Inter-cell Interference Mitigation through Flexible Resource Reuse in OFDMA based Communication Networks

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Abstract— **The inter-cell interference problem is a key issue in OFDMA-based mobile cellular networks. In order to deal with this problem, several flexible radio resource reuse schemes for the downlink are examined in this paper. The goal is to improve the cell edge throughput as well as the average cell throughput, compared to a network with frequency reuse factor 1. The cell capacity under those reuse schemes is estimated and compared. Performance in realistic packet-switched networks is also evaluated and compared by extensive system-level simulations.**

I. INTRODUCTION

The OFDMA (Orthogonal Frequency Division Multiple Access) technology is considered as a promising candidate for the downlink air interface of the next generation mobile communication systems. Several communication standards, such as the IEEE 802.16e, and the ongoing standardization of 3G LTE (3rd Generation Long Term Evolution) [1], both choose OFDMA as the downlink transmission scheme. OFDMA features a scalable bandwidth, a high spectral efficiency and a very flexible multi-user access. However, if the frequency resource is universally reused in every cell of the network, no inter-BS (base station) macro diversity and no power control is adopted, the users at the cell edge inevitably have the weakest signal strength, and suffer the most from inter-cell interference. Traditional frequency reuse schemes, such as a reuse factor 3 deployment can significantly reduce the average inter-cell interference and enhance the SINR, but at a great sacrifice of the accessible frequency resource for each cell.

This paper focuses on the study of an OFDMA-based downlink in a FDD broadband RAN (Radio Access Network). We study a SISO (Single Input and Single Output) channel, which has one transmitting antenna at the BS and one receiving antenna at the mobile, both with fixed antenna pattern. Such relatively simple setting could serve as a good basis of study for future wireless systems that employ MIMO (Multiple Input Multiple Output) and adaptive antennas. In 3GPP's current standardization process of 3G LTE, inter-cell interference avoidance schemes are discussed in similar settings. The proposals for resource management based interference coordination/avoidance mainly fall into two categories, namely, the scheme of soft frequency reuse, which is for example discussed in [2]; and the partial frequency reuse scheme, originally proposed in [3]. However, there is not yet a comprehensive study of comparison among those schemes. This paper proposes a way to estimate the average cell capacity under different resource reuse schemes, assuming a multi-user scenario. HARQ-incorporated system-level simulations are also done to examine the performance in a realistic setting.

The rest of this paper is organized as follows. In section II We first explain the schemes of interference coordination. The method of cell capacity estimation is discussed in section III. The system-level simulation methodology is introduced in section IV. In section V, the results of both the capacity estimation and the dynamic simulation are shown and discussed. Finally, conclusions are drawn in section VI.

II. INTERFERENCE COORDINATION SCHEMES

We consider a tri-sector cell layout, with three 120° sectorized antennas per site. One BS (base station) is at the center of the site, controlling the three cells (sectors). On the downlink the modulated OFDM symbols are transmitted in the unit of *chunks*. One chunk is defined as a block of physical layer resources that spans over one TTI (Transmission Time Interval) in time and a fixed number of adjacent OFDM subcarriers in the frequency domain. We assume that each cell always uses its maximum total transmission power, which is kept constant and is the same for all the schemes that we are going to analyze. Throughout this paper, we use a static power allocation over the chunks on the available frequency band. So the power per chunk is fixed and no adaptive power loading is employed. Nevertheless, transmission rate adaptation is still performed by altering the modulation and coding scheme on the chunks.

A. Scheme A – Soft Frequency Reuse

The soft frequency reuse scheme works as follows, for each cell in the network, a part of the frequency band is reserved for the cell edge users, on which the transmission power is amplified. In a tri-sector network, the reserved part is normally 1/3 of the total frequency band and is orthogonal among the neighboring cells. It is called soft frequency reuse as the frequency partition only applies to the cell edge users, whilst the effective frequency reuse factor is still close to one. From now on, we abbreviate the soft frequency reuse scheme as *Scheme A*, and we will refer to the 1/3 frequency sub-band

