OFDMA vs. SC-FDMA

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OFDMA VS. SC-FDMA: PERFORMANCE COMPARISON IN LOCAL AREA IMT-A SCENARIOS

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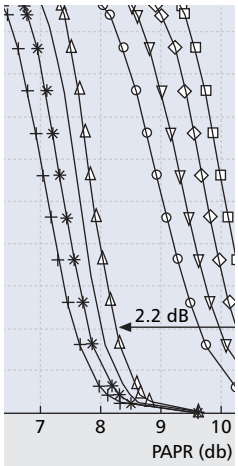

The authors discuss the suitability of using OFDMA or SC-FDMA in the uplink for local area high-data-rate scenarios by considering as target performance metrics the PAPR and the multi-user diversity gain.

ABSTRACT

The system requirements for IMT-A are currently being specified by the ITU. Target peak data rates of 1 Gb/s in local areas and 100 Mb/s in wide areas are expected to be provided by means of advanced MIMO antenna configurations and very high spectrum allocations (on the order of 100 MHz). For the downlink, OFDMA is unanimously considered the most appropriate technique for achieving high spectral efficiency. For the uplink, the LTE of the 3GPP, for example, employs SC-FDMA due to its low PAPR properties compared to OFDMA. For future IMT-A systems, the decision on the most appropriate uplink access scheme is still an open issue, as many benefits can be obtained by exploiting the flexible frequency granularity of OFDMA. In this article we discuss the suitability of using OFDMA or SC-FDMA in the uplink for local area high-data-rate scenarios by considering as target performance metrics the PAPR and multi-user diversity gain. Also, new bandwidth configurations have been proposed to cope with the 100 MHz spectrum allocation. In particular, the PAPR analysis shows that a localized (*not* distributed) allocation of the resource blocks (RBs) in the frequency domain shall be employed for SC-FDMA in order to keep its advantages over OFDMA in terms of PAPR reduction. Furthermore, from the multi-user diversity gain evaluation emerges the fact that the impact of different RB sizes and bandwidth configurations is low, given the propagation characteristics of the assumed local area environment. For full bandwidth usage, OFDMA only outperforms SC-FDMA when the number of frequency multiplexed users is low. As the spectrum load decreases, instead, OFDMA outperforms SC-FDMA also for a high number of frequency multiplexed users, due to its more flexible resource allocation. In this contex different channel-aware scheduling algorithms have been proposed due to the resource allocation differences between the two schemes.

INTRODUCTION

The International Telecommunication Union (ITU) is currently specifying the requirements for the next generation of mobile communication systems, the so-called International Mobile Telecommunications — Advanced (IMT-A). The deployment of the latter at the mass market level is expected to take place around 2015 and facilitate what has already been a buzzword for the last decade: the fourth generation (4G). IMT-A systems are expected to provide peak data rates on the order of 1 Gb/s in local areas and 100 Mb/s in wide areas [1]. In order to cope with such targets, the employment of multiple-input multiple-output (MIMO) antenna technology and very high spectrum allocations (in the range of 100 MHz) is foreseen.

The standardization of the Long Term Evolution (LTE) of Universal Terrestrial Radio Access began in the first half of 2005 and, practically, will set the main reference for next-generation systems' assumptions, LTE- Advanced (LTE-A). As a consequence, in order to achieve maximum compatibility, LTE and LTE-A should be aligned. LTE has selected orthogonal frequency-division multiple access (OFDMA) in the downlink and single-carrier frequency-division multiple access (SC-FDMA) in the uplink [2]. However, other standards, such as Worldwide Interoperability for Microwave Access (WiMAX), use OFDMA in both links, given the benefits of having the same access scheme in terms of reciprocity, allocation flexibility, and bandwidth efficiency [3]. While OFDMA is a strong candidate for IMT-A systems in the downlink, the same cannot be ensured for SC-FDMA in the uplink. Note that the influence of the scenario in which future technologies are expected to be deployed, and backwards compatibility with earlier releases, will definitely play a determinant role in the selection of the proper solution. In this article we provide a performance evaluation of both uplink candidates, OFDMA and SC-FDMA, for IMT-A systems in local area scenarios. Furthermore, in order to cope with the 100 MHz requirements, we propose new

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bandwidth configurations where the selection of the spectrum parameters will again depend on the scenario conditions.

The rest of the article is organized as follows. The next section presents the basic principles of OFDMA and SC-FDMA. The following section introduces the proposed 100 MHz bandwidth configurations, and their pros and cons are discussed in detail. We then show the peak-to-average power ratio (PAPR) analysis for the previously defined configurations, and the following section focuses on the multi-user diversity gain evaluation of both access schemes. In particular, the latter describes the channel-aware scheduling algorithms employed for OFDMA and SC-FDMA, and the semi-analytical framework used to derive the simulation results. The final section summarizes the main conclusions of this work and outlines the future directions of investigation.

