OFDMA vs. SC-FDMA
Berardinelli, Gilberto; Maestro, Luis Angel; Frattasi, Simone; Rahman, Muhammad Imadur; Mogensen, Preben Elgaard

Published in:
IEEE Wireless Communications

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
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 multi-user diversity gain. This article provides a performance evaluation of both uplink candidates, OFDMA and SC-FDMA, for IMT-A systems in local area scenarios. Furthermore, 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 context different channel-aware scheduling algorithms have been proposed due to the resource allocation differences between the two schemes.
OFDM 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 results in 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 with 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, as 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 a higher peak-to-average power ratio (PAPR) than OFDM [6]. This is also referred to as discrete Fourier transform (DFT) spread, which results in high PAPR, making SC-FDM less attractive than OFDM for uplink applications.

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]. The new system solutions, 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.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>20 MHz</th>
<th>100 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δf (Hz)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>NFFT</td>
<td>2048</td>
<td>8192</td>
</tr>
<tr>
<td>N_c</td>
<td>1200</td>
<td>6000</td>
</tr>
<tr>
<td>F_0 (MHz)</td>
<td>30.72</td>
<td>122.88</td>
</tr>
<tr>
<td>T_s (µs)</td>
<td>66.67</td>
<td>66.67</td>
</tr>
<tr>
<td>T_slot (ms)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Symbols per slot</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>CP (µs/samples)</td>
<td>5.2/160</td>
<td>4.68/144</td>
</tr>
</tbody>
</table>

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.

Authorized licensed use limited to: Aalborg Universitetsbibliotek. Downloaded on January 15, 2010 at 07:38 from IEEE Xplore. Restrictions apply.
• **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. 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.

### 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 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.
- **Distributed:** Resource allocation is performed independently on each RB.

In this way we observe that a distributed allocation results in higher PAPR for both OFDM and SC-FDM. This is due to the non-contiguous nature of the transmission, which leads to a higher number of subcarriers outside the bandwidth of interest, thus resulting in a higher peak-to-average ratio (PAR).

In order to mitigate this effect, we have considered two different scheduling algorithms:

- **Greedy:** Users are scheduled in decreasing order of their outage probability.
- **RME:** Users are scheduled in decreasing order of their residual mean error (RME).

![Table 2. Simulation parameters and models.](image-url)

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

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].
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 approximately 1 dB, while for SC-FDM 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.
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 $[\text{number of users}, \text{number of RBs}]$ 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 ($UE_0$) in Fig. 2a.

**Step 2:** Assign RB0 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-allocated UEs (Fig. 2b–2c). Stop when all the UEs 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 $P_{\text{max}}$, where the transmitted power per subcarrier of user ($P_k$) 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

$$S_{\text{OFDMA},k}(P_{\text{max}}, I_{RB,k}) = \frac{1}{N_{RB}} \sum_{i} \frac{1}{N_{sub,RB}} \log_2 \left( 1 + \frac{P_k}{\sigma_n^2 + \Delta f L_{\text{loss},R} H_{ik}^2} \right)$$

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

$$\gamma_k = \frac{P_k}{\sigma_n^2 + \Delta f L_{\text{loss},R} H_{ik}^2},$$

where $|H_{ik}|^2$ is the channel gain of subcarrier $i$ for user $k$; $L_{\text{loss},R}$ is the path loss and shadowing term of user $k$; $\sigma_n^2$ is the noise power per Hertz; and $\Delta f$ 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

$$S_{\text{SC-FDMA},k}(P_{\text{max}}, I_{RB,k}) = \frac{1}{N_{RB}} \sum_{i} \frac{1}{N_{sub,RB}} \log_2 \left( 1 + \frac{1}{\Delta f L_{\text{loss},R} H_{ik}^2} \right)$$

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.
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 \(k\) in 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. In particular, users. In a partially loaded scenario, OFDMA outperforms SC-FDMA for the case with a low 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 inter-cell interference and intercell synchronization losses will be investigated.

