

Uplink and Downlink of LTE-Release 10 in Cellular Communications

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ABSTRACT

In LTE-Advanced, orthogonal frequency division multiple access (OFDMA) has been selected as the multiple access scheme for downlink and single-carrier frequency division multiple access (SC-FDMA) for uplink. OFDM is an attractive modulation technique in a cellular environment to combat frequency selective fading channels with a relatively low- complexity receiver. However, OFDM requires an expensive and inherently inefficient power amplifier in the transmitter due to the high peak-to-average power ratio (PAPR) of the multicarrier signal. This paper, presents the main components of LTE-Advanced including the all the details of Uplink (SC-FDMA) and Downlink (OFDMA). Also this paper clarifies the main reasons of using SC-FDMA in uplink and using OFDMA in downlink only, in order to obtain flexible mobile communication technology.

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1. INTRODUCTION

The LTE-A downlink transmission scheme is based on orthogonal frequency division multiple access (OFDMA), which is a multiuser version of the OFDM modulation scheme. In the uplink, single carrier frequency division multiple access (SC-FDMA) is used, which can be also viewed as a linearly pre-coded OFDM scheme known as discrete Fourier transform (DFT)-spread OFDM.

However, SC-FDMA has been selected for the uplink due to the lower peak-to-average power ratio (PAPR) of the transmitted signal compared to OFDM. Low PAPR values benefit the terminal in terms of transmit power efficiency, which also translates into increased coverage. The processing sequence in the signal generation process is quite similar in downlink and uplink, the main difference comes from the elimination of the antenna mapping process and the addition of a DFT-spread block, which is the key process for the PAPR reduction [1].

OFDMA and SC-FDMA are the multiple-access versions of OFDM and a similar modulation scheme, Single-Carrier Frequency-Domain Equalization (SC-FDE). In order to compare the differences between the multiple-access methods, it is important to first cover the differences between their underlying modulation schemes. Section 2 of this paper discusses the current development of LTE-Advanced and the limited research directions related to the development of communication systems, while section 3 describes Long Term Evolution-Advanced downlink which is represent OFDMA. Long Term Evolution-Advanced Uplink is included in section 4 with the block diagram for SC-FDMA. Section 5 explains the downlink data transmission for OFDMA and in section 6 uplink data transmission LTE-Advanced technologies are considered. Section 7 and 8 contain the capacity of OFDMA and SC-FDMA respectively .While section 9 contains the summary and discussions of the main points for this paper which can be consider for reader to

understand the current development for performance of Uplink and Downlink in wireless communication technology. Finally, section 10 concludes some general observations and recommendations for this paper.

2. LONG TERM EVOLUTION-ADVANCED (LTE-A)

The 3GPP Technical Report (TR) 36.913 [2] details the requirements for LTE-Advanced to satisfy. The document stressed backward compatibility with LTE in targeting IMT-Advanced. It does, however, also indicate that support for non-backward compatible entities will be made if substantial gains can be achieved. Minimizing complexity and cost and enhanced service delivery are strongly emphasized [3].

The objective of reduced complexity is an involved one, but it includes minimizing system complexity in order to stabilize the system and inter-operability in earlier stages and decreases the cost of terminal and core network elements. For these requirements, the standard will seek to minimize the number of deployment options, abandon redundant mandatory features and reduce the number of necessary test cases. The latter can be a result of reducing the number of states of protocols, minimizing the number of procedures, and offering appropriate parameter range and granularity. Similarly, a low operational complexity of the UE can be achieved through supporting different RIT, minimizing mandatory and optional features and ensuring no redundant operational states.

Enhanced service delivery, with special care to Multimedia Broadcast/Multicast Service (MBMS), will be made. MBMS is aimed at realizing TV broadcast over the cellular infrastructure. It is expected, however, that such services will be undersubscribed in 3G networks. It is hence very critical to enhance MBMS services for 4G networks as it will be a key differentiating and attractive service.

LTE-Advanced will feature several operational features. These include relaying, where different levels of wireless multi-hop relay will be applied, and synchronization between various network elements without relying on dedicated synchronization sources. Enabling co-deployment (joint LTE and LTE-Advanced) and co-existence (with other IMT-Advanced technologies) is also to be supported. Facilitating self-organization/healing/optimization will facilitate plug-n-play addition of infrastructure components, especially in the case of relay and in-door BS. The use of femtocells, very short-range coverage BSs, will enhance indoors service delivery. LTE-Advanced systems will also feature facilitating advanced radio resource management functionalities, with special emphasis on flexibility and opportunism, and advanced antenna techniques, where multiple antennas and multi-cell MIMO techniques will be applied.

LTE-Advanced will support peak data rates of 1 Gbps for the downlink, and a minimum of 100 Mbps for the uplink. The target uplink data rate, however, is 500 Mbps. For latencies, the requirements are 50 ms for idle to connected and 10 ms for dormant to connected. The system will be optimized for 0–190 km/h mobility, and will support up to 500 km/h, depending on operating band. For spectral efficiency, LTE-Advanced requirements generally exceed those of IMT-Advanced, for example, the system targets a peak of 30 bps/Hz for the downlink and 15 bps/Hz for the uplink.

