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A closed concept for OFDM-Synchronization in 3GPP LTE Systems

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***Abstract*— LTE implements Orthogonal Frequency Division Multiplexing (OFDM) for its downlink and Single-Carrier Frequency-Division Multiple Access (SC-FDMA) for its uplink. The bases used for comparison will be capacity, outage probability and peak-to-average power ratio (PAPR). While the first two bases have always been traditionally used in analyses, PAPR is especially important for the uplink of mobile devices. Amplifiers used in circuits today have a linear region in which they must operate so as not to introduce signal distortion, and it is ideal to run with maximum amplification. However, if there is a high PAPR, the device is forced to run with lower amplification so the peak power does not lie in the non-linear gain region. The farther these amplifiers are operated from the peak, the less power efficient the devices become, leading to increased power consumption and while this might not be very important for a base station, it will reduce drain batteries on mobile devices more quickly. Therefore it is important to keep a low PAPR on the uplink. However, one of the major drawbacks of OFDMA is its sensitivity to the TO and CFO, especially in the uplink. While the TO can be overcome by using sufficiently long CP, the CFO problem is more difficult to deal with. Due to oscillator inaccuracy and Doppler shift, each user in the uplink of the OFDMA-based system experiences an independent CFO, which destroys the orthogonality among subcarriers and consequently produces ICI and MUI. The goal is to provide practical solutions to alleviate the synchronization issues in the uplink of the OFDMA-based system.**

***Index Terms*— Cyclic Prefix, CFO, LTE, OFDMA, Offsets, PAPR, SC-FDMA, TO.**

1.INTRODUCTION

The explosive growth of the mobile broadband usage and that increases the traffic volume. To better meet these future requirement various technology standard explore options for 4G technology. The next-generation mobile broadband technologies i.e. LTE and WiMAX are leading technologies which are technological foundation for 4G wireless broadband network. QoS structure is essential element of next-generation i.e. 4G broadband wireless network to better meet to the current and future needs and mobile internet applications. These technologies are designed to support current and future QoS. QoS structure and aspect of 4G mobile broadband technologies that are LTE, IEEE 802.16E and IEEE 802.16M to sustain various applications of QoS needs. LTE make available a better-quality combination of network performance and required least cost to reach future demands of users for wireless broadband services.

Driving the evolution of wireless broadband technology is customers' increasing expectations for speed, bandwidth, and global access. Customers want more information, such as business and consumer applications, and entertainment available through their mobile devices, but with greater speeds. For wireless carriers to achieve greater speeds and pervasive connectedness, their networks need to start behaving more like landline IP-based networks. This line of thinking represents a fundamental shift in perspective—from mobile services to broadband connections—for customers and service providers alike. Enter the fourth-generation (4G) wireless network. Unlike earlier wireless standards, 4G technology is based on TCP/IP, the core protocol of the Internet. TCP/IP enables wireless networks to deliver higher-level services, such as video and multimedia, while supporting the devices and applications of the future. The conflict of rapidly growing users and limited bandwidth resources requires that the spectrum efficiency of mobile communication systems be improved by adopting some advanced technologies.

In the last few years, we have witnessed an explosion of IP connectivity demand, translated into a rapid development of the corresponding technologies in the wireless access network domain. IP services provision anytime and anywhere becomes very challenging and is seen by the mobile operators as a major opportunity for boosting the average revenue per unit. The further success of IP services deployment requires true mobile broadband IP connectivity on a global scale. For accomplishing this request, two technologies emerged with the aim of providing voice, data, video and multimedia services on mobile devices at high speeds and cheap rates: WiMAX (Worldwide Interoperability for Microwave Access) and LTE (3GPP Long Term Evolution).

