Redline Communications Inc.

Throughput Performance of Mobile WiMAX Systems

WiMAX Whitepaper

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Physical Layer (PHY) Throughput Performance

The PHY layer throughput indicates the aggregate data rate transferred over the air which includes overhead from higher layers. The PHY throughput is an upper limit on the expected throughput of a system.

Throughput for Mobile WiMAX which is based on the Scalable OFDMA (S-OFDMA) PHY of the IEEE 802.16e-2005 standard will depend on the permutation mode (PUSC, FUSC, AMC, etc.). Here, we focus on the PUSC mode which is the standard, WiMAX Forum certifiable permutation mode for Mobile WiMAX.

OFDMA divides the channel bandwidth into a number of sub-carriers. In S-OFDMA, the carrier spacing is constant, therefore, the number of carriers increase the wider the channel bandwidth. S-OFDMA supports 128, 512, 1024 or 2048 carriers, of which 512 and 1024 are most common as they are part of the Mobile WiMAX system profile.

Figure 1 shows a description of the sub-carrier space constituting a frequency channel. Sub-carriers include null sub-carriers at the edges of the channel for guard band purpose, pilot carriers used for channel estimation and corrections resulting from mobility (e.g. phase noise), and data sub-carriers used to carry management and traffic data. Table 1 shows the utilization of carriers in Mobile WiMAX. Note that 3.5 MHz channel bandwidth is not part of the IEEE 802.16e-2005 standard for the S-OFDMA PHY, but is supported by the RedMAX 4C base station. Also, there is a higher number of pilot sub-carriers for the uplink (mobile to base station) path which is designed to provide better correction for effects of mobility on the uplink communication channel.

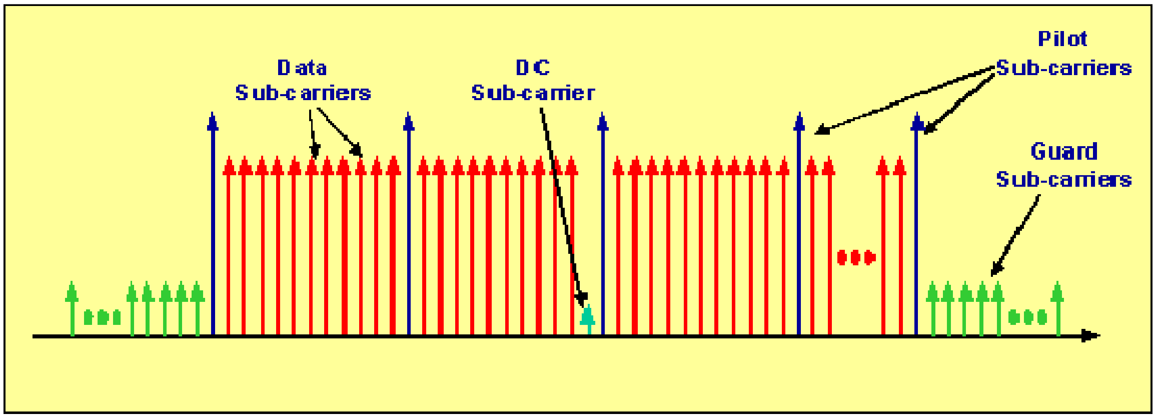

Figure 1 S-OFDMA Sub-carrier structure.

Table 1 Sub-carrier utilization in Mobile WiMAX.

Bandwidth (MHz)	3.5		7		5		10	
Total Sub-Carriers	512		1024		512		1024	
Path	DL	UL	DL	UL	DL	UL	DL	UL
Used Carriers	420	408	840	840	420	408	840	840
Data Carriers	360	272	720	560	360	272	720	560
Pilot Carriers	60	136	120	280	60	136	120	280
Null Carriers	92	104	184	184	92	104	184	184
Sub-channels	15	17	30	35	15	17	30	35

Based on the sub-carrier space, a number of parameters for the S-OFDMA PHY can be derived. These parameters are shown in Table 2 for a frame of 5 msec and cyclic prefix of 1/8 as per the Mobile WiMAX System Profile.

Table 2 Key parameters for the S-OFDMA PHY in PUSC mode.