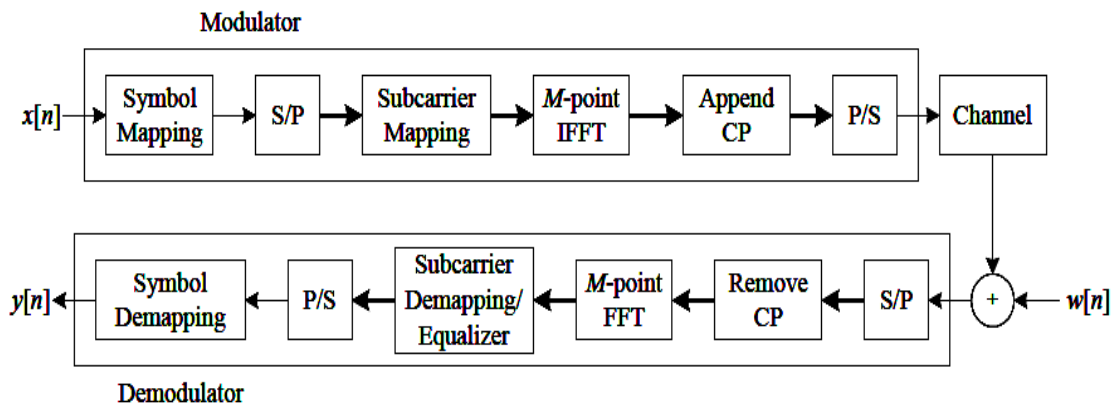


Figure 1. Block diagram for OFDMA [5]

3. DOWNLINK OF LONG TERM EVOLUTION-ADVANCED

Orthogonal frequency division multiple access (OFDMA) has several advantages over the wideband code-division multiple-access (WCDMA) technique used in the previous generations of UMTS. As demonstrated in [4], OFDMA provides better performance in terms of spectral efficiency (i.e. how much data can be transmitted for a given amount of bandwidth) than does WCDMA both for broadcast and for unicast

services. This is due to the lack of inter-symbol interference from multipath channels and the absence of intra-cell interference because users are orthogonal (i.e. they do not interfere with each other) in the frequency domain. In addition, the OFDMA transmission technique scales easily to different bandwidths, so multiple system bandwidth configurations can be efficiently supported. In addition, low-complexity receivers can be used with OFDMA.

In addition, frequency-domain scheduling and MIMO processing techniques can be used. An example of frequency-domain scheduling techniques is frequency-selective scheduling. In frequency-selective scheduling, users are assigned data only on good frequency bands (i.e. bands with large gain), which are determined on the basis of channel quality feedback from the UE. For broadcast services, single-frequency broadcast networks can be supported. In this case, multiple base stations transmit the same broadcast signals. The signals are coherently combined at the user, thus improving performance at the cell edge substantially.

A basic block diagram illustrating OFDMA signal generation for one OFDM symbol is shown in Figure 1. Data symbols from different users are mapped to different subcarriers depending on the frequency bands assigned to those users. This is done in the frequency domain. The information is then subjected to an inverse fast Fourier transform (IFFT) to convert the frequency-domain subcarriers into time-domain signals. A cyclic prefix is then added, and the signal is ready for transmission.

Note that the basic transmission unit for data is a subframe that spans multiple OFDM symbols. At the receiver, the reverse operation is performed. The cyclic prefix is removed, and then the time-domain signal is subjected to a fast Fourier transform (FFT) so that the modulation symbols on each subcarrier can be extracted. Each user then extracts the frequency resource units corresponding to his assigned subcarriers. Equalization is performed and the data is passed onward for decoding.

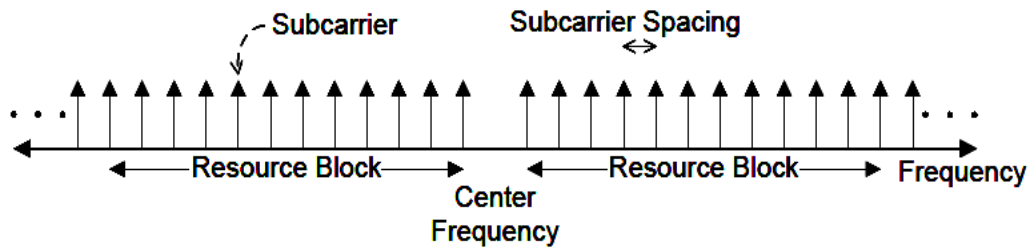


Figure 2. Frequency-domain illustration of OFDM

A frequency-domain illustration of OFDM transmission is shown in Figure 2, where each data symbol is modulated onto one of the subcarriers. The OFDM parameters must be selected carefully in order to meet LTE-A requirements while minimizing overhead. Key design parameters include cyclic-prefix length, subcarrier spacing, and resource-block size. In LTE-A, the direct-current (DC) subcarrier (the subcarrier at the center frequency) is not used since the performance of this subcarrier can be very poor for certain transmitter and receiver designs. Thus, the usable subcarriers are located around this center frequency as shown in Figure 2. The subcarrier spacing is the frequency spacing between two adjacent subcarriers. Small subcarrier spacing means that more subcarriers are available for a given amount of bandwidth, thus increasing the spectral efficiency since more data symbols are available for a given amount of bandwidth.

