Orthogonal Frequency Division Multiple Access in WiMAX and LTE – A Comparison

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Abstract—**Orthogonal frequency division multiple access (OFDMA) has been adopted by all the proposals which have been considered for the fourth generation (4G) wireless technologies. Specifically, the two main contenders in the 4G marketplace are likely to be evolutions of WiMAX and LTE. In this work, we compare the use of OFDMA in these standards.**

Keywords- OFDMA, WiMAX, LTE

I. Introduction

This IEEE 802.16e based WiMAX and 3GPP based LTE are the two standards that are likely to dominate the 4G wireless landscape [1, 2]. Both use several common technologies with subtle differences in the approach. One of the common technologies is orthogonal frequency division multiple access (OFDMA). In WiMAX, OFDMA is used both on the downlink (DL) and the uplink (UL) whereas in LTE it is used only on the DL. The reason for choosing OFDMA is based on several advantages which are well documented in the literature [1]. Some of the important reasons are the multipath handling capability, scalability of operation in different bandwidths, capability to handle different data rates, and the ease with which it can be combined with multiple antenna techniques.

The advantages of OFDM based transmission in a multipath environment is well known, leading to relatively simpler channel compensation techniques. In addition, frequency diversity (FD) and channel feedback can be used effectively to improve robustness and throughput. As support for higher data rates was a major requirement in modern wireless systems, the use of OFDM has been considered to be suitable for the above reasons. Several technologies like DSL, powerline communications, WLANs, wireless USB and now 4G cellular have adopted OFDM as the base technology due to its ability to handle multipath. One of the features of the current cellular systems has been the separation of technologies for data and voice. For example, GSM and UMTS cater to voice very effectively, whereas HSPA and EVDO cater to data services. This approach needs investments in multiple radio technologies and core networks leading to higher costs for services. For next generation wireless systems, an integrated radio and core network catering to various services is envisaged. The use of OFDMA technology helps achieve this goal as resources can be split into smaller granular units which can be allocated for various services as required. There is uncertainty about the bandwidth availability for 4G wireless systems and consequently, a technology which can be easily scaled across different bandwidths is more appropriate. The OFDMA technology fits this bill as certain basic parameters like the subcarrier spacing can be kept constant leading to reuse of baseband algorithms in different implementation scenarios.

The ability of OFDM systems to integrate well with MIMO technology (also called as MIMO-OFDM) is a factor in the choice of OFDMA as the latter is considered vital for achieving high spectral efficiencies in 4G wireless systems. Successful implementations of MIMO-OFDM in IEEE 802.11n based WLANs have removed any doubts about the practical viability of the technology for wireless systems [3]. Certain disadvantages like peak-to-average power ratio (PAPR) have been the reason for not using OFDMA on the UL in LTE. However, intelligent use of the time-frequency resources in WiMAX can reduce the PAPR burden on the mobile in a practical context [4]. Our focus will be on the use of OFDMA in DL for LTE and WiMAX systems. We shall compare the usage and relate it to the various concepts like frequency and multiuser diversity. Specifically, we shall review the signals that have to be observed by a mobile before it performs network entry.