Mode	802.16e S-OFDMA PHY; PUSC Permutation			
Bandwidth (MHz)	3.5	7	5	10
Sampling Factor	8/7	8/7	28/25	28/25
FFT Size	512	1024	512	1024
Sampling Frequency (MHz)	4	8	5.6	11.2
Sample Time (msec)	250	125	178.6	89.3
Sub-carrier Frequency Spacing (kHz)	7.8	7.8	10.9	10.9
Useful Symbol Time (μsec)	128	128	91.4	91.4
Cyclic Prefix	1/8	1/8	1/8	1/8
Guard Time (μsec)	16	16	11.4	11.4
OFDMA Symbol Time (μsec)	144	144	102.9	102.9
Frame Length (msec)	5	5	5	5
Symbols/Frame	33	33	47	47
RTG (μsec)	60	60	60	60
TTG (μsec)	188	188	106	106

Table 2 also shows the total number of symbols available for control and data traffic in an S-OFDMA frame. These symbols are assigned to the downlink (base station to mobile) or uplink path. The maximum number of symbols for 3.5 and 7 MHz channels is 33, while for 5 and 10 MHz channels it is 47. We have already accounted for the transition gaps between the downlink and uplink symbols in RTG and TTG. Figure 2 shows the frame structure for Mobile WiMAX.

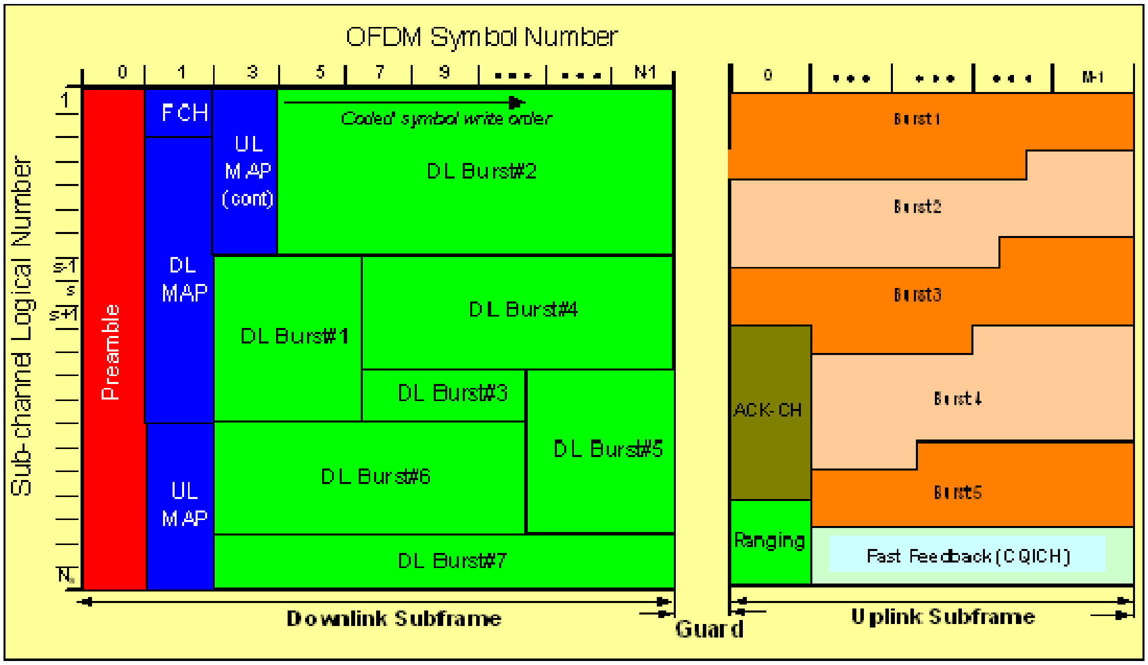

Figure 2 Mobile WiMAX Scalable OFDMA frame structure.

The throughput rates can be calculated from the number of available data carriers and the number of symbols in each sub-frame. Table 3 shows the throughput rate per modulation coding scheme (MCS) for a 60:40 traffic ratio (20:13 and 28:19 DL:UL symbols for 3.5/7 MHz and 5/10 MHz channels, respectively). Note that 64QAM is not part of the Mobile WiMAX System Profile, but will be supported in the RedMAX 4C base station.

Table 3 Physical layer throughput (Mbps) for PUSC mode assuming 60:40 traffic ratio.

Bandwidth (MHz)	3.5		7		5		10	
Modulation \ Path	DL	UL	DL	UL	DL	UL	DL	UL
BPSK ½	0.7	0.4	1.4	0.7	1.0	0.5	2.0	1.1
QPSK ½	1.4	0.7	2.9	1.5	2.0	1.0	4.0	2.1
QPSK ¾	2.2	1.1	4.3	2.2	3.0	1.6	6.0	3.2
16QAM 1/2	2.9	1.4	5.8	2.9	4.0	2.1	8.1	4.3
16QAM 3/4	4.3	2.1	8.6	4.4	6.0	3.1	12.1	6.4
64QAM 2/3	5.8	2.8	11.5	5.8	8.1	4.1	16.1	8.5
64QAM 3/4	6.5	3.2	13.0	6.6	9.1	4.7	18.1	9.6
64QAM 5/6	7.2	3.5	14.4	7.3	10.1	5.2	20.2	10.6

We can add the downlink and uplink rates to find the total throughput supported by Mobile WiMAX physical layer.