In addition, small subcarrier spacing also ensures that the fading on each subcarrier is frequency-non-selective. However, performance degrades as subcarrier spacing decreases due to Doppler shift and phase noise. Doppler shift is caused by UE movement with larger shift as UE velocity increases. This causes inter-carrier interference whose degradation increases as the subcarrier spacing decreases. Phase noise is caused by fluctuations in the frequency of the local oscillator, and will cause inter-carrier interference as well. To minimize performance degradation from phase noise, the subcarrier spacing should be greater than 10 kHz. Furthermore, to support UE up to a speed of 350 km/h, the subcarrier spacing should be around 9–17 kHz. As a result, a subcarrier spacing of 15 kHz was chosen for LTE-A.

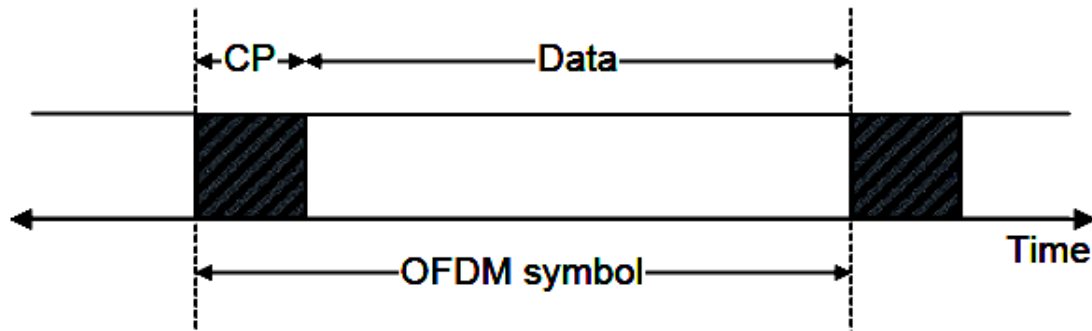


Figure 3. OFDM symbol in the time domain

In LTE-A, frequency resource is assigned in units of resource blocks. Several factors must be considered in the selection of the resource block size in frequency. First, it should be small enough that the frequency selective scheduling (i.e. scheduling data transmission on good frequency subcarriers) gain is large. Small resource-block size ensures that the frequency response within each resource block is similar, thus enabling the scheduler to assign only good resource blocks. However, since the eNB does not know which resource blocks are experiencing good channel conditions, the UE must report this information back to the eNB. Thus, the resource-block size must be sufficiently large that the feedback overhead is not too high. It also should be sufficiently large to minimize downlink control signaling, which must be used to inform the UE of its resource allocation. In [6], performance analysis of frequency selective scheduling was performed. It was found that a resource block of size 200–900 kHz provides good performance. Since, in LTE-A, a subframe size of 1 ms is used to ensure low latency, the resource block size in frequency should be small so that small data packets can be efficiently supported. As a result, 180 kHz (12 subcarriers) was chosen as the resource-block bandwidth.

A cyclic prefix is needed for OFDMA transmission in order to prevent inter-symbol interference from previously transmitted OFDM symbols. The OFDM symbol with cyclic prefix and data is shown in Figure 3. Note that the cyclic prefix does not carry useful data and is removed at the receiver prior to processing. As a result, it is desirable to have as small a cyclic prefix as possible in order to minimize the overhead. In general, the length is chosen on the basis of the expected delay spread of the propagation channel plus some margin to allow for imperfect timing alignment.

4. UPLINK OF LONG TERM EVOLUTION-ADVANCED

In the uplink, SC-FDMA is selected due to its ability to provide similar advantages to OFDM, such as orthogonality among users, frequency domain equalization, and robustness with respect to multipath operation while maintaining a low power amplifier back-off or de-rating requirement [5]. The key characteristic of single-carrier transmission is that each data symbol is transmitted using the entire allocated bandwidth. This is different than OFDM, where each data symbol is transmitted using only one subcarrier. Since single-carrier transmission spreads the data power over the entire bandwidth, it requires lower power amplifier back-off. The power back-off is the required reduction in the mean transmission power to ensure that the maximum power stays within the linear region of the power amplifier. Operating outside of the linear region of the power amplifier causes signal distortion and interference.

For instance, given the maximum transmit power of 23 dBm (equivalent to 200 mW) and a power amplifier back-off requirement of 3.4 dB for an OFDM signal, the maximum mean transmission power is reduced to 19.6 dBm, which will reduce uplink coverage significantly. A good measure of the power back-off requirement is the cubic metric, defined in [7] as the cubic power of the signal of interest compared with a reference signal. Table 1 provides the cubic metric values for OFDMA and SC-FDMA. Another measure of the power back-off requirement is the peak-to-average power ratio (PAPR). A PAPR comparison between OFDMA and SC-FDMA has been presented in [8], showing that the results for SC-FDMA are similar to those for the cubic-metric gain shown in Table 1. The PAPR, however, has been shown to be a less accurate predictor of amplifier power back-off than the cubic metric [9].