LTE technology evolved from UMTS/HSDPA cellular technology to meet current used demands of high data rates and increased mobility. The LTE radio access is based on OFDM technique and supports different carrier frequency bandwidths (1.4-20 MHz) in both frequency-division duplex (FDD) and time-division duplex (TDD) modes. The use of SC-FDMA in the uplink reduces Peak-to-Average Power Ratio compared to OFDMA, increasing the battery life and the usage time on the UEs. In downlink peak data rates go from 100 Mbps to 326.4 Mbps, depending on the modulation type and antenna configuration used. While the orthogonality among subchannels can be

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maintained relatively easily in the downlink, keeping the orthogonality in the uplink is much more difficult. LTE aims at providing IP backbone services, flexible spectrum, lower power consumption and simple network architecture with open interfaces.

This paper is organized as follows. First, Section 1 gives an introduction, Section 2 gives the choice of using Orthogonal Frequency Division Multiple Access (OFDMA) Scheme in mobile wireless communication system, Section 3 gives the description about the importance of synchronization and cell search in OFDM-based LTE system. Finally, conclusion is presented in Section 4.

2. ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACESS (OFDMA) SCHEME

The choice of an appropriate modulation and multiple-access technique for mobile wireless data communications is critical to achieving good system performance. In particular, typical mobile radio channels tend to be dispersive and time-variant, and this has generated interest in multicarrier modulation. In general, multicarrier schemes subdivide the used channel bandwidth into a number of parallel subchannels as shown in Figure 1(a). Ideally the bandwidth of each subchannel is such that they are, ideally, each non-frequency-selective (i.e. having a spectrally flat gain); this has the advantage that the receiver can easily compensate for the subchannel gains individually in the frequency domain.

Orthogonal Frequency Division Multiplexing (OFDM) is a special case of multicarrier transmission where the non-frequency-selective narrowband subchannels, into which the frequency-selective wideband channel is divided, are overlapping but orthogonal, as shown in Figure 1(b). This avoids the need to separate the carriers by means of guard-bands, and therefore makes OFDM highly spectrally efficient. The spacing between the subchannels in OFDM is such that they can be perfectly separated at the receiver. This allows for a low complexity receiver implementation, which makes OFDM attractive for high-rate mobile data transmission such as the LTE downlink[1-3].

It is worth noting that the advantage of separating the transmission into multiple narrowband subchannels cannot itself translate into robustness against time-variant channels if no channel coding is employed. The LTE downlink combines OFDM with channel coding and Hybrid Automatic Repeat reQuest (HARQ) to overcome the deep fading which may be encountered on the individual subchannels. These aspects are considered and lead to the LTE downlink falling under the category of system often referred to as 'Coded OFDM' (COFDM).

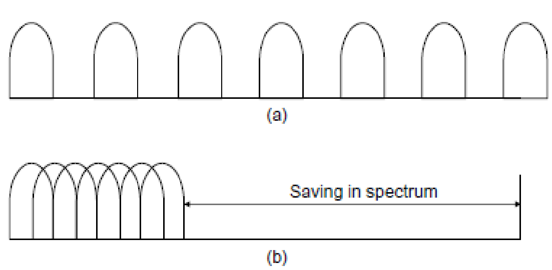

Fig.1 Spectral efficiency of OFDM compared to classical multicarrier modulation:(a) classical multicarrier system spectrum; (b) OFDM system spectrum

A high-rate data stream typically faces the problem of having a symbol period Ts much smaller than the channel delay spread Td if it is transmitted serially. This generates Inter- Symbol Interference (ISI) which can only be undone by means of a complex equalization procedure. In general, the equalization complexity grows with the square of the channel impulse response length. In OFDM, the high-rate stream of data symbols is first Serial-to-Parallel (S/P) converted for modulation onto M parallel subcarriers. This increases the symbol duration on each subcarrier by a factor of approximately M, such that it becomes significantly longer than the channel delay spread. This operation has the important advantage of requiring a much less complex equalization procedure in the receiver, under the assumption that the time-varying channel impulse response remains substantially constant during the transmission of each modulated OFDM symbol. Figure 2 shows how the resulting long symbol duration is virtually unaffected by ISI compared to the short symbol duration, which is highly corrupted. The next key operation in the generation of an OFDM signal is the creation of a guard period at the beginning of each OFDM symbol x [k] by adding a Cyclic Prefix (CP), to eliminate the remaining impact of ISI caused by multipath propagation.