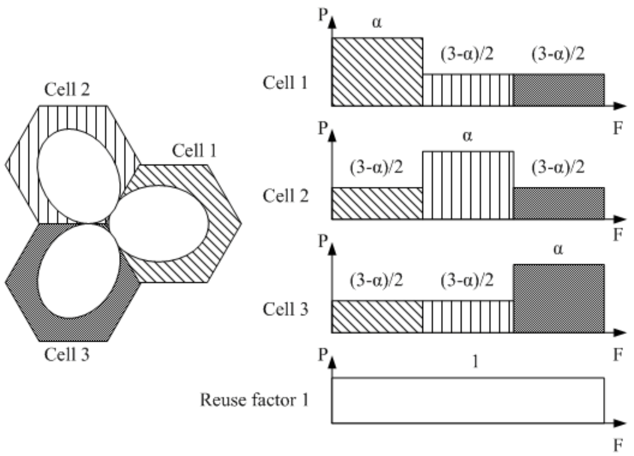

Fig. 1. Frequency-Power arrangement of Scheme A

that has amplified power as the *cell edge band*, since the cell edge users are restricted to use this frequency sub-band only. On the other hand, the remaining 2/3 frequency sub-band for each cell is called the *cell center band*, since it's used by the cell center users only. However, if the cell edge band is not occupied by data of the cell edge users, it can still be used by the cell center users. If we denote the power per chunk in the reuse factor one case as 1, the power per chunk on the edge band becomes α, which is the power amplification factor. By the constant total power assumption, the power per chunk on the center band becomes $(3-\alpha)/2$. In figure 1, the right part shows the power-frequency arrangement in three cells of the same site, which is compared with the reuse factor 1 case. The left part shows an approximate pattern of the available frequency sub-band for users in different regions of one site. Users at the cell center could use the whole frequency band (painted white), but with lower priority than the cell edge users on the cell edge band.

B. Scheme B – Partial Frequency Reuse

The partial frequency reuse scheme was originally proposed in [3], the idea is to partition the whole frequency band into two parts, with reuse factor 1 on one part and reuse factor 3 on the other one. From now on, we refer to the partial frequency reuse scheme as *Scheme B*. Just like in Scheme A, the reuse factor 3 part of the frequency band is called the *cell edge band*, the other part is called the *cell center band*. The restrictions of frequency access for the cell center/edge users are the same as in Scheme A, that the cell edge users are only allowed to use the cell edge band, while the cell center users are allowed to access both the cell center and edge band, but with lower priority than the edge users. If we denote the number of chunks on the center band as C, and the number of chunks on the edge band as $3E$, with a total of 24 chunks in the 10MHz bandwidth (see table V), the effective frequency reuse factor for Scheme B is:

$$r_{eff} = \frac{24}{C+E} \tag{1}$$

As we have the constant total power assumption, the power per chunk can be increased in Scheme B. One option is to increase the power uniformly for each chunk, in this case the power amplification factor β would be the same as the effective reuse factor. The other option is to have different power level on the cell center/edge band, we would evaluate the case that the edge band has three times of power per chunk, while the center band power per chunk is kept unchanged. The power-frequency arrangement is illustrated in figure 2, in which the left/right part shows the equal/unequal power allocation cases, respectively.

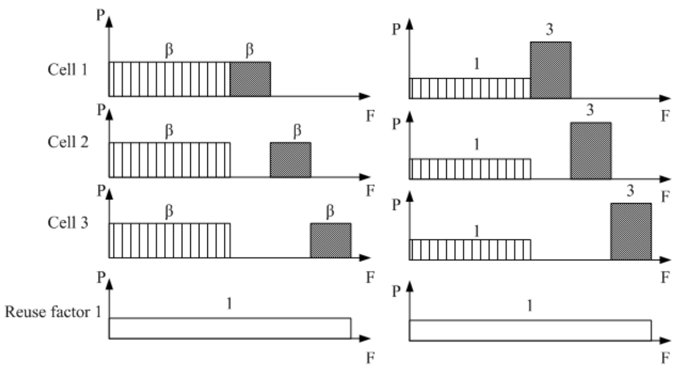

Fig. 2. Frequency-Power arrangement of Scheme B

The proposed resource reuse schemes are not necessarily static. For example, the edge band power amplification factor α in Scheme A could be adaptive. Also, the edge band in Scheme B may not necessarily follow the equal partition rule, but may instead be differently allocated to a group of adjacent cells/sites. Such adjustments should be made to meet the needs of the varying cell edge traffic requirements. In this paper, our focus is not on the temporal adjustment of the resource reuse schemes, but rather on the capacity comparisons of particular static resource reuse schemes.