Table 1. Comparison of cubic metric between OFDMA and SC-FDMA

Modulation	Cubic metric	
	OFDMA	SC-FDMA
QPSK	3.4	1.0
16-QAM	3.4	1.8
64-QAM	3.4	2.0

From Table 1, it can be seen that SC-FDMA has a significantly lower cubic metric than that for OFDMA. For cell-edge users, where QPSK modulation is generally used, SC-FDMA enjoys a cubic-metric advantage of 2.4 dB over OFDMA. This means that cell-edge users can transmit at 1.74 times higher average power with SC-FDMA than with OFDMA for the same maximum-power limitation. As a result, for the same uplink cell edge data rate, SC-FDMA can provide greater coverage. For example, at a distance of 0.8 km from the cell, SC-FDMA can deliver a data rate of 200 kbit/s, compared with 70 kbit/s for OFDMA. This is the primary reason why SC-FDMA is selected for the uplink. The low power back-off property is accomplished by transmitting the data symbols serially rather than in parallel like in OFDMA, which results in substantially reduced signal fluctuations. This helps conserve battery life or extend the range by reducing the back-off due to non-linearity in the power amplifier. The performance of SC-FDMA, however, is not as good as that of OFDMA given the same type of receiver. The performance for QPSK modulation is approximately the same, while OFDMA outperforms SC-FDMA by 0.5–1 dB for 16-QAM [8]. Although this negates the benefits of SC-FDMA somewhat, especially for indoor users, coverage and cell-edge data rate were seen as the most important criteria in the uplink.

In LTE-A, discrete Fourier transform–spread–OFDM (DFT-S-OFDM) is used to generate the SC-FDMA signal in the frequency domain as shown in Figure 4. Note that generation of the SC-FDMA signal using DFT-S-OFDM is almost identical to that of OFDM, with the exception of the additional M-point discrete Fourier transform (DFT). Although DFT processing is more computationally intensive than the FFT, efficient implementation for certain DFT sizes is available. Specifically, DFTs of prime length can be calculated using efficient FFT algorithms. The method shown in Figure 4 generates SC-FDMA signal in the frequency domain.

This allows frequency-domain pulse shaping to be applied prior to the IFFT to further reduce the cubic metric.

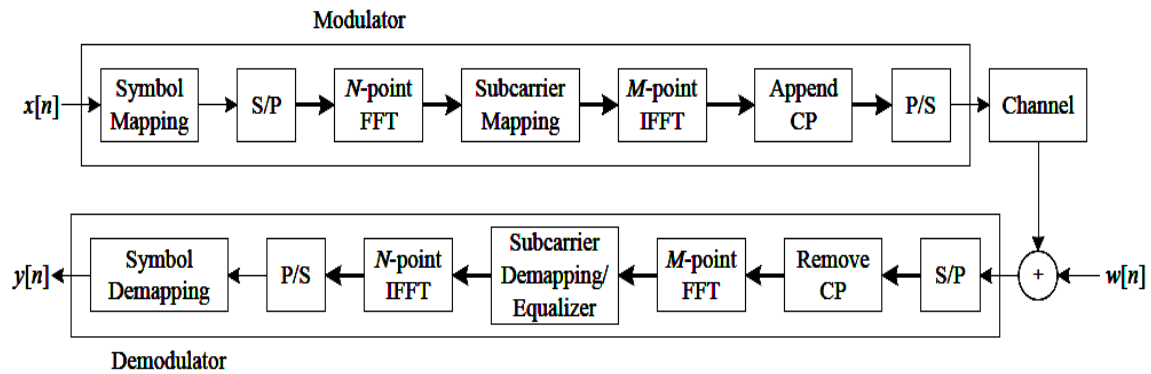


Figure 4. Block diagram for SC-FDMA [5]

The first M-point DFT is used to provide frequency-domain precoding, which is mapped to M contiguous-frequency subcarriers prior to the IFFT. To preserve the single-carrier property, transmission from a user within an SC-FDMA symbol must be either contiguous or evenly spaced in the frequency domain. Two different types of single-carrier transmission can be generated using DFT-S-OFDM, depending on how the resource-element mapping is done. The mapping may be done such that a distributed or localized frequency allocation is generated as shown in Figure 5. Localized mapping means that the entire allocation is contiguous in frequency. This allows good channel-estimation performance since the pilots are contiguous, thus interpolating techniques can be used in channel estimation.

In addition, it will be easy to multiplex different users together in the spectrum. However, frequency diversity is poor. Distributed mapping means that the allocated bandwidth is evenly distributed in frequency. This provides very good frequency diversity. However, the pilots must be distributed, and thus channel-estimation performance suffers.