OFDMA and SC-FDMA Principles

OFDMA is a multiple access scheme based on the well-known orthogonal frequency-division multiplexing (OFDM) modulation technique. Its main principle is to split the data stream to be transmitted onto a high number of narrowband orthogonal subcarriers by means of an inverse fast Fourier transform (IFFT) operation, which allows for an increased symbol period. The latter, together with the use of a guard interval appended at the beginning of each OFDM symbol, provides this technology great robustness against multipath transmission [4]. A realization of this guard interval is the so-called cyclic prefix (CP), which consists of a repetition of the last part of an OFDM symbol. As long as the CP is longer than the maximum excess delay of the channel, degradations due to intersymbol interference (ISI) and intercarrier interference (ICI) are avoided. Furthermore, the goal of employing narrowband subcarriers is to obtain a channel that is roughly constant over each given subband, which makes equalization much simpler at the receiver. Finally, since these subcarriers are mutually orthogonal, overlapping between them is allowed, yielding a highly spectral efficient system. Despite all these benefits, OFDM also presents some drawbacks: sensitivity to Doppler shift, synchronization problems, and inefficient power consumption due to high PAPR [4].

SC-FDMA is a multiple access scheme based on the single-carrier frequency-division multiplexing (SC-FDM) modulation technique, sometimes also referred to as discrete Fourier transform (DFT)-spread OFDM. Its main principle is the same as for OFDM; thus, the same benefits in terms of multipath mitigation and low-complexity equalization are achievable [5]. The difference though is that a DFT is performed prior to the IFFT operation, which spreads the data symbols over all the subcarriers carrying information and produces a virtual single-carrier structure. As a consequence, SC-FDM presents a lower PAPR than OFDM [6]. This property makes SC-FDM attractive for uplink transmissions, as the user equipment (UE) benefits in terms of transmitted power efficiency. On one hand, DFT spreading allows the frequency selectivity of the channel to be exploited, since all symbols are present in all subcarriers. Therefore, if some subcarriers are in deep fade, the information can still be recovered from other subcarriers experiencing better channel conditions. On the other hand, when DFT despreading is performed at the receiver, the noise is spread over all the subcarriers and generates an effect called noise enhancement, which degrades the SC-FDM performance and requires the use of a more complex equalization based on a minimum mean square error (MMSE) receiver [5].

	20 MHz	100 MHz			
Δf(kHz)	15	15	30	60	120
N_{FFT}	2048	8192	4096	2048	1024
N_c	1200	6000	3000	1500	750
F_0 (MHz)	30.72	122.88	122.88	122.88	122.88
T_S (μs)	66.67	66.67	33.33	16.67	8.33
T_{slot} (ms)	0.5	0.5	0.5	0.5	0.5
Symbols per slot	7	7	14	28	56
CP (μs/samples)	5.2/160[1] 4.68/144[2]	5.2/640 4.68/576	2.6/320 2.34/288	1.3/160 1.17/144	0.65/80 0.58/72

[1] First OFDM/SC-FDM symbol in a slot.
[2] 2nd–7th OFDM/SC-FDM symbol in a slot.

Table 1. *100 MHz bandwidth configurations.*

100 MHz Bandwidth Configurations

In order to satisfy the 100 MHz spectrum requirements for IMT-A systems, we propose new definitions of bandwidth allocation (Table 1), where the 20 MHz LTE case is taken as a reference [7] so that the new system solutions appear as its natural evolution. As there are strong dependencies among configuration parameters, let us briefly introduce some of the latter as follows:

- *Subcarrier spacing* (Δf): spectrum offset between adjacent subcarriers.
- *FFT size* (N_{FFT}): total number of orthogonal subcarriers in the system; for computational efficiency reasons, this value must be power of 2 [8].
- *Number of used subcarriers* (N_c): in a real system, due to some spectral constraints such as bandwidth allocation and spectral mask, not all the subcarriers are employed. This reduced number of tones together with the subcarrier spacing defines the useful transmission bandwidth.
- *Sampling frequency* (F_0): minimum time resolution the receiver must adopt in sampling the received signal in order to correctly reconstruct it; practically, $F_0 = N_{FFT} \times \Delta f$.

- *Useful symbol duration* (T_s):inverse of the subcarrier spacing.
- *Cyclic prefix* (CP): guard interval appended at the beginning of each OFDM/SC-FDM symbol to avoid degradations due to ISI and ICI.

As the subcarrier spacing increases, the useful symbol duration is reduced; therefore, in order to keep low spectral efficiency loss, the CP should be proportionally decreased. However, this could lead to ISI and ICI for long channel impulse response environments. On the other hand, reducing the symbol duration provides higher robustness against Doppler shift [9] and yields a loss in frequency-domain granularity, which is instead important for scheduling purposes. In order to keep contiguity with LTE, its slot duration (T_{slot} = 0.5 ms) is preserved. This leads to different numbers of transmitted OFDM/SC-FDM symbols within a slot according to the chosen configuration. Moreover, the long CP defined in Table 2 shall be employed each 7 symbols in order to keep the desired slot duration. Regarding complexity, it can be seen that when the subcarrier spacing decreases, the FFT size increases, thus bringing higher computational complexity and thereby higher power consumption at the UE. Finally, it has to be pointed out that in all cases the sampling frequency is increased four times with respect to the LTE value.