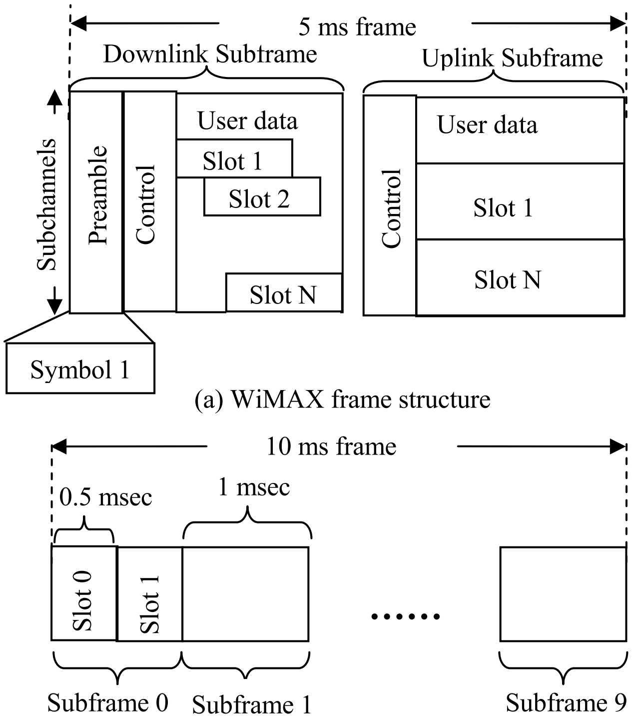
II. Use of OFDMA in WIMAX and LTE

A. *Frame Structure*

In WiMAX , a frame duration of 5 ms is used along with time division duplexing (TDD). The frame is divided into OFDM symbols (for e.g., 48) of which some are allocated for DL and the rest for UL transmissions. The first symbol in the frame is used for preamble transmission. Control and data transmissions are sent using subchannels which are formed out of a group of subcarriers. A typical allocation spans the subchannel and symbol axes and typically a 2-dimensional region is assigned for a transmission for both DL and UL transmissions as shown in Fig.1. The basestation (BS) announces a schedule every frame period (i.e., 5 ms) to convey the DL and UL allocation. In LTE, the frame duration of 10 ms is divided into subframes of 1 ms duration. Two slots of 0.5 ms duration each are formed out of a subframe. The BS schedules transmissions every 1 ms and resource blocks are formed from the subcarriers for allocation on the DL.

B. *Resource mapping from subcarriers*

Subcarriers (also referred to as resource elements in LTE) are the smallest granular units in the frequency domain and OFDM symbol duration is the smallest granular unit in the time domain in OFDMA systems. However, subcarriers are too large in number to handle in the allocation plane and hence groups of subcarriers are considered together in an OFDM symbol. On the time axis, a group of OFDM symbols are handled together to minimize the signaling overhead while still achieving granularity in the achievable rates so as to support various services.



(a) WiMAX frame structure

(b) LTE frame structure

Figure 1. Frame structures in WiMAX and LTE

In WiMAX, subchannels are formed from a group of subcarriers. There are 2 important subchannelization methodologies; one is based on a distributed subcarrier grouping called as partially used subcarriers (PUSC) and the other is based on adjacent subcarrier grouping called as Band AMC (BAMC) [1]. The number of subcarriers in a subchannel can vary between the two methods. A slot is formed by combining a subchannel with different numbers of OFDM symbols. In all the subchannelization methods used in WiMAX, 48 data subcarriers are available in a slot. For example, in PUSC, 24 subcarriers over 2 consecutive OFDM symbols makeup a slot while in the popular BAMC implementation, the slot is made up of 16 subcarriers spread out over 3 OFDM symbols. In PUSC, the subchannel bandwidth is about 250 KHz while in BAMC it is about 170 KHz. Hence, the minimum PHY layer data rate that is possible on the DL assuming a 5 ms frame is 9.6 Kbps.

In LTE, 12 adjacent subcarriers are grouped as an unit in the frequency axis and 7 OFDM symbols (or 6 OFDM symbols in case of extended CP) are considered as an unit in the time axis. The 84 (72) subcarriers thus grouped is called as a resource block (RB). However, 2 RBs are the minimum unit allowed in a frame and this implies that 168 subcarriers is the minimum number of subcarriers that can be allocated in the case of LTE. The minimum PHY layer rate that can be supported on the DL is 16.8 Kbps. For transmitting certain control messages, mini resource blocks consisting of 4 contiguous subcarriers in an OFDM symbol can also be used.

C. *Use of Frequency Diversity*

The multipath channel responses are likely to be frequency-selective for both these wideband wireless systems. Consequently, the frequency diversity (FD) in the channel can be leveraged by suitable mapping of subcarriers to subchannels and by coding and interleaving. It has been shown that by leveraging FD, the performance of OFDMA can be much better than that of single carrier FDMA (SCFDMA) systems which have been considered in the UL of LTE due to power efficiency reasons [6].

In WiMAX, in the mandatory subchannelization method called as PUSC, subchannels are formed by grouping 24 subcarriers which are present in different parts of the spectrum. This pseudorandom selection of the positions of the subcarriers is dependent on the CELL_ID (DL_perm_base) and is clearly specified in the standard. Analysis of the subcarrier positions that are assigned to subchannels for various CELL_IDs show that the positions are distributed over the entire band as seen in Table 1. All the basic control messages are also sent using this diversity based subchannelization method so that it can benefit from the gain due to the frequency selectivity in the channel. To choose the appropriate modulation and coding (MCS) to be used over this subchannel, average channel characteristics are used, i.e., average signal-to-noise plus interference ratio over the entireband used.