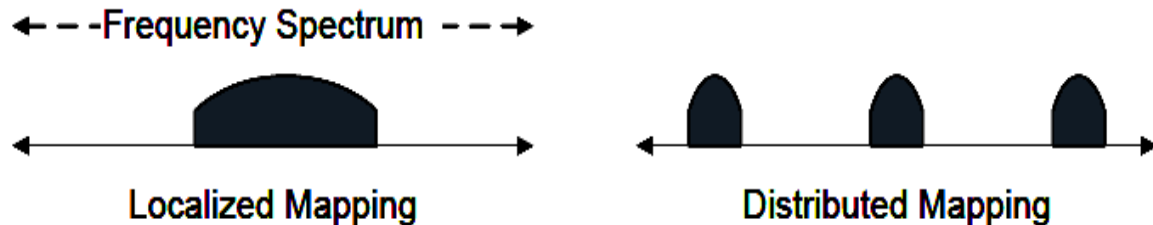


Figure 5. Localized versus distributed mapping for DFT-S-OFDMA

It can also be difficult to multiplex all the users together in the spectrum. In addition, frequency-selective scheduling where a user is assigned only a selected portion of the spectrum (generally one that is providing good radio conditions) cannot be taken advantage of. Performance comparisons of localized versus distributed mapping using realistic channel estimation have been published in [9]. The results showed that the two methods provide similar performance. The gain in frequency diversity from distributed transmission is lost through poorer channel-estimation performance. Given these performance results and other difficulties with scheduling of users, only localized mapping is supported in LTE-A. However, to provide frequency diversity, hopping, whereby the user hops from one localized frequency assignment to a different frequency, can be used.

At the receiver, the reverse operation of the transmitter functions is performed for data demodulation. The received signal first undergoes RF processing and analog-to-digital conversion. Then the cyclic prefix is removed and an FFT is performed. Channel estimation is performed on the basis of the pilots that have been embedded into the transmission packet. In addition to channel estimation, frequency and timing estimation and correction may also be performed. Subcarrier demapping and equalization is done next, followed by an IDFT and finally an M-point IDFT.

Unlike in conventional FDMA, the addition of an M-point DFT/IDFT is used to spread out each modulated data symbol onto all of the subcarriers used. This lowers the peak-to-average power of the transmission signal, resulting in higher maximum transmission power. However, because of the M-point IDFT, all the transmitted modulated symbols within the SCFDMA symbol have the same SINR. The performance of the receiver depends on the type of receivers as well as channel estimation, frequency and time tracking, and decoding algorithms. Several types of receivers can be used for SC-FDMA, including, in practice, a minimum-mean-squared-error or interference-rejection combining receiver is usually used because of its good performance and manageable complexity.

5. DOWNLINK DATA TRANSMISSION

For transmission of data over the air interface, it was decided to use a new transmission scheme in LTE-A which is completely different from the CDMA approach of UMTS. Instead of using only one carrier over the broad frequency band, it was decided to use a transmission scheme referred to as Orthogonal Frequency Division Multiple Access, or OFDMA for short. OFDMA transmits a data stream by using several narrow-band subcarriers simultaneously, for example 512, 1024, or even more, depending on the overall available bandwidth of the channel (e.g. 5, 10, 20 MHz). As many bits are transported in parallel, the transmission speed on each subcarrier can be much lower than the overall resulting data rate. This is important in a practical radio environment in order to minimize the effect of multipath fading created by slightly different arrival times of the signal from different directions. The second reason this approach was selected was because the effect of multipath fading and delay spread becomes independent of the amount of bandwidth used for the channel. This is because the bandwidth of each subcarrier remains the same and only the number of subcarriers is changed. With the previously used CDMA modulation, using a 20 MHz carrier would have been impractical, as the time each bit was transmitted would have been so short that the interference due to the delay spread on different paths of the signal would have become dominant [10].

Figure 6 shows how the input bits are first grouped and assigned for transmission over different frequencies (subcarriers). In the example, 4 bits (representing a 16 QAM modulation) are sent per transmission step per subcarrier. A transmission step is also referred to as a symbol. With 64 QAM modulations, 6 bits are encoded in a single symbol, raising the data rate further. On the other hand, encoding more bits in a single symbol makes it harder for the receiver to decode the symbol if it was altered by interference. This is the reason why different modulation schemes are used depending on transmission conditions.