III. ESTIMATION OF CELL CAPACITY

A. Modeling of the Downlink SINR (Signal to Interference and Noise Ratio)

The radio propagation can be modeled by three parts, namely the multi-path fast fading, the distance-dependent attenuation (path loss) and the shadowing. Here we refer to the latter two as *slow fading*. The link propagation model can be described as:

$$P_r = P_{tx} \cdot A \cdot G_p(R) \cdot S \cdot F \tag{2}$$

in which P_{tx}, P_r stand for the transmit power and the received power. A is the product of the Tx and Rx antenna gains, $G_p(R)$ is the path gain for a particular BS-UE link, which includes the distance-dependent path loss and also the penetration loss. Here R is the distance from the UE to the BS in km. S is the shadowing gain and F is the fast fading gain. In equation 2, all these notations refer to the absolute value.

In our SINR model we do not consider the fast fading of the interfering signals. Thus, the SINR can be written as:

$$SINR = \frac{P_s \cdot A_s \cdot G_p(R_s) \cdot S_s \cdot F}{\sum_{i=1}^{n}(P_i \cdot A_i \cdot G_p(R_i) \cdot S_i) + P_N} \tag{3}$$

where the subscripts s and i stand for the serving cell and the interfering cells, P_N denotes the UE noise power, and n is the number of interferers.

All components of the above equation refer to the absolute value, detailed values in dB scale can be found in table V.

B. Cell Capacity Estimation by Shannon's Equation

In general, Shannon's equation gives the capacity of a SISO AWGN channel. For the estimation of cell capacity, multiple users have to be taken into account. We here give our method for cell capacity estimation, by assuming multi-user "opportunity-fairness" (explained below), and utilizing Shannon's equation.

According to Shannon's equation for the AWGN channel, the capacity for a particular user on one chunk is:

$$ChunkCapacity = ChunkBandwidth * log_2(1 + SNR) \tag{4}$$

We estimate the chunk capacity, with the following additional assumptions:

1) The SNR (signal to noise ratio) in Shannon's equation can be replaced by the user's average SINR.
2) Each user's average SINR can be calculated by slow fading, since the fast fading is averaged out. The calculation of the average SINR is done as in equation 3, except that F (fast fading) is removed from the numerator.
3) For capacity estimation, a fully loaded network is assumed. As no wrap-around method is deployed, only users at the center site are incorporated for the evaluation.
4) The users are uniformly distributed in the cells, we assume 36 users are active for each cell, and each user has unlimited traffic to transmit on the downlink (full load). The choice of 36 users per cell is motivated as follows: This number is sufficiently high to introduce the desired multi-user diversity, and still represents a practical user density in a hexagonal cell of 0.866 square kilometers.[1]
5) We assume the users have equal chance of access to every chunk on the same frequency sub-band. This assumption is termed as "opportunity- fairness".
6) According to the "opportunity-fairness" assumption, the average chunk capacity is obtained by averaging over the capacity results for each user.

After obtaining the average chunk capacity of a particular sub-band (center/edge), the sub-band capacity becomes:

$$Capacity_{sub-band} = \sum_{i=1}^{m} Capacity_{chunk_i} \tag{5}$$

The average cell capacity thus becomes

$$Capacity_{cell} = Capacity_c + Capacity_e \tag{6}$$

in which c stands for the cell center band and e stands for the cell edge band, and m is the available number of chunks on the particular sub-band.