If we now consider the local area scenario, which is within the scope of this article, some of the above-mentioned constraints can be relaxed. For example, the subcarrier spacing can be increased up to 120 kHz without ISI and ICI degradations, as the CP is long enough to cover for the arrival of all the multipath components.[1] Therefore, lower values of FFT size can be also employed, thus reducing the complexity of the system. However, the impact of this large subcarrier spacing on the frequency granularity should be further analyzed in terms of scheduling.

Parameter	Value
Cell radius	30 m
Minimum BS-UE distance	3 m
Carrier frequency	3.5 GHz
Antenna scheme	SISO, SIMO (1x2)
Number of users	1-20
UE speed	3 km/h
Simulated slots	2000
Maximum transmitted power per user	24 dBm
Power control	no
Noise power	–160 dBm/Hz
Channel model	A1NLOS [10]
PathLoss and shadowing models	from Winner II project [10]
Access schemes	OFDMA, SC-FDMA
Power backoff for OFDM	3.5 dB
Power backoff for SC-FDM	2 dB
Scheduling metric	PF
Scheduling algorithm for OFDMA	Greedy
Scheduling algorithm for SC-FDMA	RME

Table 2. *Simulation parameters and models.*

PAPR Evaluation

Despite its wide acceptance, OFDM exhibits large envelope variations of the transmitted signal. This is due to the transmission of data over parallel subcarriers, which could constructively add in phase and yield high instantaneous peak power compared to its average. Signals with high PAPR require highly linear power amplifiers in order to avoid excessive intermodulation distortion. Therefore, the amplifier must operate with a large backoff from its peak value. This leads to low power efficiency, which is measured as the ratio of the transmitted power over the *dc* dissipated power. High PAPR is particularly critical for uplink transmissions, given the power constraints at the UE. As pointed out previously, the low PAPR properties of the SC-FDM signal make it a very attractive solution for the uplink. In this section we carry out a PAPR evaluation for OFDM and SC-FDM with the proposed 100 MHz bandwidth configurations, where results are obtained by means of Monte Carlo simulations, assuming 16-quadrature amplitude modulation (QAM).

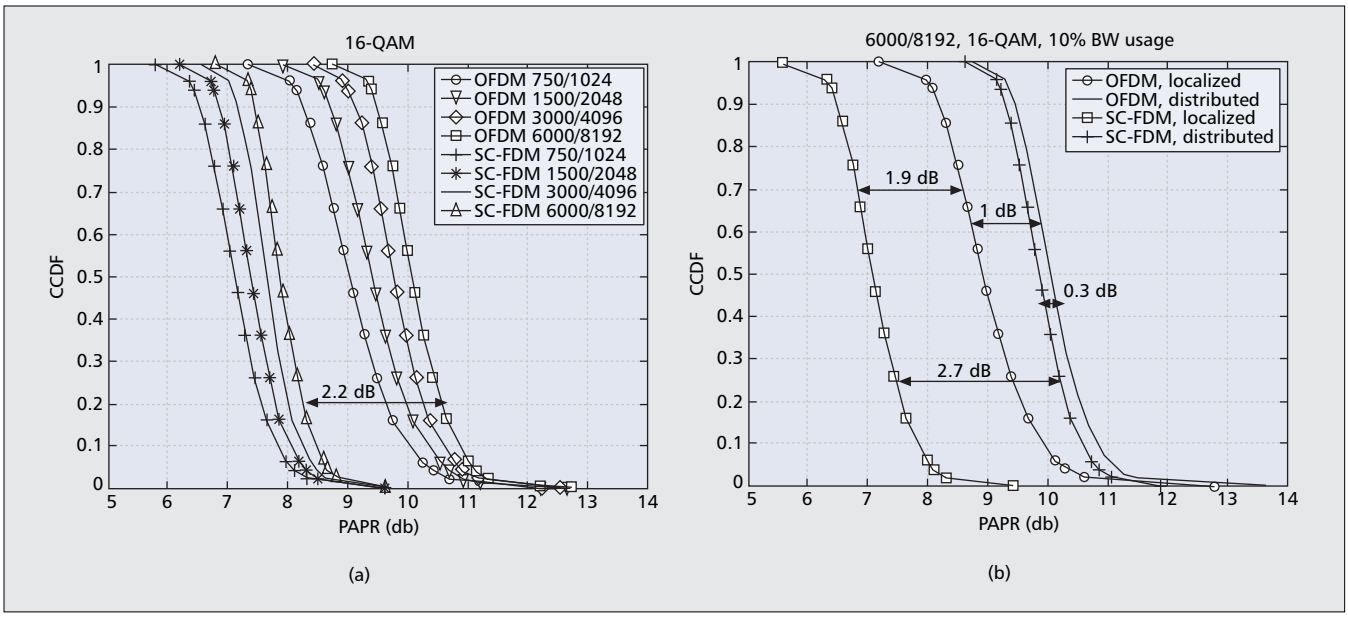
From the cumulative complementary distribution functions (CCDFs) in Fig. 1a, we observe that the PAPR of the transmitted user signal is strictly dependent on the number of subcarriers. In particular, the configuration with the lowest number of subcarriers (750/1024) provides the best results (i.e., the lowest PAPR values) for both OFDM and SC-FDM. Note that for all the configurations, the PAPR gain of SC-FDM over OFDM is approximately 2.2 dB.