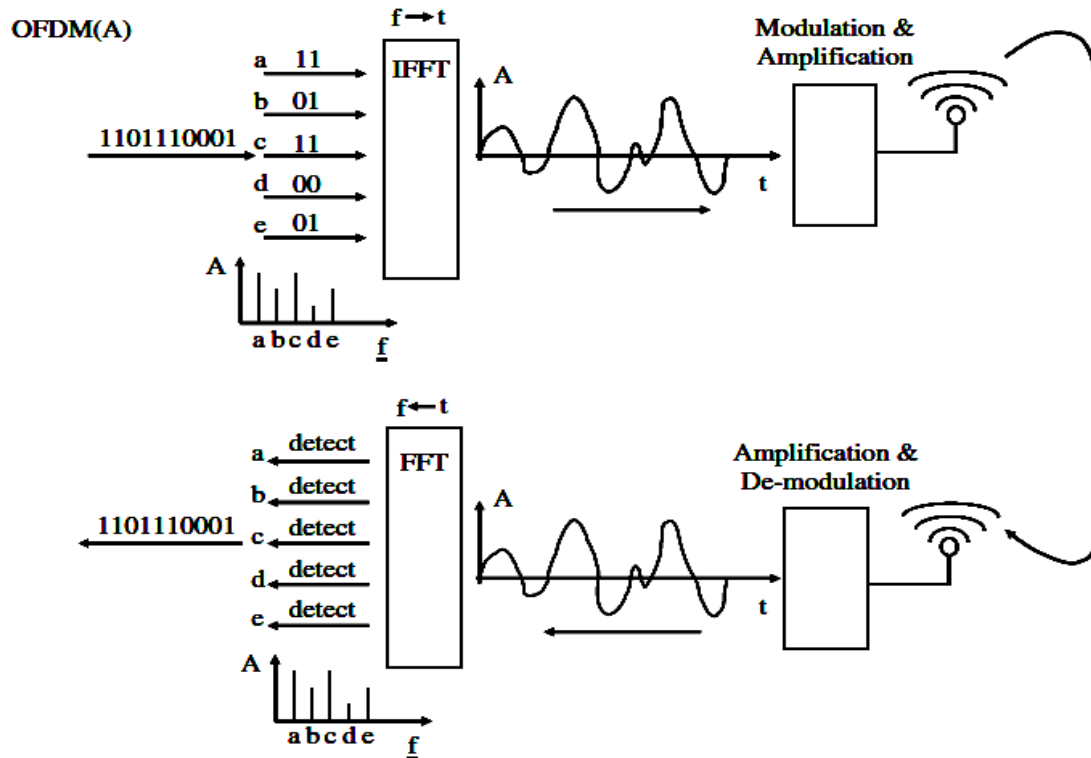


Figure 6. Principles of OFDMA for downlink transmission

In theory, each subcarrier signal could be generated by a separate transmission chain hardware block. The output of these blocks would then have to be summed up and the resulting signal could then be sent over the air. Because of the high number of subcarriers used, this approach is not feasible. Instead, a mathematical approach is taken as follows. As each subcarrier is transmitted on a different frequency, a graph which shows the frequency on the x-axis and the amplitude of each subcarrier on the y-axis can be constructed. Then, a mathematical function called Inverse Fast Fourier Transformation (IFFT) is applied, which transforms the diagram from the frequency domain to the time domain. This diagram has the time on the x-axis and represents the same signal as would have been generated by the separate transmission chains for each subcarrier when summed up. The IFFT thus does exactly the same job as the separate transmission chains for each subcarrier would do, including summing up the individual results.

On the receiver side, the signal is first demodulated and amplified. The result is then treated by a fast Fourier transformation function which converts the time signal back into the frequency domain. This reconstructs the frequency/amplitude diagram created at the transmitter. At the center frequency of each subcarrier a detector function is then used to generate the bits originally used to create the subcarrier.

The explanation has so far covered the Orthogonal Frequency Division aspect of OFDMA transmissions. The Multiple Access (MA) part of the abbreviation refers to the fact that the data sent in the downlink is received by several users simultaneously. Control messages inform mobile devices waiting for data which part of the transmission is addressed to them and which part they can ignore. This is, however, just a logical separation. On the physical layer, this only requires that modulation schemes ranging from QPSK over 16QAM to 64QAM can be quickly changed for different subcarriers in order to accommodate the different reception conditions of subscribers [10].

6. UPLINK DATA TRANSMISSION

For data transmission in the uplink direction, 3GPP has chosen a slightly different modulation scheme. OFDMA transmission suffers from a high Peak to Average Power Ratio (PAPR), which would have negative consequences for the design of an embedded mobile transmitter; that is, when transmitting data from the mobile terminal to the network, a power amplifier is required to boost the outgoing signal to a level high enough to be picked up by the network. The power amplifier is one of the biggest consumers of energy in a device and should therefore be as power-efficient as possible to increase the battery life of the device. The efficiency of a power amplifier depends on two factors:

- The amplifier must be able to amplify the highest peak value of the wave. Due to silicon constraints, the peak value determines the power consumption of the amplifier.
- The peaks of the wave, however, do not transport any more information than the average power of the signal over time. The transmission speed therefore does not depend on the power output required for the peak values of the wave but rather on the average power level.

As both power consumption and transmission speed are of importance for designers of mobile devices, the power amplifier should consume as little energy as possible. Thus, the lower the difference between the PAPR, the longer is the operating time of a mobile device at a certain transmission speed compared with devices that use a modulation scheme with a higher PAPR.

A modulation scheme similar to basic OFDMA, but with a much better PAPR, is SC-FDMA (Single Carrier-Frequency Division Multiple Access). Due to its better PAPR, it was chosen by 3GPP for transmitting data in the uplink direction. Despite its name, SC-FDMA also transmits data over the air interface in many subcarriers, but adds an additional processing step as shown in Figure 7. Instead of putting 2, 4 or 6 bits together as in the OFDM example to form the signal for one subcarrier, the additional processing block in SC-FDMA spreads the information of each bit over all the subcarriers. This is done as follows: again, a number of bits (e.g. 4 representing a 16 QAM modulation) are grouped together. In OFDM, these groups of bits would have been the input for the IDFT.

In SC-FDMA, however, these bits are now piped into a Fast Fourier Transformation (FFT) function first. The output of the process is the basis for the creation of the subcarriers for the following IFFT. As not all subcarriers are used by the mobile station; many of them are set to zero in the diagram. These may or may not be used by other mobile stations.