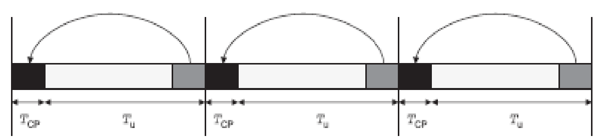

Fig.2 OFDM Cyclic Prefix (CP) insertion

To avoid ISI completely, the CP length G must be chosen to be longer than the longest channel impulse response to be supported. The CP converts the linear (i.e. aperiodic) convolution of the channel into a circular (i.e. periodic) one which is suitable for DFT processing. The insertion of the CP into the OFDM symbol and its implications are explained more formally later in this section. The output of the IFFT is then Parallel-to-Serial (P/S) converted for transmission through the frequency-selective channel. At the receiver, the reverse operations are performed to demodulate the OFDM signal. Assuming that time- and frequency-synchronization is a number of samples corresponding to the length of the CP are removed, such that only an ISI-free block of samples is passed to the DFT. If the number of subcarriers N is designed to be a power of 2, a highly efficient FFT implementation may be used to transform the signal back to the frequency domain. Among the N parallel streams output from the FFT, the modulated subset of M subcarriers are selected and further processed by the receiver.

Let $x(t)$ be the symbol transmitted at time instant t. The received signal in a multipath environment is then given by (1):

$$r(t) = x(t) * h(t) + z(t) \qquad (1)$$

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where $h(t)$ is the continuous-time impulse response of the channel, $*$ represents the convolution operation and $z(t)$ is the additive noise.
In summary, the CP of OFDM changes the linear convolution into a circular one. The circular convolution is very efficiently transformed by means of an FFT into a multiplicative operation in the frequency domain. Hence, the transmitted signal over a frequency-selective (i.e. multipath) channel is converted into a transmission over N parallel flat-fading channels in the frequency domain given by (2):