C. Additional Assumptions for Capacity Estimation

In the proposed schemes, the cell edge/center users are differentiated by the *Geometry Factor* (i.e. ratio of total base station power and interference from the other cells including thermal noise), as we assume fully loaded network, the geometry factor equals the calculated SINR for each user in the reuse factor 1 case. It seems a threshold of the geometry factor has to be evaluated for separating the cell center/edge users, nevertheless any fixed threshold can not be optimal in reality, due to the temporal change of the users' SINR distribution. So here we avoid the discussion of a geometry factor threshold, rather we assume a certain percentage of users should be regarded as cell edge users. Those users are the ones with the worst geometry factor. In reality the geometry factor (SINR) can be provided by UE-side measurement of the downlink common pilot channel.

According to the above analysis, remaining open questions are: 1) in Scheme B, how many chunks should be allocated to the cell center/edge band? 2) how much percent of users with the worst geometry should be allocated to the cell edge band (regarded as the cell edge users)? Those questions are addressed in the next section.

D. Load Balancing Requirement

In a fully loaded network, it becomes unlikely that cell center users would still be able to access the cell edge band (due to the higher priority of cell edge users on this band) and would thus be confined to the cell center band. This basically yields a separation of the user groups such that the cell center users are occupying the cell center band only while the cell edge users are using the cell edge band only. In this critical high load case, we aim at providing a balanced load to both sub-bands, which means that the traffic load of the two user groups should be proportional to the capacity of the two frequency sub-bands, so that the average delay of the cell edge user group and the cell center user group would be similar.

Assuming each user has the same offered traffic load, and with the following notations:

K_c: the average chunk capacity at the center band.
K_e: the average chunk capacity at the edge band.
N_c: the number of cell center users.
N_e: the number of cell edge users.
C: the number of chunks of the center band.
E: the number of chunks of the edge band.
T: offered traffic per user (assumed equal for all users).

The load balancing requirement yields:

$$\frac{CK_c}{N_cT} = \frac{EK_e}{N_eT} \qquad \frac{C}{E} = \frac{K_eN_c}{K_cN_e} \tag{7}$$

[1]calculated by the inter-site-distance in table V

$$\frac{N_c}{N_e} = \frac{K_c C}{K_e E} \tag{8}$$

With a known user distribution, if we regard a certain percentage of users as the cell edge users, the average chunk capacity on the cell center/edge band can be calculated. Then with equation 7, C/E can be calculated, which tells us how to partition the whole frequency band for Scheme B. For Scheme A, C/E is always 2, but we can not obtain the reasonable percentage of the edge users by equation 8, because K_c and K_e depend on N_c/N_e. So for the moment we assume 1/3 of all the users are edge users in Scheme A, for the capacity estimation. For Scheme B, due to the limit that C,E must be integers and $C + 3E = 24$, we obtain the possible partitions as shown in table I.

It is very likely that an edge band of only 3 chunks per cell is too limited to satisfy the cell edge users' traffic. Hence we decide to evaluate only the latter three choices of table I. With the load balancing requirement, we can obtain the reasonable percentage of cell edge users for each configuration, as listed in table II. So finally, the capacity of each scheme can be reasonably estimated. The results will be presented in section V.

TABLE I
POSSIBLE BAND PARTITION FOR SCHEME B

C	15	12	9	6
E	3	4	5	6
C/E	5	3	1.8	1
Reuse Factor	1.33	1.5	1.71	2

TABLE II
CONFIGURATION SET FOR SCHEME B

	Reuse Factor	Percentage of edge users
Scheme B, equal power	1.5	22%
	1.71	31%
	2	45%
Scheme B, unequal power	1.5	22%
	1.71	35%
	2	50%

IV. SYSTEM-LEVEL SIMULATION METHODOLOGIES

A. Protocol Stack

We consider a simplified downlink protocol stack as illustrated in figure 3. The traffic generator generates packets, which are then stored temporarily as prioritized flows in the queue. The RLC (Radio Link Control) layer segments the data from the service queue, encapsulates them into RLC layer PDUs, and forwards them to the MAC for further multiplexing before the HARQ processes. After the HARQ sender, the data goes through the channel model, and finally reaches the UE, where receiver protocol entities are modeled. In reality, retransmission by HARQ is not enough, and should be compensated by an outer level of ARQ that resides in the RLC layer. For simplicity, RLC layer ARQ is omitted in our simulation, so the downlink simulation chain can be terminated at the HARQ receiver, where the statistics are collected.

