reuse because the interfering BSs in other clusters are changing at each scheduling instance. It is possible that the inter-cell interference surges temporally if the transmitting BSs in different clusters happen to be located in the vicinity of each other. This necessitates the coordination of the interference in the cluster level, yet it is assumed that the clusters have limited communication capability between themselves, which renders a dynamic and frequent inter-cluster coordination unavailable.

### B. Basic Idea of NSOP

The proposed NSOP is a static rule of coordinating clusters which is implemented autonomously by each cluster and does not require communication between clusters. In the NSOP, BSs in a cluster are given designated numbers called *nominal scheduling order* as depicted in Fig 1. Then, each BS is allotted a priority in transmission according to the scheduling order, i.e. BSs take turns to get the transmission priority in a cluster in round-robin manner. The nominal scheduling order is assigned to BSs in a similar manner to the frequency planning, i.e. maximizing the distance between BSs of the same order in other clusters.

The NSOP gives the same spectral efficiency as the frequency reuse if the nominal scheduling order is strictly obeyed. However, the scheduling order is called *nominal* because each cluster is allowed to decide independently whether to follow the order and the decision is made at every scheduling instance. The nominal scheduling order can be defied by a cluster if the violation of the order is expected to bring a performance improvement to the cluster. For example, the cluster may decide to schedule a MS in an out-of-priority cell at a particular scheduling instance if the MS has sufficiently good channel condition to cope with a possible increase in the inter-cell interference. Since this decision of the cluster may cause an adverse impact to other clusters, the following question needs to be addressed:

- *How much freedom of scheduling should be given to clusters in order to maximize the overall system performance*?

A notion of *penalty* is introduced in order to determine the level of scheduling freedom for clusters. The idea is that the system imposes a penalty on the MSs that are connected to out-of-priority BSs when calculating the scheduling metric. With a high penalty, MSs in out-of-priority cells will not be chosen unless they have significantly higher scheduling metric than MSs in priority cells. On the contrary, MSs will be scheduled regardless of the nominal scheduling order if the penalty is not applied to the system.

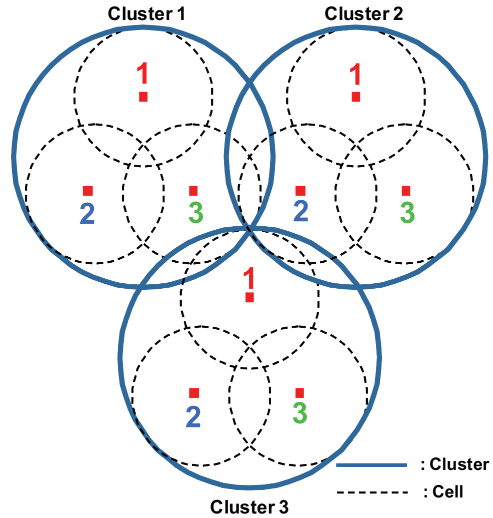


Fig. 1: Clusters of BSs where the numbers at the centers of cells denote the nominal scheduling order

### C. Proportional Fair Scheduler with NSOP

The idea of the NSOP can be readily adapted to any scheduling algorithm. PF scheduler is considered as a practical application in this study since it has been widely employed by various cellular systems. The PF scheduler also has an advantage that it effectively describes both opportunistic and max-min fair schedulers depending on its fairness exponent. Let $M_k(\tau)$ be the scheduling metric of MS $k$ at the scheduling instance $\tau$. The scheduling metric under the PF scheduler is given as follows [13]:

$$M_k(\tau) = \frac{R_k(\tau)}{T_k(\tau)^\alpha}, \tag{1}$$

where $R_k(\tau)$ and $T_k(\tau)$ denote the achievable instantaneous data rate and the average throughput of MS $k$ at the scheduling instance $\tau$, respectively. Fairness exponent $\alpha$ adjusts the balance between the system throughput and the fairness. The PF scheduler is more likely to choose the MS with higher instantaneous SIR as $\alpha$ becomes smaller. Thus, it acts as the opportunistic scheduler as $\alpha$ approaches zero. On the other hand, high value of $\alpha$ gives equal throughput to all MSs, which results in the max-min fair scheduling.