$$Rm[k] = Xm[k] \cdot Hm[k] + Zm[k] \qquad (2)$$

As a result, the equalization is much simpler than for single-carrier systems and consists of just one complex multiplication per subcarrier.
Orthogonal Frequency Division Multiple Access (OFDMA) is an extension of OFDM to the implementation of a multiuser communication system. In the discussion above, it has been assumed that a single user receives data on all the subcarriers at any given time[5]. OFDMA distributes subcarriers to different users at the same time, so that multiple users can be scheduled to receive data simultaneously. Usually, subcarriers are allocated in contiguous groups for simplicity and to reduce the overhead of indicating which subcarriers have been allocated to each user. OFDMA for mobile communications was first proposed in [21] based on multicarrier FDMA (Frequency Division Multiple Access), where each user is assigned to a set of randomly selected subchannels. OFDMA enables the OFDM transmission to benefit from multi-user diversity. Based on feedback information about the frequency-selective channel conditions from each user, adaptive user-to-subcarrier assignment can be performed, enhancing considerably the total system spectral efficiency compared to single-user OFDM systems.
The OFDM itself is just a modulation technique, and it is up to system designers to choose a multiple access technique which allows users to share the resources. In wireless cellular communications, the resources can be time, frequency, power and space, and therefore the choice of multiple access technique can be Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), Space Division Multiple Access (SDMA) or any combination of those. The Time Division Multiple Access (TDMA) can be applied on OFDM by assigning each user one or more independent OFDM symbols for transmission. This technique is simplest, but it is also less flexible due to the fact that all subcarriers must be given to one user at any given time, even if that particular user does not require that much resource. The combination of Code Division Multiple Access (CDMA) and OFDM is often referred to as Multicarrier Code Division Multiple Access (MC-CDMA), where each input data bit is multiplied with a given spreading code and then modulated in the baseband by IFFT for transmission [12-15]. The spreading can be done in frequency, i.e. the spreaded bits are transmitted via parallel subcarriers, or in time, where the spreaded bits are transmitted over several OFDM symbols, or a combination of both frequency and time [18]. MC-CDMA inherits the OFDM's sensitivity to synchronization error and PAPR issue, and in addition, it is more complex than the Orthogonal Frequency Division Multiplexing - Time Division Multiple Access (OFDM-TDMA) scheme, since the spreading and despreading operations are involved. SDMA employes multiple antnnas to allow multiple users to transmit in the same time-frequency block. It makes use of the fact that users are seldom at exactly the same spatial location, and if we can find spatial multipath that only talk to the user being address but not the others, then users are said to be separable in space domain. Combination of SDMA and OFDM is attractive because OFDM effectively turns the frequency-selective fading channel into flat fading one, and allows for simple SDMA algorithm to be implemented. However, the number of separable users in SDMA is restricted by the number of antennas in the system, which is often limited due to complexity and physical constrains.
If the FDMA is adopted in OFDM system, it is referred to as Orthogonal Frequency Division Multiple Access (OFDMA) technique. In this multiple access scheme, each user is given an independent time-frequency block, which spans one or several OFDM symbols and consists of a number of subcarriers. The main different between the canonical OFDM and OFDMA is that multiple users are allowed to share the same OFDM symbol(s), but using different sets of subcarriers. This allows for an increment in the level of bit granularity and straightforward dynamic subchannel assignment for multiuser diversity [33]. These, combining with the advantages inherited from OFDM, make OFDMA a promising candidate for multiple access technique of the future broadband wireless systems.
If one looks at the downlink of OFDMA-based systems, there are no different between OFDMA and OFDM-TDMA, except that an user can now only access a smaller and pre-defined set of subcarriers. Since the same BS generates all users' data, and transmits the sum via the same channel to a particular user, the timing and frequency-offset related to the received signal is unique, and therefore that user can applied traditional synchronization techniques designed for OFDM at the downlink of the OFDMA-based systems. In the uplink, however, the received signal is the sum of transmitted signals from different sources, each of which may experience an independent timing and frequency-offset, which make the situation more complicated. In the following section, we will present the system model for the uplink of the OFDMA-based wireless communications, which incorporates the timing and frequency misalignment between multiple transmitters and the receiver so that the effect of such misalignment can be analyzed.

2.1Peak-to-Average Power Ratio and Sensitivity to Non-Linearity

While the previous section shows the advantages of OFDM, this section highlights its major drawback: the Peak-to-Average Power Ratio (PAPR). In the general case, the OFDM transmitter can be seen as a linear transform performed over a large block of independent identically distributed (i.i.d) QAM1-modulated complex symbols (in the frequency domain). From the central limit theorem [8,9], the time-domain OFDM symbol may be approximated as a Gaussian waveform. The amplitude variations of the OFDM modulated signal can therefore be very high. However, practical Power Amplifiers (PAs) of RF transmitters are linear only within a limited dynamic range. Thus, the OFDM

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signal is likely to suffer from non-linear distortion caused by clipping. This gives rise to out of- band spurious emissions and in-band corruption of the signal. To avoid such distortion, the PAs have to operate with large power back-offs, leading to inefficient amplification or expensive transmitters. The PAPR is one measure of the high dynamic range of the input amplitude, and hence a measure of the expected degradation. To analyze the PAPR mathematically, let *x*n be the signal after IFFT. The PAPR of an OFDM symbol is defined as the square of the peak amplitude divided by the mean power.