In a multi-user scenario the available bandwidth is divided in basic units called resource blocks (RBs), which are shared among users. As a consequence, it is also important to consider the case of partial bandwidth usage for each user in our evaluation. In particular, we decided to adopt two resource allocation strategies:

- Localized: All the RBs are allocated to the user in a contiguous manner.

[1] *The maximum delay spread of the local area indoor channel that we consider is 175 ns [10].*

[2] *We refer to distributed allocation at the RB level rather than at the subcarrier level [6]. The latter has not been considered because of its high sensitivity to the frequency offset between different types of UE [11].*



■ **Figure 1.** *CCDF of PAPR for: a) 100 MHz bandwidth configurations; b) localized vs. distributed allocation.*

- Distributed: All the RBs allocated to the user are randomly distributed over the whole bandwidth.[2]

In Fig. 1b performance results are obtained for the (6000/8192) configuration, considering 10 percent bandwidth usage (i.e., 600 assigned subcarriers). The RB size is fixed to 15 subcarriers, which means that a total of 40 RBs are assigned to the user of the 400 available. Despite its low PAPR benefit, we observe that SC-FDM is much more sensitive to resource allocation than OFDM. For localized allocation, the PAPR gain of SC-FDM over OFDM is almost 2 dB. Nevertheless, we found out that this gain is dramatically reduced for distributed allocation (0.3 dB). Therefore, if the RBs are randomly distributed along the bandwidth, the main selling point of SC-FDM with respect to OFDM falls. Hence, in order to keep its low PAPR properties, localized allocation of the RBs shall be considered for SC-FDM. This result is indeed remarkable, although it imposes a constraint on the scheduling design. Finally, note that for OFDMA the increase of PAPR when passing from localized to distributed allocation is approximately1 dB, while for SC-FDMA it is 2.7 dB.

Multi-User Diversity Gain

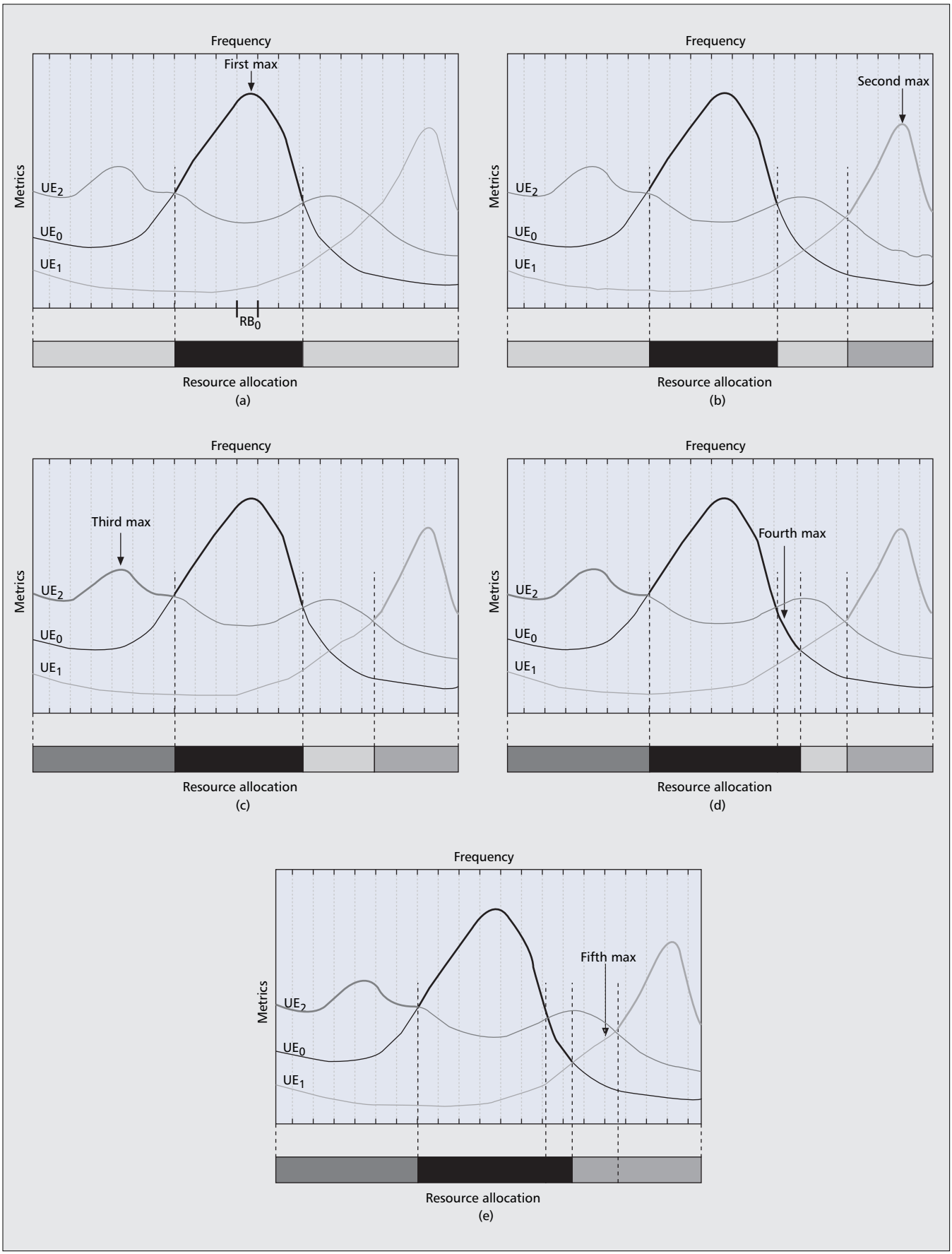
In a multi-user scenario the available bandwidth must be shared among several users. Each user may experience different conditions in terms of velocity, path loss, and shadowing. Furthermore, each may have different requirements in terms of quality of service. A smart design of the network should therefore take into account the different user conditions while providing fairness, without a drastic reduction in the overall cell throughput. A higher spectral efficiency is actually the main goal of all radio interface design. In an adaptive OFDMA-based system the cell spectral efficiency can be increased as the number of users is. This effect is called multi-user diversity gain [12], and it is mainly due to:

- The increase of the total received power at the base station (BS) with the number of users.
- The possibility of assigning orthogonal time-frequency resources to the user who can utilize them best. This is quite different from the present systems based on code-division multiple access, in which the nature of imperfect resource orthogonality leads to a reduction of the cell throughput as the number of users increases [13].

The multi-user diversity gain of OFDMA-based systems can be exploited by adopting channel-aware schedulers, where the main idea is to allocate the RBs to users experiencing better channel conditions in those frequency slots. In this way the overall cell throughput is increased with the number of users, given the availability of many different channel conditions that can be considered for the best bandwidth allocation search. Therefore, an analysis of the multi-user diversity gain should be focused on channel-aware scheduling algorithms as well as the behavior of the selected multiple access schemes in a multi-user environment. Different scheduling algorithms have therefore been considered for OFDMA and SC-FDMA, as the latter presents the constraint of localized allocation (see the previous section). Our effort has been particularly focused on the development of a novel channel-aware scheduling algorithm for SC-FDMA (discussed below). Note that the performance evaluation of OFDMA and SC-FDMA in a multi-user scenario has been investigated adopting a semi-analytical approach, which is described later.

Channel-Aware Scheduling Algorithms

OFDMA — This allows high freedom in resource allocation because no constraint on the contiguousness of the RBs is generally assumed. The optimal scheduling is based on a combinatorial



■ **Figure 2.** *Example of resource allocation by the RME algorithm.*

comparison of all the possible allocations of RBs. Nevertheless, this solution is intractable because of its high computational expense. In our investigation the well-known greedy algorithm has been considered [14]. Practically, the latter allocates the resources to the user that maximizes the marginal scheduling metric gain in each RB, and it is expected to represent a suboptimal solution.

SC-FDMA — It requires localized allocation of the RBs in order to exploit its PAPR benefits over OFDMA; this, on the other hand, reduces the resource allocation flexibility and thus rises a challenge in the scheduling design. As in the OFDMA case, the optimal solution is inapplicable. In this section we propose a relatively low-complexity channel-aware scheduling algorithm for SC-FDMA, which is based on a recursive expansion of the bandwidth to allocate to each user by starting from the maximum value of the scheduling metric. Considering as an input the matrix M, whose dimension is [*number_of_users*, *number_of_RBs*] and whose values represent all the user metrics for each RB, the steps of the proposed recursive maximum expansion (RME) algorithm are the following:

Step 1: Select the combination UE-RB with the highest metric value (UE_0–RB_0 in Fig. 2a).

Step 2: Assign RB_0 to UE_0.

Step 3: Expand the allocation in step 2 for UE_0 on both the right and left sides of M until another UE with a better metric is found(UE_1 in Fig. 2a).

Step 4: Put UE_0 in idle mode.

Step 5: Repeat steps 1–4 by searching for the maximum among the non-idled UEs (Fig. 2b–2c). Stop when all the UEs are idled or all RBs have been allocated.

Step 6: If not all RBs have been allocated, search for the UE with the maximum value of the metric among the remaining RBs.

Step 7: Check if one of the adjacent already assigned RBs belongs to the same UE found in step 6.

Step 8: If the UE is not the same, delete this maximum from M and repeat step 6.
Otherwise, expand its allocation on both the right and left sides of M until contiguousness with the previous allocation is achieved on one side. Stop to expand on the other side whenever another (idled) UE with a higher metric value is found (Fig. 2d).

Step 9: Repeat steps 6–8 until all RBs are allocated (Fig. 2e).