Let $\Psi_b(\tau)$ be the set of BSs that have the priority in scheduling at $\tau$. Note that the members of $\Psi_b(\tau)$ are replaced in round-robin manner as $\tau$ proceeds. Also, let $\Psi_m(\tau)$ be the set of MSs whose serving BSs are members of $\Psi_b(\tau)$. Then, the NSOP modifies the scheduling metric $M_k(\tau)$ depending

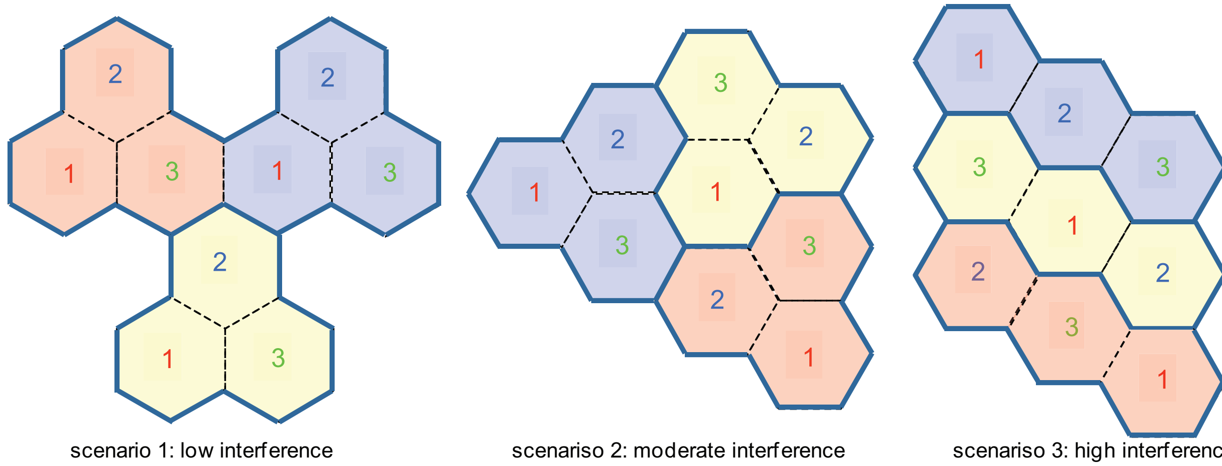


Fig. 2: Scenarios of BSs topologies for simulations ($N_b = 9$, $N_c = 3$, and $N_{c,b} = 3$)

on whether or not the MS $k$ is a member of $\Psi_m(\tau)$. The modified scheduling metric is given by

$$M_k^{nsop}(\tau) = \beta_k(\tau)\frac{R_k(\tau)}{T_k(\tau)^\alpha}, \tag{2}$$

where

$$\beta_k(\tau) = \begin{cases} 1 & \text{if } k \in \Psi_m(\tau) \\ \mu & \text{otherwise} \end{cases}. \tag{3}$$

The system-wise penalty $\mu$ ($0 \le \mu \le 1$) is applied to MSs that do not belong to $\Psi_m(\tau)$ at $\tau$.

The tradeoff between the coordination of the inter-cluster interference and the freedom of intra-cluster scheduling can be effectively tackled by determining the system-wise parameter $\mu$. Smaller value of $\mu$ stands for more stringent penalty because it leads to the increase in the difference between $M_k(\tau)$ and $M_k^{nsop}(\tau)$. When $\mu = 0$, the system employs strict interference avoidance that has the same effect to the frequency reuse[1]. On the contrary, $\mu = 1$ means that the coordination between clusters is not applied, i.e. complete freedom of scheduling in each cluster. The penalty $\mu$ can be determined at the phase of the initial network deployment depending on the topology of BSs. Then, each cluster makes an independent scheduling decision based on $\mu$. Therefore, the proposed NSOP works without communication between neighboring clusters.

## III. Simulation Model

Dynamic system level simulations are performed to examine the impact of the penalty $\mu$ on the system performance. We consider three different topologies of BSs that represent different interference scenarios. As illustrated in Fig. 2, the scenarios 1, 2, and 3 correspond to low, moderate, and high interference situations respectively in terms of the impact on other clusters when a cluster violates the nominal scheduling order.

We assume that $N_c = 3$ and $N_b = 9$ in all scenarios. Each cluster has the same number of BSs, which is denoted by $N_{c,b}$. Also, each BS is connected to the same number of MSs, $N_m$. MSs are uniformly distributed in each cell area. We assume that BSs use a fixed transmission power when they are allowed to transmit. Background noise is not taken into account in the simulation since interference-limited environments are examined.