2.1.1 PAPR Reduction Techniques

Many techniques have been studied for reducing the PAPR of a transmitted OFDM signal. Although no such techniques are specified for the LTE downlink signal generation, an overview of the possibilities is provided below. In general, in LTE the cost and complexity of generating the OFDM signal with acceptable Error Vector Magnitude (EVM) is left to the eNodeB implementation. As OFDM is not used for the LTE uplink such considerations do not directly apply to the transmitter in the User Equipment (UE). Techniques for PAPR reduction of OFDM signals can be broadly categorized into three main concepts: clipping and filtering [10–12], selected mapping [13] and coding techniques [14, 15]. The most potentially relevant from the point of view of LTE would be clipping and filtering, whereby the time-domain signal is clipped to a predefined level.
This causes spectral leakage into adjacent channels, resulting in reduced spectral efficiency as well as in-band noise degrading the bit error rate performance. Out-of-band radiation caused by the clipping process can, however, be reduced by filtering. If discrete signals are clipped directly, the resulting clipping noise will all fall in band and thus cannot be reduced by filtering. To avoid this problem, one solution consists of oversampling the original signal by padding the input signal with zeros and processing it using a longer IFFT. The oversampled signal is clipped and then filtered to reduce the out-of-band radiation. A special Forward Error Correction (FEC) code set that excludes OFDM symbols with large PAPR can be applied, so that the high PAPR situation can be avoided.
Another solution involves pre-coding linearly the OFDM's subcarriers prior to the IFFT operation, so as to minimize the PAPR of the output. A well known version of this solution is the Single Carrier-Frequency Division Multiple Access (SC-FDMA) or Linearly Precoded-Orthogonal Frequency Division Multiple Access (LP-OFDMA), which is selected as uplink's multiple access scheme for The Third Generation Partnership Project (3GPP) Long-Term Evolution (LTE) standard [27].

2.1.2 Sensitivity to Carrier Frequency Offset and Time-Varying Channels

Frequency errors typically arise from a mismatch between the reference frequencies of the transmitter and the receiver local oscillators. On the receiver side in particular, due to the importance of using low-cost components in the mobile handset, local oscillator frequency drifts are usually greater than in the eNodeB and are typically a function of parameters such as temperature changes and voltage variations. This difference between the reference frequencies is widely referred to as Carrier Frequency Offset (CFO) as shown in Figure 3. Phase noise in the UE receiver may also result in frequency errors.

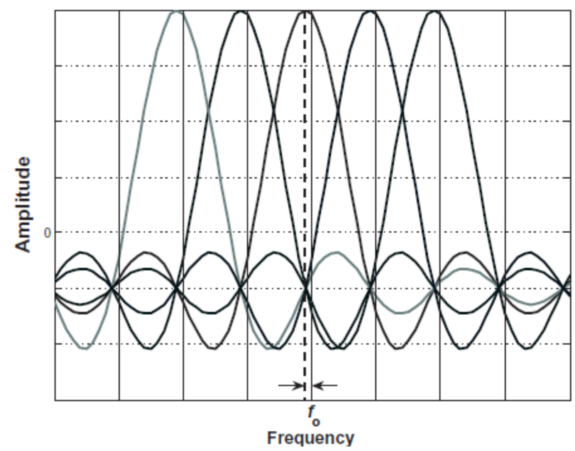

Fig.3 Loss of orthogonality between OFDM subcarriers due to frequency offset.

The CFO can be several times larger than the subcarrier spacing. It is usually divided into an integer part and a fractional part. Typically only synchronization errors of up to a few percent of the subcarrier spacing are tolerable in OFDM systems.

2.1.3 Timing Offset and Cyclic Prefix Dimensioning

In the case of a memoryless channel (i.e. no delay spread), OFDM is insensitive to timing synchronization errors provided that the misalignment remains within the CP duration. In other words, if $T_o \leq T_{CP}$ (with *T*o being the timing error), then orthogonality is maintained thanks to the cyclic nature of the CP. Any symbol timing delay only introduces a constant phase shift from one subcarrier to another. It is worth highlighting that the insensitivity to timing offsets would not hold for any kind of guard period other than a cyclic prefix; for example, zero-padding would not exhibit the same property, resulting in a portion of the useful signal power being lost. In the general case of a channel with delay spread, for a given CP length, the maximum tolerated timing offset without degrading the OFDM reception is reduced by an amount equal to the length of the channel impulse response: $T_o \leq T_{CP} - T_d$. For greater timing errors, ISI and ICI occur. The effect caused by an insufficient CP is discussed in the following section.
Timing synchronization hence becomes more critical in long-delay-spread channels. Initial timing acquisition in LTE is normally achieved by the cell-search and synchronization procedures. Thereafter, for continuous tracking of the timing-offset, two classes of approach exist, based on either CP correlation or Reference Signals (RSs). A combination of the two is also possible. The reader is referred to [19] for a comprehensive survey of OFDM synchronization techniques.