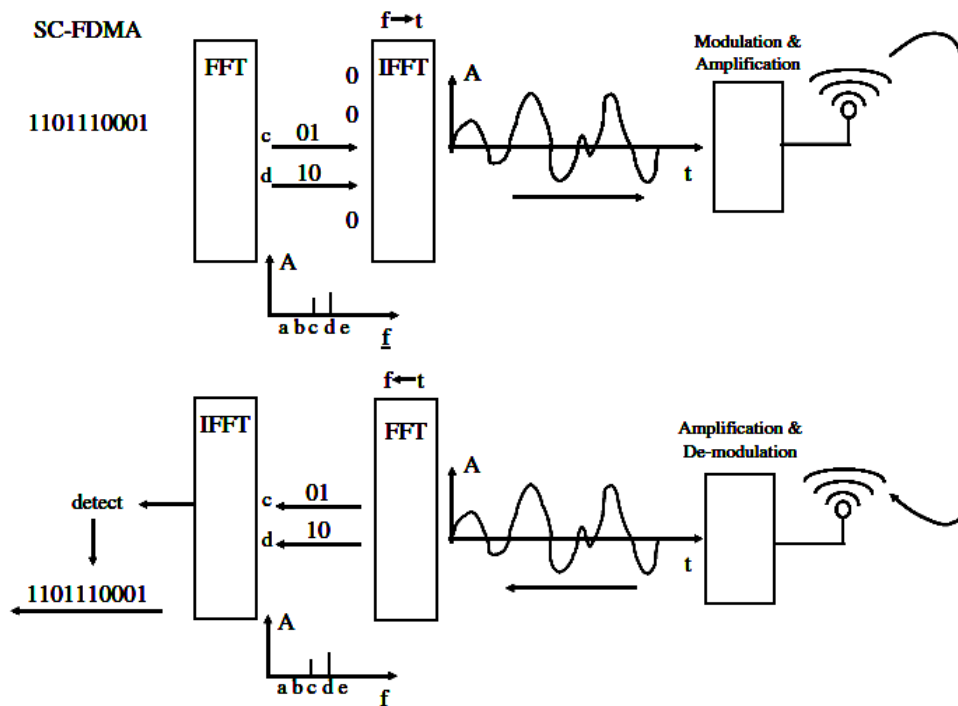


Figure 7. SC-FDMA modulation for uplink transmissions

On the receiver side the signal is demodulated, amplified and treated by the fast Fourier transformation function in the same way as in OFDMA. The resulting amplitude diagram, however, is not analyzed straight away to get the original data stream, but fed to the inverse fast Fourier transformation function to remove the effect of the additional signal processing originally done at the transmitter side. The result of the IFFT is again a time domain signal. The time domain signal is now fed to a single detector block which recreates the original bits. Therefore, instead of detecting the bits on many different subcarriers, only a single detector is used on a single carrier. The differences between OFDM and SC-FDMA can be summarized as follows: OFDM takes groups of input bits (0s and 1s) to assemble the subcarriers which are then processed by the IDFT to get a time signal. SC-FDMA in contrast first runs an FFT over the groups of input bits to spread them over all subcarriers and then uses the result for the IDFT which creates the time signal. This is why SC-FDMA is sometimes also referred to as FFT spread OFDM [10].

7. CAPACITY FOR THE DOWNLINK OF LTE-ADVANCED SYSTEM

Unlike TDMA, OFDMA allows sharing resources among multiple users accessing the system by allocating to a user only a fraction of the total bandwidth; therefore multiple users can transmit simultaneously on orthogonal subcarriers. The transmissions from multiple users are orthogonal as long as the relative delay between the received transmissions is within the cyclic prefix (CP) length. In general, the CP length is several microseconds, to account for the multi-path delay spread, and therefore makes the timing synchronization within the CP length feasible. This is in contrast to synchronous WCDMA where subchip level synchronization (generally a small fraction of a microsecond depending upon the chip rate) is required to guarantee orthogonal transmissions [11]. The uplink capacity limit for an OFDMA system can be written as:

$$C_{\text{OFDMA}} = \sum_{i=1}^K \beta_i \cdot \log_2 \left(1 + \frac{P}{fP + \beta_i N_0} \right) [\text{b/s/Hz}], \quad (1)$$

Where β_i is the fraction of bandwidth allocated to user i . For the case where the bandwidth is equally divided among the K users transmitting simultaneously, the above formula can be simplified as below:

$$\begin{aligned} C_{\text{OFDMA}} &= \sum_{i=1}^K \frac{1}{K} \cdot \log_2 \left(1 + \frac{P}{fP + \frac{N_0}{K}} \right) [\text{b/s/Hz}] \\ &= \log_2 \left(1 + \frac{KP}{fKP + N_0} \right) [\text{b/s/Hz}]. \end{aligned} \quad (2)$$

There is no intra-cell (multiple access) interference or inter-symbol-interference (ISI) due to orthogonal subcarriers used by different users and 1-tap OFDM subcarrier equalization.

However, cyclic prefix (guard interval) overhead (typically around 10%) needs to be taken into account for the OFDM case. Therefore, the capacity of an OFDMA system can be scaled-down to account for CP overhead as below:

$$C_{\text{OFDMA}} = \left(\frac{T_s}{T_s + \Delta} \right) \times \log_2 \left(1 + \frac{KP}{fKP + N_0} \right) [\text{b/s/Hz}], \quad (3)$$

Where T_s is the OFDM symbol duration and Δ is the cyclic prefix duration.