Semi-Analytical Approach

Given the different nature of their signal generation as well as the different constraints in terms of resource allocation, OFDMA and SC-FDMA are expected to behave distinctly in a multi-user scenario. An evaluation of both access schemes' performance can be done by focusing on their analytical behaviors or by means of system-level simulations. A fully analytical approach becomes intractable, though, if rigorously applied to a realistic scenario. As a consequence, in order to give our investigation a certain degree of generality and, at the same time, keep it easily manageable, we opted for a trade-off between the two approaches. The evaluation has therefore been carried out following a semi-analytical approach. First, we simulate the scenario (i.e., generate user locations, fast fading channels, shadowing, path loss, etc.). Then, based on the latter, we employ the scheduling algorithms described previously. Once the resource allocation is performed, the signal-to-noise ratio experienced by each user in the assigned resources is used in the analytical expressions below in order to calculate the optimal spectral efficiency. In this way we retrieve an upper bound that can give useful insights on the performance of the two schemes. All pieces of UE are assumed to transmit at the same power P_{max}, where the transmitted power per subcarrier of user ($P_k^{(sub)}$) depends on the number of frequency resources allocated to him. For OFDMA, the data symbols are directly k mapped over the subcarriers. Therefore, the upper spectral efficiency of user k is simply obtained by summing up the upper spectral efficiency values over the subcarriers within each RB assigned to that user, which is given by

$$S_{OFDMA,k}(P_{\max}, I_{RB,k}) = \frac{1}{N_{RB}} \sum_{i \in I_{sub,k}} \frac{1}{N_{sub,RB}} \sum_{j \in N_{sub,RB}} \log_2\left[1+\gamma_{(i-1)N_{sub,RB}+j,k}\right], \quad (1)$$

where $N_{sub,RB}$ is the number of subcarriers per RB, $I_{RB,k}$ is the set of RBs assigned to user k, N_{RB} is the total number of RBs, and the signal-to-noise ratio per subcarrier is defined as

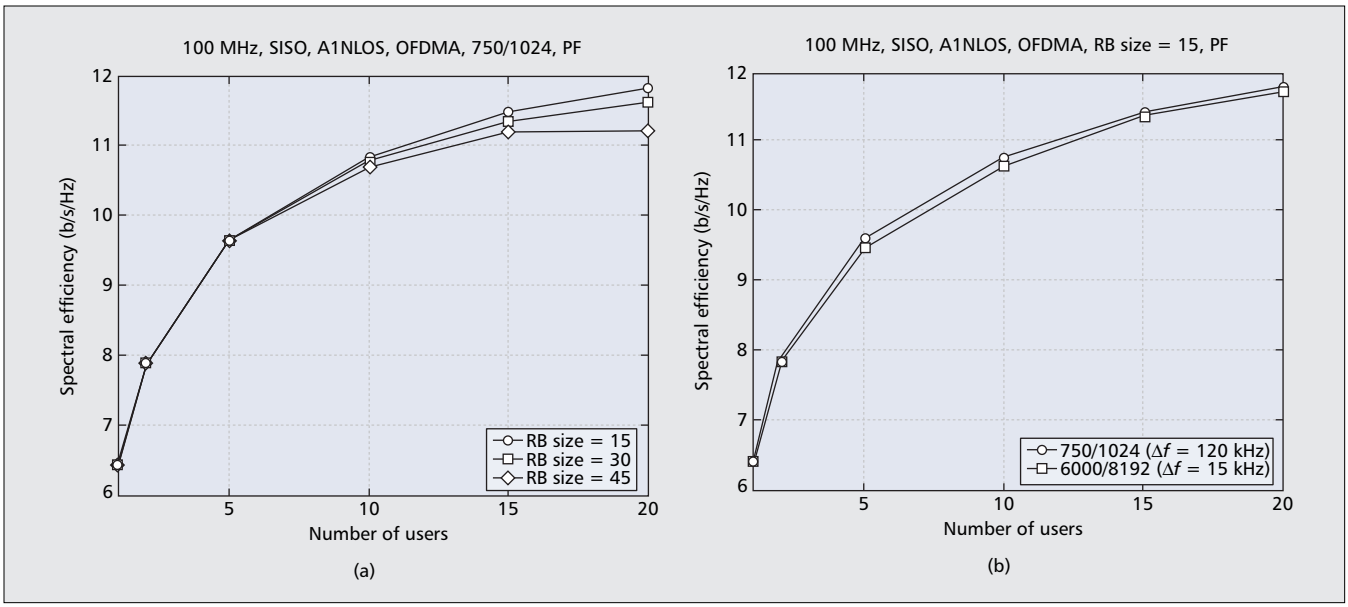
$$\gamma_{i,k} = \frac{P_k^{(sub)} \left|H_{i,k}\right|^2}{L_{loss,k}\left(\sigma_n^2 \Delta f\right)}, \quad (2)$$

where $|H_{i,k}|2$ is the channel gain of subcarrier i for user k; $L_{loss,k}$ is the path loss and shadowing term of user k; σ_n^2 is the noise power per Hertz; and Δf is the subcarrier spacing in Hertz. In SC-FDMA, the data detection is performed after an inverse DFT operation. Therefore, the upper data rate of a certain UE cannot be expressed as a linear sum of the upper data rates over all the allocated RBs. The upper spectral efficiency of user k can be then written as [15]

$$S_{SC-FDMSA,k}(P_{\max}, I_{RB,k}) = \frac{\left|I_{RB,k}\right|}{N_{RB}} \log_2 \left[1+\left(\frac{1}{\frac{1}{\left|I_{sub,k}\right|}\sum_{i \in I_{sub,k}} \frac{\gamma_{i,k}}{\gamma_{i,k}+1(\ )}} - 1\right)^{-1}\right], \quad (3)$$