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2.1.4 Effect of Insufficient Cyclic Prefix Length

As already explained, if an OFDM system is designed with a CP of length G samples such that $L < G$ where L is the length of the channel impulse response (in number of samples), the system benefits from turning the linear convolution into a circular one to keep the subcarriers orthogonal. The condition of a sufficient CP is therefore strictly related to the orthogonality property of OFDM.

As highlighted in the previous sections, certain key parameters determine the performance of OFDM and OFDMA systems. Inevitably, some compromises have to be made in defining these parameters appropriately to maximize system spectral efficiency while maintaining robustness against propagation impairments. For a given system, the main propagation characteristics which should be taken into account when designing an OFDM system are the expected delay spread Td, the maximum Doppler frequency f_{dmax} , and, in the case of cellular systems, the targeted cell size.

The propagation characteristics impose constraints on the choice of the CP length and of the subcarrier spacing. As already mentioned, the CP should be longer than the Channel Impulse Response (CIR) in order to ensure robustness against ISI. For cellular systems, and especially for large cells, longer delay spreads may typically be experienced than those encountered, for example, in WLAN systems, implying the need for a longer CP. On the other hand, a longer CP for a given OFDM symbol duration corresponds to a larger overhead in terms of energy per transmitted bit. Out of the $N + G$ transmitted symbols, only N convey information, leading to a rate loss. This reduction in bandwidth efficiency can be expressed as a function of the CP duration $T_{\text{CP}} = GT$s and the OFDM symbol period Tu = NTs (where Ts is the sampling period), as follows in (3):

$$\beta\text{overhead} = T_{\text{cp}}/T_{\text{u}} + T_{\text{cp}} \qquad (3)$$

It is clear that to maximize spectral efficiency, Tu should be chosen to be large relative to the CP duration, but small enough to ensure that the channel does not vary within one OFDM symbol. Further, the OFDM symbol duration Tu is related to the subcarrier spacing by $\Delta f = 1/T$u. Choosing a large Tu leads to a smaller subcarrier separation Δf , which has a direct impact on the system sensitivity to Doppler and other sources of frequency offset.

3. SYNCHRONIZATION AND CELL SEARCH

A User Equipment (UE) wishing to access an LTE cell must first undertake a cell search procedure. This chapter focuses on the aspects of the physical layer that are designed to facilitate cell search. The way this relates to the overall mobility functionality and protocol aspects for cell reselection and handover. The performance requirements related to cell search and synchronization. At the physical layer, the cell search procedure consists of a series of synchronization stages by which the UE determines time and frequency parameters that are necessary to demodulate the downlink and to transmit uplink signals with the correct timing. The UE also acquires some critical system parameters. Three major synchronization requirements can be identified in the LTE system:

a) Symbol and frame timing acquisition, by which the correct symbol start position is determined, for example to set the Discrete Fourier Transform (DFT) window position;

b) Carrier frequency synchronization, which is required to reduce or eliminate the effect of frequency errors1 arising from a mismatch of the local oscillators between the transmitter and the receiver, as well as the Doppler shift caused by any UE motion;

c) Sampling clock synchronization, the cell search procedure in LTE begins with a synchronization procedure which makes use of two specially designed physical signals that are broadcast in each cell: the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS). The detection of these two signals not only enables time and frequency synchronization, but also provides the UE with the physical layer identity of the cell and the cyclic prefix length, and informs the UE whether the cell uses Frequency Division Duplex (FDD) or Time Division Duplex (TDD). In the case of initial synchronization (when the UE is not already camping on or connected to an LTE cell) after detecting the synchronization signals, the UE decodes the Physical Broadcast CHannel (PBCH), from which critical system information is obtained. In the case of neighbour cell identification, the UE does not need to decode the PBCH; it simply makes quality-level measurements based on the reference signals transmitted from the newly detected cell and uses them for cell reselection (in RRC_IDLE state) or handover (in RRC_CONNECTED state); in the latter case, the UE reports these measurements to its serving cell. The cell search and synchronization procedure is summarized in Figure 4, showing the information ascertained by the UE at each stage. The PSS and SSS structure is specifically designed to facilitate this acquisition of information.