TABLE I. SUBCARRIER INDICES OF 2 SUBCHANNELS IN WIMAX FOR A TYPICAL 5MHZ DEPLOYMENT

Scr No.	Sch 0	Sch 1	Scr No.	Sch 0	Sch 1	Scr No.	Sch 0	Sch 1
1	48	57	9	222	227	17	357	356
2	52	105	10	277	274	18	362	359
3	106	109	11	281	285	19	366	367
4	112	116	12	288	286	20	370	372
5	115	140	13	292	297	21	375	380
6	131	144	14	330	329	22	379	383
7	134	216	15	335	333	23	387	385
8	218	224	16	339	340	24	391	396

Scr – Subcarrier, Sch - Subchannel

In LTE, a RB contains the same 12 contiguous subcarriers for 7 OFDM symbols. However, to leverage FD, instead of using the same RB in the second part of the subframe another RB can be used in the second slot of the subframe as illustrated in Fig 2. The difference from WiMAX is that within an OFDM symbol, there is no FD. However, since the coded and interleaved data is distributed over a subframe, the FD can be leveraged in LTE as well. Certain control messages in LTE use small bunches of contiguously placed subcarriers spread out over the entire bandwidth to leverage FD.

Based on the implementation trends, it is likely that WiMAX is placing more emphasis on FD when compared to LTE. Since the feedback rate in WiMAX is slower as compared to that in LTE, one can expect that channel information will be leveraged strongly in LTE at the cost of detailed feedback. WiMAX will tend to use FD in more situations and will not depend critically on the feedback.

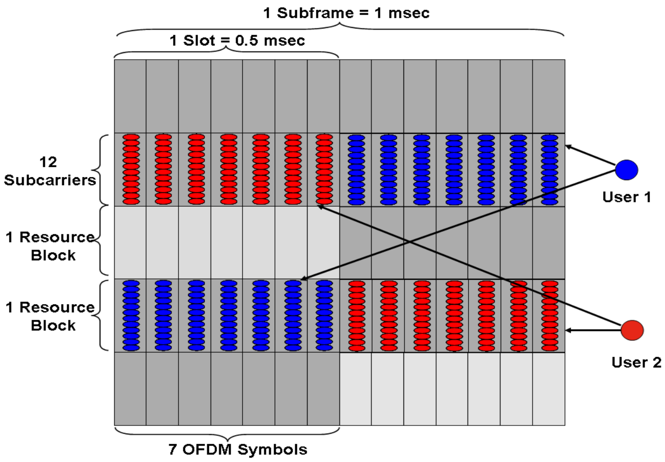


Figure 2. Frequency distributed data mapping in LTE Downlink

D. Use of Multiuser Diversity

In broadband wireless systems, the multipath channel response is frequency selective and depending on the location of the users, the frequency selectivity can differ between users. Thus, there is a potential for using multiuser diversity (MUD), i.e., usage of the differences in frequency selectivity in the channel responses by smart scheduling [7]. However, for leveraging this, one needs accurate feedback of the channel response in the frequency domain and the scheduler has to take the time-frequency characteristics of the channel for scheduling. For instance in 3.5 G systems like EVDO the MUD is leveraged using only the time-varying nature of the channel, in OFDMA, there is a potential for using both the time and frequency variation of the channel leading to higher gains.

In WiMAX, the BAMC method of subchannelization uses groups of contiguous subcarriers spread out over a few OFDM symbols to achieve multiuser diversity. The subcarriers are organized into groups of 9 contiguous subcarriers which are called as bins, as in Fig 3. Each bin has 8 data and 1 pilot subcarrier and four such bins are called as a band. The user feeds back the best 4 bands as seen by the user and also updates this information using certain messages defined in the standard. Based on this, the basestation chooses 2 bins in one of these bands and allocates the same bin over 3 consecutive OFDM symbols resulting in 48 data subcarriers for a BAMC slot. The above BAMC subchannelization is the most popular method which is needed for WiMAX certification.

In WiMAX, the channel feedback is used to determine the best bands for a user. The feedback is typically the received signal strength indicator (RSSI) and the signal to interference plus noise ratio (CINR). The statistics of these quantities are reported regularly using medium access control (MAC) messages. In addition, there can be messages which can report changes in conditions as well as respond to requests from the BTS. For BAMC, a single feedback value is used for a contiguous set of 36 subcarriers.