8. CAPACITY FOR THE UPLINK OF LTE-ADVANCED SYSTEM

Like OFDMA, SC-FDMA avoids intra-cell interference in the uplink. However, SC-FDMA can also benefit from frequency diversity because a given modulation symbol is transmitted over the whole bandwidth allocated to the UE. However, the downside of this approach is that performance of SC-FDMA suffers in a frequency-selective fading channel due to noise enhancement. This is because the IDFT operation after frequency-domain equalization at the receiver spreads out the noise over all the modulation symbols. It should be noted that noise enhancement results in inter-symbol-interference (ISI) and not the inter-user interference, that is, there is no intra-cell interference among UEs transmitting over orthogonal frequency resources. The losses of SC-FDMA link performance relative to OFDMA have been estimated ranging from no loss or a slight gain due to diversity at low SINR for QPSK modulation to about 1 dB for 16-QAM and

64-QAM modulations typically used at higher SINR [12]. Therefore, the uplink capacity limit for an SC-FDMA system is given as:

$$C_{\text{SC-FDMA}} = \left(\frac{T_s}{T_s + \Delta} \right) \times \log_2 \left(1 + \frac{KP}{fKP + N_0} \times \frac{1}{10^{(L_{\text{SC-FDMA}}/10)}} \right) [\text{b/s/Hz}], \quad (4)$$

Where: $L_{\text{SC-FDMA}}$ represents the SC-FDMA link loss in dBs relative to OFDMA. This loss occurs at higher SINR when frequency-domain linear equalization is used. It should be noted that some or all of this loss can be recovered by using a more advanced receiver [13] at the Node-B at the expense of additional complexity.

9. SUMMARY AND DISCUSSIONS

The differences between OFDM and SC-FDMA can be summarized as follows; based on the performance comparison; both OFDMA and SC-FDMA emerged as strong candidates for LTE-A uplink. One advantage of SC-FDMA relative to OFDM; is low signal-peakiness of the SC-FDMA signal. Allow signal peakiness allows a UE to transmit at a higher power providing greater coverage. However, one drawback of SC-FDMA relative to OFDMA is link performance loss in a frequency-selective channel. This loss can be over one dB at higher SINR. Hybrid uplink access scheme is discussed where DFT-precoding is only used for power limited UEs. This scheme effectively uses OFDMA when power limitation is not an issue and therefore avoids link performance loss for higher order modulation transmissions. Another drawback of SC-FDMA relative to OFDMA is additional DFT and IDFT operations at the transmitter and receiver respectively resulting in increased implementation complexity. However, the DFT and IDFT operation can be relatively simplified if the DFT-precoding sizes are limited to a few prime factors.

There was also a big debate over whether both localized and distributed transmission flavors of SC-FDMA should be allowed or a single scheme should be selected. The benefit of distributed transmission is greater frequency diversity because a given transmissions is spread over a larger bandwidth. These frequency-diversity gains from distributed SC-FDMA can be of the order of 1 dB in certain scenarios. On the other hand, localized transmissions allow employing frequency-selective multi-user scheduling as a UE can be scheduled over a frequency band experiencing high signal quality. When the channel can be tracked with fairly high accuracy, which can be the case for low UE speeds, localized transmission outperforms distributed transmission. However, at higher UE speeds when channel quality cannot be tracked with reasonable accuracy, distributed transmission can be beneficial.

For SC-CDMA, since the signals arrive at the eNodeB with substantial Inter-Symbol Interference and because SC-FDMA uses single carrier modulation, block equalization is performed at the receiver to cancel the effect of the radio channel over the received symbol and makes it non sensitive to spectra nulls. Whereas OFDMA is prone to Inter-Carrier Interference due to narrow subcarriers, SC-FDMA is not sensitive to frequency offset (Doppler) because of its single-carrier nature.

10. CONCLUSION

The main area where the flexible spectrum allocation of downlink (OFDMA) and uplink (SC-FDMA) systems is exploited is enabling wideband transmission. LTE-Advanced is supporting transmissions up to 100 MHz in downlink and 40 MHz in uplink; achieving this while being compatible with 3G networks could be achieved through the carrier aggregation. Carrier aggregation refers to the possibility of concatenating several basic (legacy) carrier components into a larger one that can be viewed and managed as a single band. It involves multiple carriers being combined at the PHY layer to provide the user with the necessary bandwidth. The utilization of guard band is possible for the actual data transmission, and utilizing basic (legacy) carrier components achieves backward compatibility with LTE-Advanced. Single-Carrier Transmission presents the key techniques for LTE-Advanced uplink as well as the baseline performance. Radio access technology is the key aspect in LTE-Advanced uplink, and two radio access schemes, SC-FDMA and OFDMA, are explained. The performance results are obtained from a detailed LTE-Advanced uplink link-level design. The diagrams show that both SC-FDMA and OFDMA can achieve a high spectral efficiency; however OFDMA has better performance with high order modulations. Meanwhile SC-FDMA has better performance with low-order modulation specifically QPSK. Hence, OFDMA can offer higher cell throughput, while SC-FDMA can provide larger cell coverage.

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