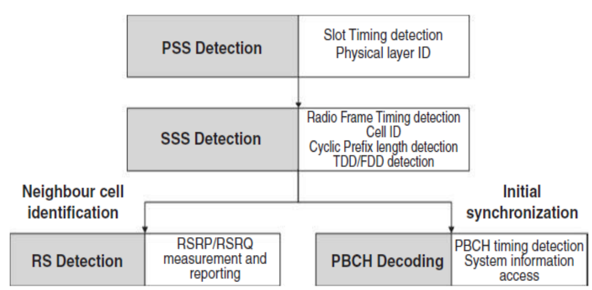

Fig.4 Information acquired at each step of the cell search procedure

The PSS and SSS structure in time for the FDD case and in for TDD: the synchronization signals are transmitted periodically, twice per 10 ms radio frame. In an FDD cell, the PSS is always located in the last OFDM (Orthogonal Frequency Division Multiplexing) symbol of the first and 11th slots of each radio frame, thus enabling the UE to acquire the slot boundary timing independently of the Cyclic Prefix (CP) length. The SSS is located

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in the symbol immediately preceding the PSS, a design choice enabling coherent detection2 of the SSS relative to the PSS, based on the assumption that the channel coherence duration is significantly longer than one OFDM symbol. In a TDD cell, the PSS is located in the third symbol of the 3rd and 13th slots, while the SSS is located three symbols earlier; coherent detection can be used under the assumption that the channel coherence time is significantly longer than four OFDM symbols as shown in Figure 5. The precise position of the SSS changes depending on the length of the CP configured for the cell. At this stage of the cell detection process, the CP length is unknown a priori to the UE, and it is, therefore, blindly detected by checking for the SSS at the two possible positions.

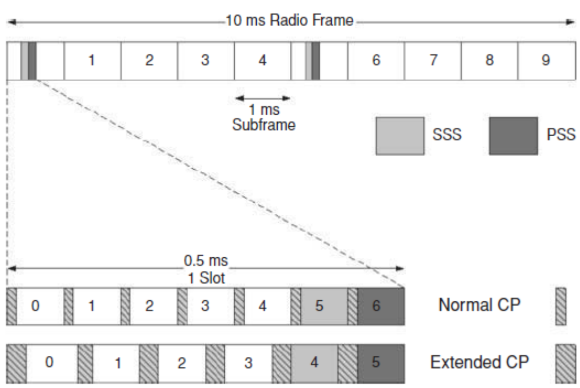

Fig.5 PSS and SSS frame and slot structure in time domain in the FDD case.

3.1 OFDM System Synchronization

OFDMA combines the technologies of OFDM [3] and frequency division multiple access (FDMA), it offers several favorable features such as high spectral efficiency and simple receiver architecture, etc. However, OFDM/OFDMA is sensitive to carrier frequency offsets (CFOs) and timing offsets. To maintain the orthogonality of subcarriers, CFOs and timing errors must be estimated and adequately compensated for. The OFDM technique is also more robust to timing offset than the single carrier system. In fact, the symbol timing offset may vary over an interval equal to the guard time without causing ICI or ISI. Hence, OFDM is quite insensitive to timing offsets. Nevertheless, any deviation from the optimum timing instant means that the sensitivity to delay spread increases, or the system can handle less delay spread than the value it was designed for. To minimize this loss of robustness, the OFDM system should be designed such that the timing error is small compared with the guard interval [20].Since the data stream is transmitted over the wireless channel using the parallel subcarriers, the quality of reception on individual subcarrier is not very important, compared to the single-carrier system. If one of the subcarriers is in error due to deep fade or narrowband interference, the whole data stream can still be recovered with sufficient channel error coding and interleaving [26]. This is an inherent advantage of the spread spectrum communication.