[3] *Equations 1 and 3 have been obtained hypothesizing that the length of the CP is greater than the length of the discrete-time baseband channel impulse response so that ISI and ICI are avoided. In the local area scenario this is consistent with all the proposed bandwidth configurations.*

Given the different nature of their signal generation as well as the different constraints in terms of resource allocation, OFDMA and SC-FDMA are expected to behave distinctly in a multi-user scenario.



■ **Figure 3.** *OFDMA spectral efficiency results for: a) different RB sizes; b) different subcarrier spacing.*

where $|I_{RB,k}|$ is the number of RBs assigned to user k and $|I_{sub,k}|$ is the total number of subcarriers of user k[3] each RB. By means of these values, the scheduling metrics are calculated according to the proportional fair (PF) criterion [16], which are then exploited by the algorithms in the previous section, Finally, Eqs. 1 and 3 are used in the final upper spectral efficiency computation for each UE given its assigned set of RBs.

Simulation Results

Table 2 shows the main parameters of the MATLAB simulator, which has been developed according to the previous semi-analytical approach. The scenario we have investigated is an isolated cell with no surrounding interferer cells, where propagation and channel models are taken from [10]. Both single and multiple receiving antenna configurations have been considered. In particular, the simulator generates a predefined number of users and uniformly distributes them within the cell. The average spectral efficiency is obtained after a simulation time equal to 2000 slots.

In Fig. 3a the maximum achievable spectral efficiency of OFDMA is shown as a function of the number of users in the cell and for different RB sizes (number of subcarriers within an RB), where the (750/1024) configuration and one receiving antenna have been considered. As a general trend, we observe that the spectral efficiency increases with the number of users, due to the multi-user diversity gain property of OFDMA-based systems. For a few users in the system (up to 10), no relevant difference between the RB sizes is appreciable. As the number of users increases, the scheme with lower RB size leads to better performance; this is due to the finer granularity in resource allocation. Nevertheless, the gap between the configurations is still small. In Fig. 3b the comparison between different bandwidth configurations is presented. The spectral efficiency curves appear almost overlapped; therefore, the throughput performance in a local area scenario can be considered independent of the selected bandwidth configuration. This consequently allows the choice of the proper bandwidth configuration to be relaxed, making it only dependent on hardware/computational complexity considerations. Similar trends have been observed for SC-FDMA; therefore, the same conclusions can be drawn for it.

In Fig. 4 the comparison between OFDMA and SC-FDMA is shown for the (750/1024) configuration and two-receiving-antennas system. In order to guarantee amplifier linearity and thereby avoid intermodulation distortion, different power backoff values, derived from cubic metric values adopted by the 3GPP for power derating computation [17], are considered in the transmitter for both OFDMA and SC-FDMA. Note that the power backoff value for OFDM is higher than that for SC-FDM because of its inherent higher PAPR. Results for different traffic load conditions are presented. In a fully loaded scenario (100 percent of bandwidth usage), SC-FDMA performs worse than OFDMA for few users in the system. The higher transmitted power does not allow the lower scheduling flexibility to be fully compensated for. For a number of users higher than 12, SC-FDMA achieves higher upper spectral efficiency. A high number of users in the system leads to few resources allocated to each of them; therefore, the lower scheduling flexibility is not so critical. Note that these results are dependent on the chosen scheduling algorithms, which are suboptimal, as outlined previously. Let us examine the case of few users in the system (up to 5). As the bandwidth usage decreases to 75 percent, the performance of SC-FDMA and OFDMA get closer. This gap is further reduced for 25 percent bandwidth usage. Low traffic load in the system enhances the freedom in SC-FDMA resource allocation, making it similar to OFDMA. On the other hand, for a high number of users (e.g., 20), the gap between SC-FDMA and OFDMA is

slightly reduced when passing to 75 percent bandwidth usage. For very low bandwidth usage (25 percent), OFDMA always performs better than SC-FDMA, and their gap tends to increase with the number of users.

Conclusions and Future Work

The definition of the system requirements for the upcoming IMT-A is currently under discussion in ITU — Radiocommunication Standardization Sector (ITU-R) Working Party 5D. Solutions should properly weigh flexibility and efficiency in order to realistically cope with the data rate targets of 1 Gb/s in local areas and 100 Mb/s in wide areas. Such targets can be reached by a combination of very wide spectrum allocation (i.e., on the order of 100 MHz) combined with high peak spectral efficiency by using multiple antennas. In this article we have analyzed 100 MHz bandwidth configurations for the uplink of local area IMT-A. The study has been carried out by varying the subcarrier spacing and keeping the slot duration as in the 3GPP LTE Release 8 specifications (i.e., varying the number of symbols within a slot). Within this framework, the performance of OFDMA and SC-FDMA, as strong access scheme candidates for the uplink, have been evaluated and compared in terms of PAPR and multi-user diversity gain.