Parameters used for the simulations are summarized as follows:

- path loss exponent: 3.5
- shadow fading standard deviation: 8 dB
- BS-to-BS shadow fading correlation: 0.5 [14]
- fast fading: time-correlated Rayleigh fading [15]
- MS speed: 5 km/h
- carrier frequency: 5 GHz
- traffic model: full buffer (continuous traffic)
- duration of a scheduling instance: 1 msec

## IV. Simulation Results

Let $S_{eff}(\mu)$ be the average spectral efficiency per cell as a function of the penalty $\mu$. $S_{eff}(\mu)$ is obtained by the Shannon capacity formula. We also define performance gain by NSOP, $D_{eff}(\mu)$, as follows:

$$D_{eff}(\mu) = S_{eff}(\mu) - S_{eff}(0). \tag{4}$$

Note that $D_{eff}(\mu)$ denotes the difference in spectral efficiency between the conventional frequency reuse and the inter-cell scheduling with $\mu$.

Fig. 3 and Fig. 4 show $S_{eff}(\mu)$ when $N_m = 2$ and $N_m = 10$, respectively. It is observed that the NSOP has different impact on $S_{eff}(\mu)$ depending on the interference scenarios and the number of MSs. The performance improvement by the NSOP is obvious in the low interference scenario. The increase in the spectral efficiency is also shown in the moderate interference case. However, only a marginal gain is

[1]Hereafter we will use the term ‘frequency reuse’ and ‘the inter-cell scheduling with $\mu = 0$’ interchangeably because they result in the same spectral efficiency.

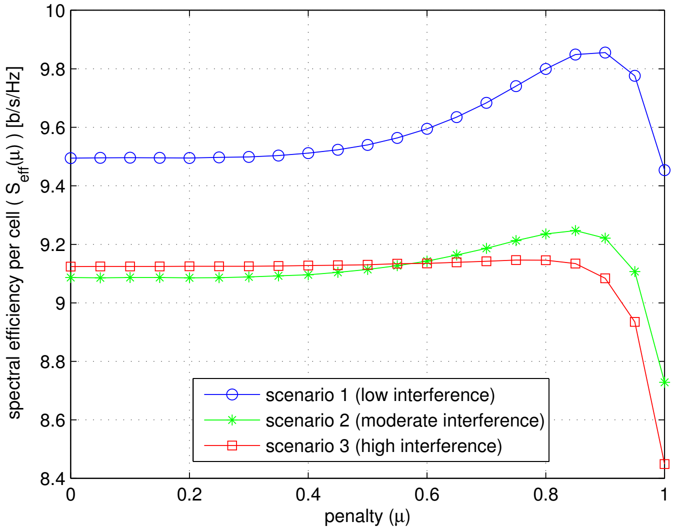


Fig. 3: $S_{eff}(\mu)$ as a function of $\mu$ ($N_m = 2$ and $\alpha = 1.0$)

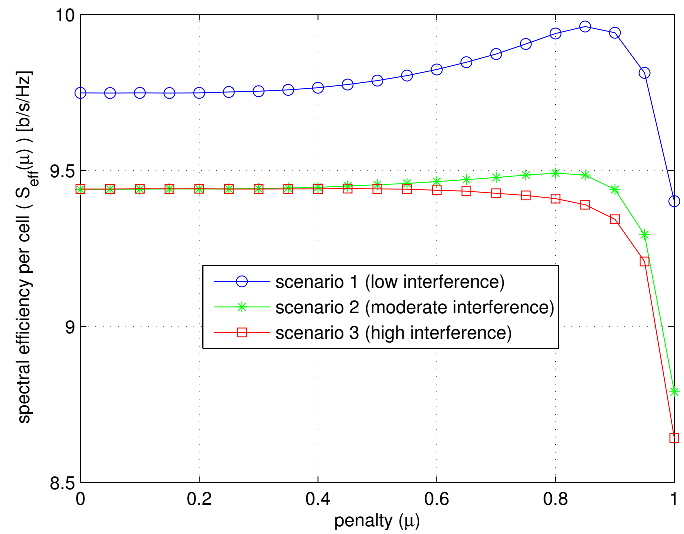


Fig. 4: $S_{eff}(\mu)$ as a function of $\mu$ ($N_m = 10$ and $\alpha = 1.0$)