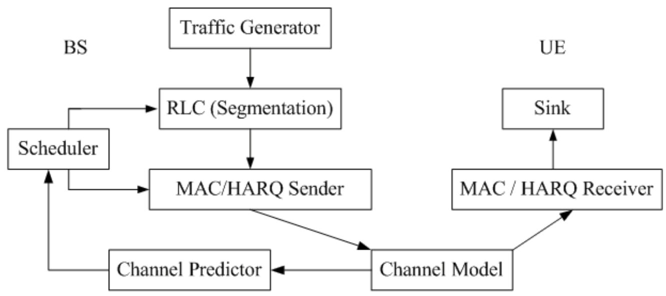

Fig. 3. Simplified downlink protocol stack

For simplicity, in our simulation we always use one chunk as the resource allocation unit, which holds exactly one MAC layer PDU and exactly one RLC layer PDU inside. A cross-layer approach is taken for the RLC/MAC/PHY layers. The scheduler decides the resource allocation for different flows, which have to consider both the new data and the retransmissions. The scheduling follows a *channel-aware Round-Robin* strategy, in which the active flows are selected in a Round-Robin fashion. The selected flow then chooses one best available chunk for itself, according to the channel prediction. After one chunk is assigned to a particular flow, the MCS (modulation and coding scheme, see table VI) over that chunk is adapted according to the user's instantaneous channel condition. By determining the MCS the number of information bits is also determined, according to which the RLC layer segmentation is done. We do not take the protocol overhead into consideration, since that does not affect the comparison among different reuse schemes.

Our simulation uses a packetized CBR (Constant Bit Rate) traffic model, and we assume each user has exactly one CBR flow with the same level of priority. The CBR traffic rate is comparable to a video stream, the parameters are listed in table VI.

For the SISO downlink we use the Pedestrian B channel model [4] for simulation. The interference and SINR is modeled according to equation 3. We assume that the base station has perfect channel knowledge from the user. The channel prediction is done by simply using the SINR information of the current TTI as the reference for the next TTI.

B. Cell Center/Edge User Partition

For the flexible reuse schemes, the data packets are scheduled in a prioritized way as: $P_{e,R} > P_{e,N} > P_{c,R} > P_{c,N}$. Here P stands for the scheduling priority, e and c stand for the cell edge users and the cell center users, R means retransmission packets and N means new data packets. As already mentioned, in the reuse schemes cell edge users are always confined to the cell edge band, where they have better protection against interference.

In the simulation we adopt a random movement model for the users, so that their average SINR changes over time. Unlike in the capacity estimation where a fixed cell center/edge user partition is assumed, now we have to dynamically adjust the user partitioning due to the temporal changes of the fading condition. The user partition algorithm follows the following principles.

1) As many users as possible are regarded as the cell edge users, so they are scheduled on the cell edge band to improve the SINR condition.
2) On the other hand, the resource utilization of the cell edge band is constantly monitored. If congestion happens, the user with the best average SINR is switched to the cell center user group.
3) The necessary information, including the users' average SINR, sub-band utilization and the geometry factor is calculated and updated regularly. We set the updating interval to be 100 ms.
4) The dynamic user partition should lead to such effects, that in low load situation, the majority (or even all) of users would be allocated only onto the cell edge band; whereas in high load situation, the load balancing requirement (see section III-D) should be fulfilled.

V. RESULTS AND ANALYSIS

A. Results of Capacity Estimation

For the capacity estimation, two rings of sites are modeled. For the center site, 36 user locations are generated in each scenario, assuming a uniform distribution. With each scenario, the average SINR in a fully loaded network is calculated for the capacity estimation. The average cell capacity is obtained by averaging the results of 100 user location scenarios. For Scheme A, we evaluated the cell capacity with the power factor α equal to 2 and 5/3.

The capacity of Scheme B is shown in figure 4, from which we can draw two conclusions. Firstly, the unequal power allocation has bigger capacity than the equal power allocation case. Secondly, the larger the edge band is (the bigger the reuse factor), the smaller the capacity becomes.