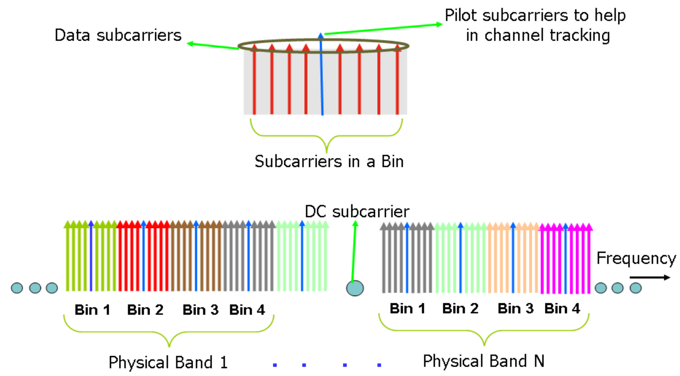


Figure 3. AMC Subchannels in 802.16e

In LTE, RBs are formed from contiguous bunch of subcarriers over several OFDM symbols and the same RBs can be assigned for the subframe duration which is the scheduling interval in LTE. The RB to be used for sending data to a user is chosen by the BTS and it uses the channel feedback from the mobile to schedule a RB for the user in a frame. The channel feedback in LTE, rather than sending explicitly the downlink channel status, sends recommendation on the transmission configuration for the base station for its scheduled downlink. The mobile recommendations are based on its transport block error rate.

The feedback can be periodic, where the mobile sends channel feedback in a separate control channel at predefined regular time intervals. The maximum and minimum period of feedback transmission are sent in a separate control channel. Typically, the minimum duration between feedback messages is 2 ms and the maximum gap between feedback messages is 160 ms. In aperiodic feedback, the BTS requests the mobile to send the channel status report. There are different modes of channel feedback which are differentiated in their frequency resolution. Depending on the mode of feedback, the channel feedback can be sent as one value for the entire operating bandwidth or as a sequence of values for a sequence of sub bands covering the entire bandwidth. The sub bands are basically groups of RBs. The minimal bandwidth resolution of the feedback that is possible in LTE is 2 RBs.

Hence, both standards have provisions for leveraging MUD. In WiMAX, it is currently an option but it is expected to be supported by all vendors since it is required for certification. In LTE, the default resource formation is based on MUD and this was a strong factor in the selection of OFDMA for the DL in LTE. In both standards [1, 2], the FD and MUD based subchannelization can be present in the same frame. In WiMAX, the concept of zones is used to separate the 2 (or more) types of transmission; typically, for cell edge and/or high-speed mobile users, the FD based method is preferred. For low mobility, close to the BTS users, BAMC can be used to improve throughput. In WiMAX, FD and MUD based transmission cannot coexist in time whereas in LTE both can be used simultaneously for different users.

E. Use of Intereference Diversity

In WiMAX, the subchannel formation depends on the CELL_ID. To operate with tight frequency resource, the subcarriers used in a reference subchannel in a reference cell are distributed in different subchannels in the reuse cells. Hopefully, the different subchannels will be allocated to different users [8] leading to frequency selective interference power. Hence, the user is likely to experience interference diversity which is likely to give better performance than the dominant interferer case. Note that interference diversity can be leveraged only in the case of PUSC transmissions. For the BAMC transmissions, interference diversity cannot be used but the MUD with the channel feedback can be used to obtain significant performance benefits.

In LTE, since the RBs are allocated to the users independent of the CELL_ID, the interference on the DL won't be randomly distributed across RBs of neighboring cells. Thus, there is no interference diversity on the DL in LTE. In order to support the QOS to the cell edge users or to increase the capacity, interference coordination is achieved between LTE basestations by assigning suitable power.

III. NETWORK ENTRY STEPS IN WIMAX AND LTE

To compare the 2 technologies, we thought it would be useful to compare the steps in the network entry process. This will clearly delineate the various control signals/messages being sent in the OFDMA framework by these technologies. Both WiMAX and LTE use frame based transmissions and the first task for any mobile is to identify the start of the frame in the presence of multipath channel, frequency offsets, and Doppler shifts. We shall review the various signals that can be used to achieve frame synchronization in the two standards.

A. Synchronisation

In WiMAX, a preamble is transmitted at the start of every frame [4, 5]. The frame duration is not fixed but the current popular implementation is 5 ms. The preamble signal is generated by using every third subcarrier in the allowed bandwidth. For example, the current popular bandwidth for WiMAX is 10 MHZ which implies a total of 1024 subcarriers. After leaving out guard subcarriers, 1/3 of the rest is used for preamble transmission. The pseudorandom sequence to be sent on the subcarriers is specified in the IEEE 802.16e standard and once the CELL_ID (cell identifier value) variable is selected by the operator, the sequence to be sent on the subcarriers for that particular preamble is determined. To achieve frame synchronization, a mobile uses the time-domain properties of the preamble sequence (which is based on the use of every 3rd subcarrier) along with the structure of the cyclic prefix (CP). Since bandwidth of the system is variable, correct detection of bandwidth is a part of the above operation.