obtained in the high interference situation. The performance even worsens in the scenario 3 with $N_m = 10$. In all scenarios, $\mu = 1$ gives lower spectral efficiency than $\mu = 0$ case. This means that the performance of the inter-cell scheduling with the complete freedom in each cluster is worse than the conventional frequency reuse when the PF scheduler of $\alpha = 1$ is employed by the system. These figures indicate that the inter-cell scheduling may cause the impairment in the overall system performance unless proper mediation between clusters is put in place. It also shows that the NSOP increases the spectral efficiency while effectively resolving the conflict between clusters by the proper choice of $\mu$. The optimal $\mu$ lies between 0.8 and 0.9 depending on the scenarios.

The performance of NSOP is compared with frequency reuse in Fig. 5 which depicts $D_{eff}(\mu)$ for scenarios 1 and 3 with $N_m = 2$ and $N_m = 10$. The increase in the number

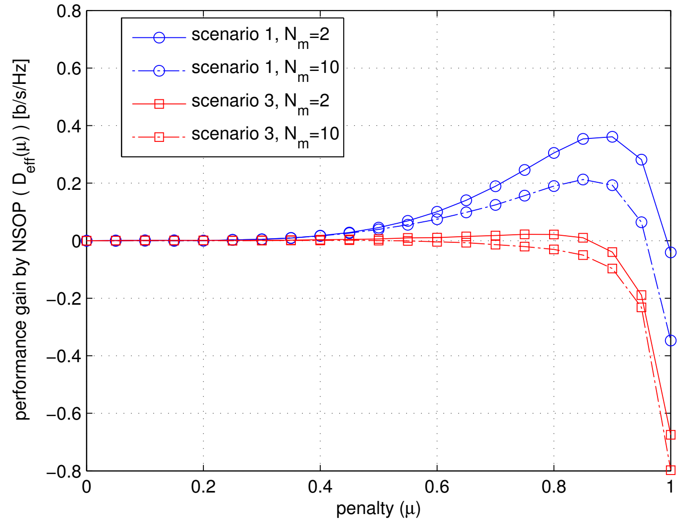


Fig. 5: $D_{eff}(\mu)$ as a function of $\mu$ ($\alpha = 1.0$)

of MSs implies that the system can exploit more multi-user diversity. This alleviates the need for the inter-cell scheduling because it is likely that each BS has already obtained enough multi-user diversity with its own MSs. Thus, smaller performance gain is achieved when $N_m = 10$ compared to when $N_m = 2$. For the case of the scenario 3 and $N_m = 10$, $D_{eff}(\mu)$ is monotonically decreasing as $\mu$ increases. This means that strict interference avoidance is desirable in the circumstance of the high inter-cluster interference and the large number of MSs.

We define a cluster-wise parameter $V_{nso}(\mu)$ which denotes the portion of scheduling instances that violate the nominal scheduling order. Note that $V_{nso}(0) = 0$ as specified in (2). Also, $V_{nso}(1)$ becomes $(N_{c,b} - 1)/N_{c,b}$ because all the cells in a cluster have the same opportunity to transmit with $\mu = 1$. Fig. 6 shows $V_{nso}(\mu)$ when $N_m = 2$. The optimal $\mu$ for scenarios 1, 2, and 3 correspond to $V_{nso}(\mu)$ of 0.25, 0.12, and 0.06, respectively. Clusters are given more freedom of violating the nominal scheduling order as the system is less interference-limited. The case of $N_m = 10$ shows similar result to Fig. 6.

The results so far have been based on the PF scheduler with the fairness exponent of $\alpha = 1$. The effect of different fairness exponents is illustrated in Fig. 7. The PF scheduler tends to choose the MS in a good instantaneous channel condition as $\alpha$ decreases. Thus, smaller $\alpha$ makes the PF scheduler behave similar to the opportunistic scheduler in the presence of the fast fading. Fig. 7 shows that the performance gain by the inter-cell scheduling becomes higher with lower value of $\alpha$. When $\alpha = 0.5$, $D_{eff}(1)$ is larger than $D_{eff}(0)$, i.e. the inter-cell scheduling without inter-cluster coordination outperforms the frequency reuse. This agrees with the results by [8]. On the contrary, the performance loss occurs when $\alpha = 2.0$ if $\mu$ is not properly chosen. Therefore, the coordination of interference in the cluster level is more crucial to the system which inclines towards the fairness rather than the spectral efficiency.