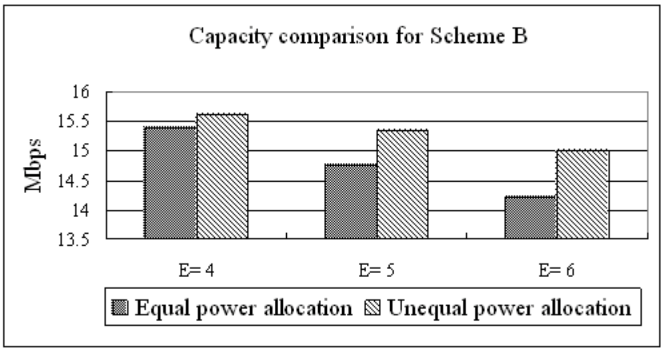

Fig. 4. Capacity comparison for Scheme B

Now we can present an overall comparison. The following conclusions can be drawn from figure 5:

1) Reuse factor 1 deployment maximizes the cell capacity.
2) The lower the power factor α is, the higher the capacity of Scheme A becomes. This is reasonable as Scheme A approaches the reuse factor 1 scheme when α goes to 1.
3) As was seen in figure 4, The biggest capacity of Scheme B is achieved when E=4 and with unequal power allocation. However, it's only similar to the capacity of the reuse factor 3 case. So the capacity of Scheme A is bigger than that of Scheme B.

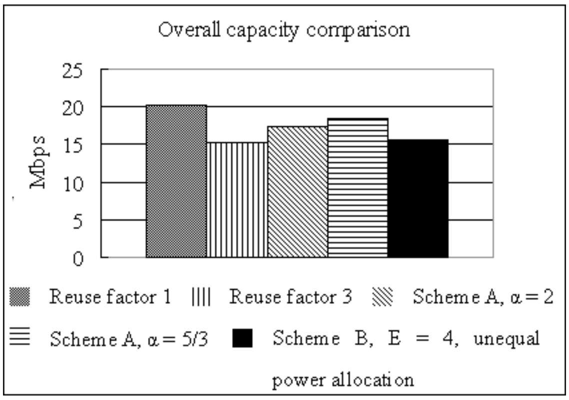

Fig. 5. Overall capacity comparison

B. Simulation Results

With simulation we aim at a more realistic comparison of the different resource reuse schemes, a verification of our initial goals, i.e. to improve cell edge user throughput as well as the average cell throughput, and also an examination of the results of the capacity estimation.

In our system-level simulation, each cell is running the same protocol stack and serving the same number of users. The users have random movement inside the cells and handover is avoided by re-positioning the users if necessary. For the ease of simulation, only one ring of sites is simulated and the center site is used for evaluation. This is reasonable since the majority of interference always comes from the first-tier sites.

As the only ARQ in our protocol stack is the HARQ, the residual packet error rate (after max. 3 times of retransmission) becomes an important performance metric. On the other hand, we give the delay performance by measuring the scheduling delay, it is defined as the delay between the packet generation time and the time that the last segment of this packet is scheduled. Because the RTT (round trip time) of HARQ is fixed (see table VI) and because of the higher priority for retransmissions, the HARQ delay is normally within 10 ms, which is much smaller than the scheduling delay in high load cases.

Although for Scheme A, the power factor α can be variable, we use a static value in our simulations for the comparison with other schemes. We compared three cases (α = 2, 1.8, 5/3), w.r.t. the following three scenarios:

1) High load: 36 users per cell, 180 kbps per user.
2) Medium-High load: 30 users per cell, 180 kbps per user.
3) Medium load: 36 users per cell,120 kbps per user.

The results are shown in table III. From the throughput results

TABLE III

RESULTS FOR α SELECTION

Throughput (Mbps)			
Scenario	α=2	α=1.8	α=5/3
1)	6.4644	6.4669	6.4681
2)	5.3862	5.3879	5.3866
3)	4.3144	4.3147	4.3144

we see little difference for the three choices of α. This is because the user partition algorithm well adapts to the different power distributions. α=1.8 nevertheless slightly outperforms the others in the latter two scenarios. Hence we choose it as an empirical value for further simulations.