**Acknowledgments**

This work has been supported by Nokia Siemens Network (NSN).
REFERENCES


BIographies

GILBERTO BERARDINELLI (gb@es.aau.dk) received his first and second level degrees in telecommunication engineering, cum laude, from the University of L’Aquila, Italy, in 2003 and 2005, respectively. He also received a second level master degree in techniques and economics of telecommunications in 2006 from the University of Padova, Italy. In 2006 he worked with the Radio Frequency Engineering Department of Vodafone NV, Padova, Italy, where he studied the issues related to coverage of HSDPA services, and also radio propagation in urban and suburban environments. Since 2007 he has been employed as a research assistant in the Radio Access Technology Section of Aalborg University, where he is head of the RATE section. He is internationally recognized for his research in mobile communication systems and has more than 130 internationally published and refereed papers; technical reports; and patent appli-cations. He has served as a reviewer for several journals, magazines and international conferences, and as a Guest Editor for Springer, Wireless Personal Communications Journal; IEEE, Technology & Society Magazine; Wiley, Wireless Communications and Mobile Computing Journal; and Academy Publishers, Journal of Communications. He was the main instructor for two half-day tutorials on wireless location at IEEE PIMRC ‘07 and IADIS WAC’07. He was General Chairman of the First International Workshop on Cognitive Radio and Advanced Spectrum Management (CERT 2007) in June 2007, and his M.Sc. degree cum laude and B.Sc. degree in telecommunications engineering from “Tor Vergata” University, Rome, Italy, in 2002 and 2001, respectively. From 2002 to 2005 he was employed as a research assistant at Aalborg University, where he worked on two European projects (STRIKE and VeRT) and one industry project (JADE) in collaboration with the Global Standards & Research Team, Samsung Electronics Co. Ltd., Korea. Since 2005 he has been an assistant professor, where, besides still contributing to the JADE project, he has been leading a Danish-funded project (COMET). In November 2007 he joined the Radio Access Technology Section (RATE), where he is currently project leader of an industri-al project (LA-TDD) in collaboration with Nokia Siemens Networks, Aalborg, Denmark. He is author/co-author of around 50 papers published in journals, magazines, and proceedings of international conferences; book chapters; encyclopedia papers; technical reports; and patent appli-cations. He has a number of courses related to wireless networks, link layer techniques, wireless location, quality of service mechanisms, next-generation wireless services and architectures, user perspectives, and socio-logical dimensions related to the evolution of technology and society.

MUHAMMAD IMADUR RAHMAN (imr@es.aau.dk) He received his Ph.D., M.Sc., and B.Eng. degrees in 2007, 2003, and 2000 respectively from Aalborg University, Helsinki University of Technology, Finland, and Multimedia University, Malaysia, respectively. Since January 2008 he has been working as a research engineer in the Access Technologies and Signal Processing Department of Ericsson Research, Kista, Swe-den. He is primarily involved in 3GPP standardization research on PHY and MAC layer issues. Prior to that he was an assistant professor at Aalborg University in 2007, when he also managed a project, Local Area TDD Solutions for Future Gigabps Wireless Systems, funded by Nokia Siemens Network and Danish Research Council. At Aalborg University he taught a number of courses related to wireless communications, and supervised many M.Sc. and two Ph.D. students. He has published a number of papers in interna-tional journals and conferences. He is an active IEEE volun-teer, and has led many projects in student and recent graduates activities for the IEEE Denmark section. Currently he is involved in THE IEEE Sweden section. He was one of the initiators and first General Chair of the Aalborg Univer-sity IEEE Student Paper Conference in 2007. His main research interests include radio access techniques, signal processing, radio resource management, and future cognitive networks.

PREFERE MOGENSEN (pm@es.aau.dk) received M.Sc.E.E. and Ph.D. degrees from Aalborg University, Denmark, in 1988 and 1996, respectively. He is currently a professor at Aalborg University, where he is head of the RATE section. He is internationally recognized for his research in mobile communication systems and has more than 130 interna-tional publications. He has successfully completed 14 successfully completed Ph.D. projects. Since 1995 he has also worked part time with Nokia and later on with Nokia Siemens Net-works, working on LTE and IMT-Advanced related projects.