Since the CP is not fixed, a search procedure might have to be performed to obtain the correct CP value. Frequency synchronization can be achieved once the starting point of the frame is detected using the various properties of the preamble. The identification of the sequence sent on the preamble subcarriers helps the mobile determine the CELL_ID which is important for reading further control messages in the frame. The preamble typically spans the entire bandwidth (except for the guard band) and hence, channel estimation can also be performed after the detection of the pseudo-random sequence. Since the preamble is sent at the start of every frame corrections to the channel estimate, frequency, and time can be done using the preamble.

In LTE, the frame synchronization is obtained by detecting the primary synchronization sequence (PSS) which is sent twice in a frame whose duration is fixed at 10 ms. The sequence is sent in the centre 64 subcarriers occupying 0.96MHz bandwidth, irrespective of the bandwidth of operation. Hence, unlike the preamble in WiMAX, the number of subcarriers used for PSS is fixed. Moreover, consecutive subcarriers in the middle part of the bandwidth are used for sending the sequence implying that no information about the bandwidth needs to be known for detecting the PSS. The Zadoff-chu sequence that is loaded onto the subcarriers is specified in the standard. Identification of the PSS in the received signal gives two potential starting points in the frame as there are two PSS transmissions in the frame. The ambiguity is resolved by the secondary synchronization sequence (SSS) which is sent 1 OFDM symbol ahead in the same set of subcarriers as the PSS. The detection of the SSS gives information about the CP duration used and the cell ID. Hence, irrespective of bandwidth, a common processing can be evolved to achieve frame synchronization, CP duration detection, and cell identifier detection. These signals are also used for achieving frequency synchronization. In summary, the frame synchronization in LTE appears to be simpler when considering operation in different bandwidths and different CP durations.

B. Network entry

In WiMAX, a mobile has to search for a valid preamble to acquire frame synchronization. The uncertainties are the RF frequency, bandwidth, CP duration, number of subcarriers, the segment, and the CELL_ID. Once it acquires synchronization, the mobile reads the FCH message which points to the length of the DL-MAP message which contains the various allocations in the frame. In WiMAX, the location of the FCH and the DL-MAP is fixed once the segment is identified in the preamble processing. Using the DL-MAP, further messages like DCD and UCD which occur periodically have to be read along with the UL-MAP to initiate the network entry process.

In LTE, irrespective of bandwidth and the number of subcarriers, the first step remains the same for all mobiles, i.e., locating the PSS and SSS and obtaining the CELL_ID. This is an important difference as compared to WiMAX. However, to read complete system information, one needs to read PBCH which contains information about the bandwidth of the LTE signal. The PBCH message does not leverage FD as it contiguously occupies the 1.08 MHz wide central portion of the transmission bandwidth. To enable reliable decoding of the system messages in the BCH, repetition coding is used.

During the network entry process, the receiver doesn't know whether the basestation had used multiple antennas for the transmission of PBCH. Consequently, the receiver has to determine the number of antennas used by the LTE BTS. For each antenna configuration a different CRC mask is defined in the standard and this can be used in determining the number of antennas. Then one needs to read PCFICH, which gives information about the number of OFDM symbols allocated for the resource allocation messages. Finally, the last step before initiating network entry is to read the PDCCH information which conveys the allocation information to the mobile. A loose link between the various messages, signals in WiMAX and LTE is presented in Table II.

TABLE II. CONTROL MESSAGES / SIGNALS IN WIMAX AND LTE

Information	**Control messages / signals**	
	WiMAX	**LTE**
Frame & Symbol timing, Frequency synchronization, Cyclic prefix information, CELL_ID	Cell Specific Preamble	Cell Specific Primary and Secondary Synchronization signals (PSS & SSS)
Bandwidth	Preamble	Physical Broadcast Channel (PBCH)
Resource allocation messages ; location, MCS, number details	Frame Control Header (FCH)	Physical Control Format Indicator Channel (PCFICH)
Physical layer resource allocation info for both DL and UL transmissions	DL-MAP and UL-MAP	Physical Downlink Control Channel (PDCCH)
Type of MCS used in various parts of the frame or in various slots for both DL and UL	Downlink Channel Descriptor (DCD), Uplink Channel Descriptor (UCD)	Physical Downlink Control Channel (PDCCH)