For the overall comparisons we show the results of the following schemes:

1) Reuse factor 1
2) Reuse factor 3 (reuse based on cells)
3) Scheme A with power factor α=1.8
4) Scheme B with unequal power allocation, for a edge band of 6, 5, 4 chunks (reuse factor 2, 1.71, 1.5).

The simulation scenarios include:

1) Medium load case: 120 kbps per user, 36 users per cell (offered traffic load 4.32 Mbps per cell)
2) Medium-high load series: 180kbps per user, 30, 32, 34, 36, 38 users per cell (offered load 5.40, 5.76, 6.12, 6.48, 6.84 Mbps per cell)

The results of the residual PER performance is shown in figure 6. It can be seen that the reuse factor 1 deployment

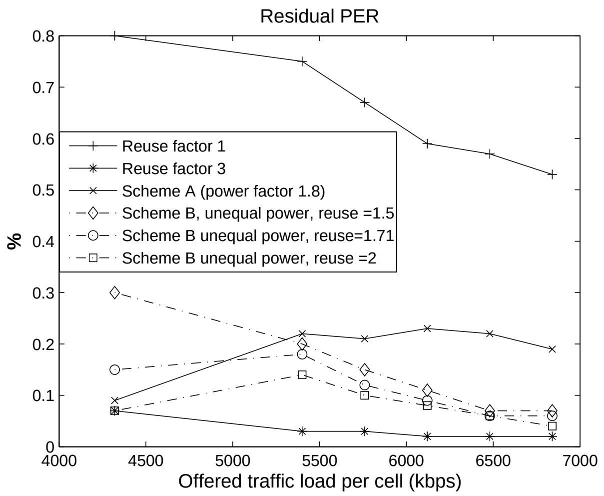

Fig. 6. Residual PER of the center site

constantly has a high residual PER (around 0.7%). All other schemes yield a significantly lower residual PER of less than half of that seen in the reuse factor 1 case. The reuse factor 3 scheme has the lowest residual PER, while Scheme A has a slightly higher residual PER than Scheme B in high load cases, this is due to the fact that the edge band in Scheme A suffers from more interference than that in Scheme B.

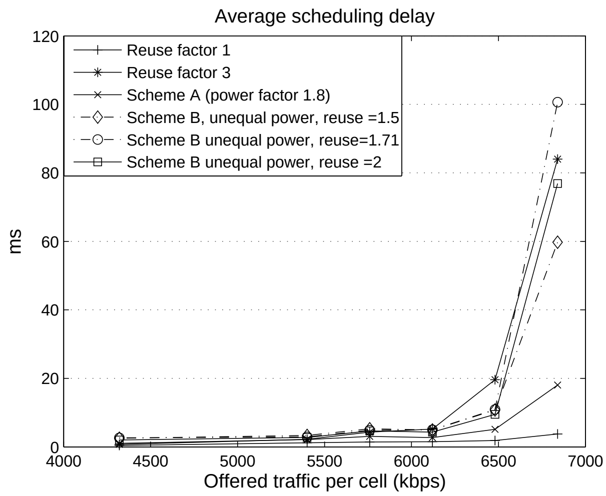

Fig. 7. Scheduling delay of the center site

Figure 7 shows the scheduling delay. We see that at the rightmost point, only Scheme A and the reuse factor 1 scheme have average delay below 20ms. All other scheme have significantly higher delay, which means they have reached the capacity limit and the traffic meets great congestion. This demonstrates the fact that Scheme A has bigger capacity than Scheme B and the reuse factor 3 scheme, which was predicted by the capacity estimation.