3.1.1 Timing Offset

In single-user or downlink multiple-user scenarios, the timing offset is caused by incorrect symbol timing synchronization. In general, the multiple timing-offsets issue in the OFDMA uplink can be solved by increasing the CP duration, so that it covers both the longest transmission delay and the channel's maximum delay spread. This technique, however, increases system's overhead, and therefore reduces the system's throughput [18, 19]. Another method to alleviate the multiple timing-offsets is called "timing advance" in GSM world, where the BS periodically measures the transmission delay of each user, and sends a message in the downlink control channel to request the user to transmit earlier by a timing-advance value so that its signal reaches the BS at the same time as the others. The OFDMA system with sufficient CP can handle small timing offset misalignment, and such timing offset only introduces a phase rotation at the output of the OFDMA modulator. This phase is linear in terms of frequency, i.e. time-invariant and frequency-dependent, and will be removed in the channel estimation/correction process.

3.1.2 Carrier Frequency offset

The frequency offset is resulted from the misalignment of the carrier-frequency oscillator at the receiver with the one at the transmitter, and also from the Doppler shift of the wireless medium.
It is worth to note that both of the ICI terms can be expressed as deterministic function, which depend on a number of parameters, namely the channel gain, modulated data symbol, and the distance (in terms of frequency) between interfering subcarrier and interfered one. If the distance between interfering subcarrier and interfered one is an integer number of subcarrier spacing, then the ICI is evaluated to zero, or the orthogonality between subcarriers are preserved. In this case, there is no interference occurring. If the distance is non-integer, the value of the periodic-sinc function will be non-zero. One can observe that the ICI level decreases quickly as the distance between the two subcarriers k and k0 increases, and it reaches local maximum when the CFO value _fu approaches half of the subcarrier spacing.
The CFO value of user(s), which indicates the frequency misalignment between the transmitter and the receiver, is selected randomly between [−fmax, +fmax], where fmax is the maximum normalized CFO. The FFT size is N = 128, and the modulation scheme used in evaluation is Quadrature Phase Shift Keying (QPSK). In the single-user without CFO correction scenario, where there is only one user in the system and the receiver does not compensate for the user's CFO, one can observe that the performance degrades quickly with the increase of CFO value. This is expected result, as the OFDM technique is known to be very sensitive to frequency offset: To achieve negligible degradation of about 0.1 dB, the frequency offset must be kept to be less than 1% of the subcarrier spacing [8]. Therefore, it is strictly required that any frequency offset in the received signal be estimated and corrected before arriving to the OFDM demodulator.

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4. CONCLUSION

The OFDMA technique is currently considered as the preferred solution for the physical layer of the next generation broadband wireless networks. OFDMA and SC-FDMA are the multiple-access versions of OFDM and a similar modulation scheme, Single-Carrier Frequency-Domain Equalization (SC-FDE). SC-FDMA offers similar performance and complexity as OFDM. However, the main advantage of SC-FDMA is the low PAPR (peak-average-power ratio) of the transmit signal. This success comes from the fact that OFDMA combines the multiuser ability of FDMA with the advantages of the famous OFDM technique, thus creating a flexible and highly efficient multiple access scheme. Similar to OFDM, OFDMA is capable of simplifying the equalization task at the receiver in a multipath fading environment, increasing the robustness to narrowband interference and offer high spectra efficiency. In addition, by letting users share available subcarriers simultaneously, OFDMA offers an increment in the level of bit-granularity and a possibility to apply dynamic subcarrier allocation scheme to achieve multiuser diversity. However, one of the major drawbacks of OFDMA is its sensitivity to the TO and CFO, especially in the uplink. While the TO can be overcome by using sufficiently long CP, the CFO problem is more difficult to deal with. Due to oscillator inaccuracy and Doppler shift, each user in the uplink of the OFDMA-based system experiences an independent CFO, which destroys the orthogonality among subcarriers and consequently produces ICI and MUI. These CFOs must be estimated and accounted for before decoding data at the receiver, or severe performance degradation will occur. The goal is to provide practical solutions to alleviate the synchronization issues in the uplink of the OFDMA-based system.

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