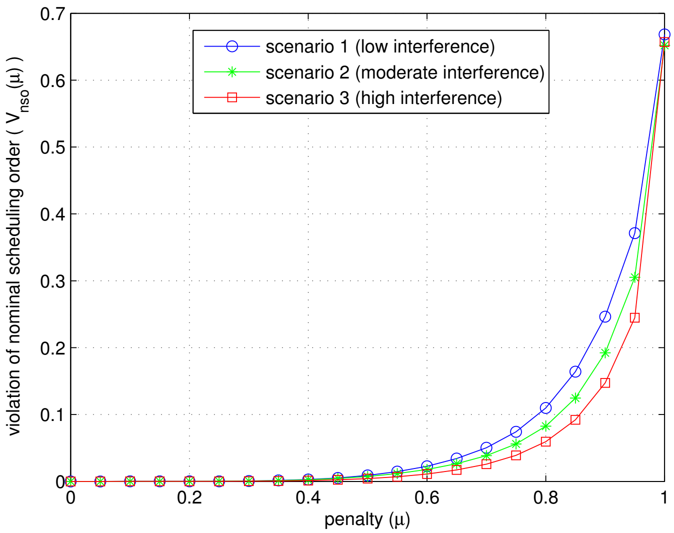


Fig. 6: $V_{nso}(\mu)$ as a function of $\mu$ ($N_m = 2$ and $\alpha = 1.0$)

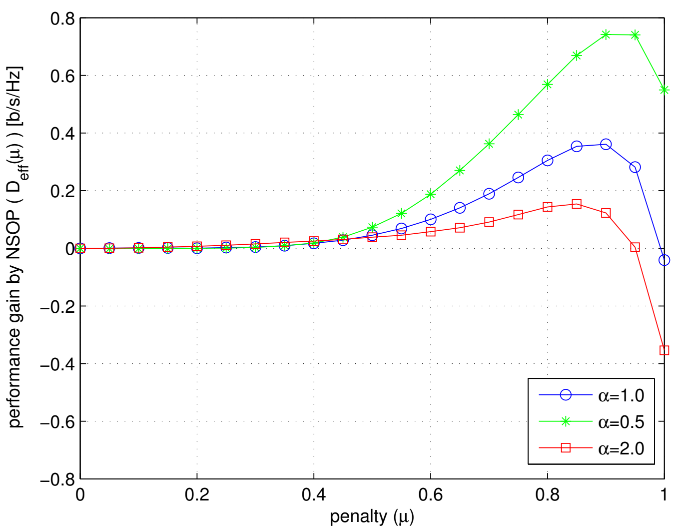


Fig. 7: The impact of $\alpha$ on $D_{eff}(\mu)$ for the case of the scenario 1 ($N_m = 2$)

## V. Conclusion

In this paper, we addressed the coordination between clusters of BSs in the cellular communication system which employs the inter-cell scheduling. Since the burden of inter-cluster communication for the real time coordination is prohibitive in existing systems, we aimed at devising a rule of the inter-cluster coordination by which the independent implementation is achieved in each cluster without information exchange between clusters. The concepts of *nominal scheduling order* and *penalty* were introduced to determine the level of scheduling freedom for the clusters. Dynamic system level simulations have been performed in three different interference scenarios. It is shown that the proposed NSOP effectively strikes a balance between the inter-cluster interference avoidance and the intra-cluster multi-user diversity by simply adjusting the system-wise penalty parameter. The optimal penalty was found by extensive simulations in this study. An efficient way of obtaining the optimal penalty in various environments remains as further research area.

The simulation results also provide insights into the design of wireless systems. First, more freedom of scheduling can be allowed to clusters in the low interference case. However, the uncoordinated inter-cell scheduling may result in worse performance than the conventional frequency reuse for the case of the PF scheduler. Second, strict avoidance of the inter-cluster interference is preferred for large number of MSs because it is likely that BSs have already obtained enough multi-user diversity without the inter-cell scheduling. Third, the inter-cluster coordination is crucial to the system that is more apt to the fairness than the spectral efficiency.

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