As we assume a random movement model of the users, it is not easy to have a direct comparison on the cell edge throughput, nevertheless we could tell the improvement of cell edge performance by observing a gain of the 5th percentile cell throughput. We choose the case of 36 users per cell (the second highest load scenario), in which the network is highly loaded. The detailed results for the 5th percentile and the 85th percentile cell throughput, as well as the average cell throughput are given in table IV. Compared to the reuse factor 1 scheme, Scheme A and B both have more than 10% gain for the 5th percentile of cell throughput. So we can see that,

TABLE IV

THROUGHPUT RESULTS, NEAR FULL LOAD CASE

Schemes	5th percentile (Mbps)	85th percentile (Mbps)	Average (Mbps)
reuse 1	3.940	8.120	6.451
reuse 3	4.340	7.633	6.460
Scheme A,α=1.8	4.433	7.967	6.467
Scheme B, reuse=1.5	4.473	7.813	6.471
Scheme B, reuse=1.71	4.667	7.707	6.471
Scheme B, reuse=2	4.840	7.547	6.471

compared to reuse factor 1, Scheme A, B, and the reuse factor 3 scheme all have better average throughput. However at the 85th percentile, reuse factor 1 is the highest, so it still has the biggest achievable throughput. Scheme A is the second best at 85th percentile.

VI. CONCLUSION

Our capacity estimation method, which makes use of the "opportunity-fairness" assumption and the load balancing assumption, successfully estimates the cell capacity under different reuse schemes, its results are verified by the simulation. The conclusions are the following:

1) Reuse factor 1 deployment maximizes the cell capacity, but fails to guarantee the cell edge throughput.
2) By allocating more power to the cell edge users, and less to the cell center users, the soft frequency reuse (Scheme A) has smaller capacity than reuse factor 1. But it greatly reduces the residual PER and enhances the cell edge throughput (shown by the 5th percentile throughput).
3) Although the partial frequency reuse (Scheme B) and the reuse factor 3 scheme have better transmission quality (lower residual PER), they show smaller cell capacity than the soft frequency reuse scheme.

In sum, our capacity estimation and the simulation with homogeneous traffic load among cells both show that the soft frequency reuse scheme is a good candidate to enhance the cell edge throughput, without sacrificing the average cell throughput. To achieve better performance as compared to the reuse factor 1 case, a dynamic cell center/edge user partitioning should be adopted. In the future, inhomogeneous traffic load among cells and more advanced scheduling could be examined. However, we expect the same qualitative behavior in terms of relative performance comparison among the different schemes.

TABLE V
PHYSICAL PARAMETER SET

Carrier frequency	2 GHz
Bandwidth	10 MHz
Number of antennas	1 Tx, 1 Rx
Number of chunks	24
Chunk bandwidth	375 kHz
Chunk size	150 OFDM symbols
TTI	0.5 ms
Antenna horizontal pattern	$A(\theta) = -min\left[12(\frac{\theta}{\theta_{3dB}})^2, A_m\right]$ $\theta_{3dB} = 70^\circ$, $A_m = 20$dB
BS/UE antenna gain	14dBi/0dBi
Inter Site Distance(ISD)	1.732 km
Path loss model (in dB)	Loss = 128.1 + 37.6 $log_{10}(R)$ R: Distance in km
Penetration loss	20 dB
BS Tx power (one cell)	46 dBm
Shadowing:	Lognormal distribution
- Standard deviation	8 dB
- Inter-site correlation	0.5
- De-correlation distance	50 m
UE noise figure	9 dB
UE thermal noise density	-174 dBm/Hz

TABLE VI
LIST OF THE PROTOCOL PARAMETER

Packetized CBR traffic generator	
Inter-generation time	0.02s
Packets per generation	2 or 3
Packet Size	1200 bits
Data Rate	120 kbps or 180 kbps
HARQ	
HARQ type	Chase Combining with same MCS
Round Trip Time (RTT)	4 TTIs (2ms)
Max. number of re-transmissions	3

TABLE VII
MCS SELECTION ON ONE CHUNK

Payload bits	Coding rate	Modulation scheme	SNR(dB) for targeted 10% PER
100	1/3	QPSK	8.175784e-001
150	1/2	QPSK	2.797697e+000
200	2/3	QPSK	4.882767e+000
300	1/2	16QAM	7.605835e+000
400	2/3	16QAM	1.007865e+001
500	5/6	16QAM	1.302393e+001
600	2/3	64QAM	1.492084e+001
750	5/6	64QAM	1.817362e+001
810	9/10	64QAM	1.980680e+001

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