C. *Performance Bounds for synchronization and channel estimation*

In WiMAX, normally, the channel estimation is done using the preamble. However, taking mobility into account, channel estimation can also be done using the pilots in the data symbols. The frequency domain spacing of the subcarriers where the preamble sequence is transmitted is approximately 33 KHz. The maximum amount of delay spread that can be tolerated for channel estimation is the inverse of the pilot spacing in the frequency domain [10]. Hence, the maximum delay spread that can be tolerated for channel estimation is about 30 μsec. In the mandatory PUSC mode of transmission, the average subcarrrier spacing between pilots is 43.75 KHz. Hence, the maximum delay spread that can be estimated for WiMAX using the data symbols is close to 22.85 μsec. This value is higher than the maximum supported CP duration supported in WiMAX.

Since the preamble PN sequences modulates every third subcarrier, the maximum frequency offset that can be estimated, by correlating the quasi periodic portions of the preamble, is $\pm$16.4 KHz [3]. The maximum Doppler spread that can be taken care by the pilots, for channel estimation, is inverse of the time duration between ofdm symbols carrying pilots. Since the pilots are transmitted in each ofdm symbol which is approximately 100 μsec in duration, the maximum tolerated doppler spread in WiMAX is about 10 KHz . This Doppler spread is much higher than what is likely to occur in practice for most WiMAX deployments.

In LTE, the channel estimation is not done using the PSS and SSS signals. Hence, channel estimation is entirely dependent on the pilots in the data symbols. Consequently, the maximum delay spread that can be estimated is around 11.11 microsec as the pilot spacing in the frequency domain is close to 90 KHz. In LTE the pilots are not transmitted in all the ofdm symbols. The symbols which carry pilots are spaced in time by 4*71.42 μsec which implies that the maximum doppler spread that can be tolerated in channel estimation is around 3.5 KHz. Hence, considering both the pilot carrying symbols, where the pilots are staggered in the subcarrier positions, maximum delay spread that can be estimated is around 22 μsec. For LTE, maximum frequency offset tolerable as in given in [9] is +/-13.45 KHz.

IV. CONCLUSION

We have considered the use of OFDMA in WiMAX and LTE standards. Both systems leverage many facets of OFDMA and these include FD, MUD, and the granularity available in the frequency and time axes. Subtle differences leading to usage of different advantages of OFDMA were highlighted. We plan to quantify some of the performance aspects as a part of future work.

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REFERENCES

[1] Jeffrey G. Andrews, Arunabha Ghosh, Rias Muhamed, *Fundamentals of WiMAX: Understanding Broadband wireless Networking*, Prentice Hall, 2007.

[2] Stefania Sesia, Issam Toufik, matthew Baker, *LTE – The UMTS Long Term Evolution: From Theory to practice*, Wiley, 2009.

[3] E. Perahia and R. Stacey, *Next Generation Wireless LANs*, Cambridge Univeristy Press, 2008.

[4] IEEE 802.16-2004, "Local and Metropolitan Area Networks — Part 16: Air Interface for Fixed Broadband Wireless Access Systems," May. 2009

[5] Wenze Qu Jie Chen Zhongrui Qi Hao Zhang Xin Qiu Yi Liu , "Low Complexity Cell Search Algorithm for Mobile OFDMA Systems", pages 1-4, Proc. *4th International Conference on Wireless Communications, Networking and Mobile Computing*, 2008. WiCOM '08.

[6] H. Sari, " A review of OFDMA and SC-FDMA and some recent results,"WICAT SC-FDMA Workshop, March 2009 http://scfdmaworkshop.googlepages.com/

[7] D. Tse and P. Viswanath, *Fundamentals of wireless communications*, Cambridge University Press, 2006.

[8] S. Srikanth et.al., "Orthogonal Frequency Division Multiple Access : Is it the Multiple Access System of the Future?**"**, whitepaper downloadable at http://www.au-kbc.org/comm/comm_resource.htm

[9] 3GPP TS 36.101: "Evolved Universal Terrestrial Radio Access (E-UTRA); Use equipment transmission and reception.

[10] H.Arslan et al, "Channel Estimation for Wireless OFDM Systems", IEEE Surveys and Tutorials, No 2, Vol 9, 2nd Quarter 2007.