The PAPR analysis has shown a dependence on the number of subcarriers. In particular, in order to preserve a low PAPR, bandwidth configurations with a low number of subcarriers are preferable. Furthermore, we found out that only localized allocation of RBs shall be considered in order to keep the PAPR benefits of the SC-FDM signal. However, this leads to a constraint on the flexibility of resource allocation in a multi-user scenario. As a consequence, we have proposed a new channel-aware scheduling algorithm for SC-FDMA, which combines suboptimal performance with low implementation and computational complexity. However, note that the focus of this article was not to compare several scheduling algorithms for SC-FDMA, but just to propose and utilize a solution that would cope with the aforementioned issue.

The cell spectral efficiency performance has been evaluated for a local area scenario, with low user mobility (3 km/h) and a PF metric for scheduling. Despite its higher transmitted power due to lower power backoff, SC-FDMA performs slightly worse than OFDMA for the case with a low number of frequency multiplexed users. In a partial loaded scenario, OFDMA always performs slightly better than SC-FDMA even for a high number of users. Furthermore, no significant differences have been observed for different bandwidth configurations or different RB sizes. This is a consequence of the selected scenario in which the wide coherence bandwidth reduces the sensitivity to different configuration parameters. To sum up, the following main conclusions can be derived:

- Bandwidth configurations with a low number of subcarriers (e.g., 750/1024) can be considered in a local area IMT-A scenario if no backward compatibility issues are required. Their short CP length still allows ISI and ICI to be avoided due to the low delay spread of the indoor office channel. Furthermore, using a low number of subcarriers is advantageous in terms of PAPR. Finally, the granularity reduction due to the larger subcarrier spacing does not lead to worse performance in terms of aggregate throughput in a multi-user scenario with a PF scheduling metric.
- The sensitivity of the aggregate throughput to RB size in the range of 15–45 subcarriers is negligible, especially for few users. Considering the benefits in terms of signaling overhead reduction of a large resource unit, an RB length of 45 subcarriers could therefore be considered without degrading the performance up to 10 users.
- The cell throughput difference between OFDMA and SC-FDMA is related to the traffic load in the system. In a fully loaded scenario OFDMA performs slightly better than SC-FDMA for a low number of frequency- multiplexed users and slightly worse for a large number of multiplexed users. Reducing the traffic load in the cell, and therefore the bandwidth usage, OFDMA tends to slightly outperform SC-FDM regardless of the number of users, even considering the increased power backoff penalty of OFDMA. Future work will be focused on the development of smarter scheduling algorithms for SC-FDMA, allowing its performance to be leveraged without dramatically increasing the computational complexity, as well as an evaluation of the behavior of both access schemes in a multi-cell scenario, where issues related to intercell interference and intercell synchronization losses will be investigated.

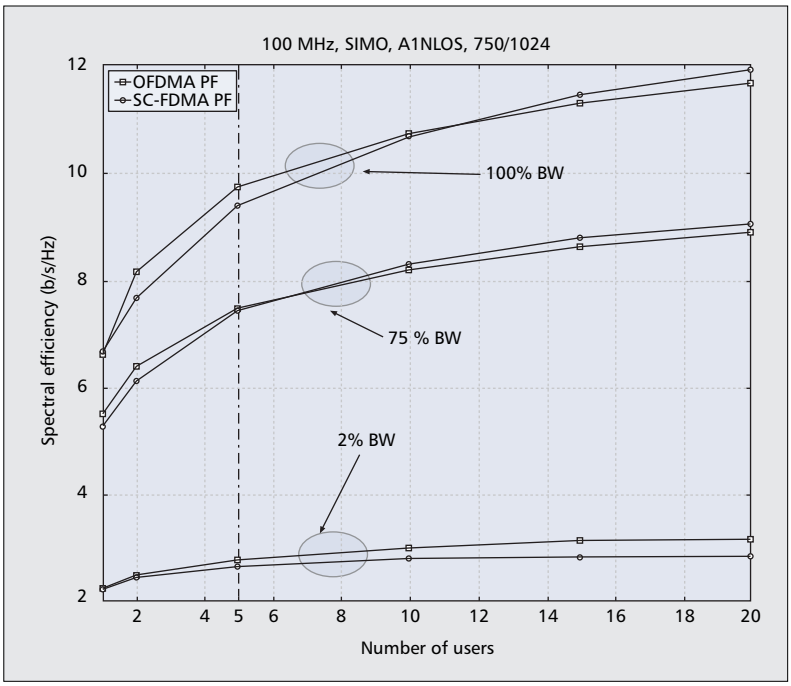


Figure 4. *Performance comparison between OFDMA and SC-FDMA for a two-receiving-antenna system.*

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