Layer 2 (MAC) Throughput Performance

Medium Access Control (MAC) layer rate factor control overhead into the throughput performance. From Figure 2, each frame starts with a preamble symbol used for synchronization and downlink channel estimation. This is followed by a frame control header (FCH) which provides information to decode the MAP messages that follow (e.g. sub-channels used by the sector in the current frame, coding and length of the subsequent DL-MAP message, etc. The MAP messages indicate the resource allocation (user data bursts) for the downlink and uplink sub-frames.

UL sub-frame starts with the uplink control channels: CQICH, ACKCH and Ranging Channels. The CQICH and ACK channels is used for transmitting channel state information and ACK information from mobile stations to the base station, respectively. The ranging channel is used for various types of ranging (initial, refresh, and reentry).

The control overhead consists of fixed and variable parts. The fixed part includes the preamble, FCH, and control channels. The variable part includes the DL-MAP and UL-MAP which also consist of a fixed and a variable part. The DL-MAP and UL-MAP contain as many Information Elements (IE) as the number of data bursts. Each IE has a one-to-one correspondence to a user data burst. Table 4 shows an accounting of the size of the fixed allocation for DL-MAP and UL-MAP. Table 5 shows the accounting for the DL-MAP-IE and UL-MAP-IE.

Table 4 Fixed allocation of DL-MAP and UL-MAP.

DL-MAP	**Bits**
Management Message Type	8
PHY SYNC. Field	32
DCD Count	8
Base Station ID	48
Number of OFDMA Symbol	8
Nibble Padding (if needed)	4
Total DL-MAP	**104**
UL-MAP	
Management Message Type	8
Uplink Channel ID	8
UCD Count	8
Alloc. Start Time	32
No. of OFDMA Symbol	8
Nibble Padding	4
Total UL-MAP	**64**

Table 5 Size of DL-MAP-IE and UL-MAP-IE.

DL-MAP-IE	**Bits**
CID	16
N_CID	8
DIUC	4
OFDMA Symbols Offset	8
Sub-channel Offset	6
Boosting	3
Number of OFDMA Symbols	7
Number of sub-channels	6
Repetition Coding Indicator	2
Total DL-MAP_IE	**60**
UL-MAP-IE	
CID	**16**
UIUC	**4**
Duration	**10**
Repetition Coding Indicator	**2**
Total UL-MAP_IE	**32**

The CID is the connection identifier that uniquely determines a connection between a base station and a mobile station in one direction. The N_CID is the number of CIDs in the corresponding burst (N_CID = 1 in the example above). Each burst can contain more than one CIDs. DIUC/UIUC (Downlink/Uplink Interval Usage Code) indicates the usage information of the corresponding burst (e.g., modulation and coding schemes used). The OFDMA Symbol offset is the offset for the symbol at which the burst starts (measured in symbols). The sub-channel offset is the lowest index OFDMA sub-channel used for carrying the burst, starting from sub-channel 0. The boosting field indicates whether the sub-carriers for this allocation are power boosted. For example, 000 means no power boost, 001 means +6db, etc. The number of OFDMA symbols is the number of symbols that are used to carry the burst. Similarly, the number of sub-channels is the number of sub-channels that are used to carry the burst. The repetition coding indicates how many times the code is repeated. For example, 00 means no repetition, 01 means two, 10 means 4, and 11 means 6 repetitions.

Based on the above, the size of the MAP messages depends on the number of users active on a sector and the size will be as follows:

DL-MAP: 104 + N * DL-MAP-IE bits
UL-MAP: 64 + N* UL-MAP_IE bits

Since the MAPs carry critical information, all the mobile stations in the cell are supposed to decode them correctly. To make sure that even the mobile stations near the cell boundary decode the MAPs correctly, the coding overhead is rather high for the MAP data. In case of Mobile WiMAX, these parts are encoded with MCS QPSK 1/2 with 4 repetitions. Therefore, effective data rate is 1/8. Depending on the frequency reuse, repetition 6 may have to be used (e.g. frequency reuse of 1). Because of this, the MAP overhead can be quite a big portion of a WiMAX frame. For an effective coding rate of 1/8 over QPSK (2 bits) coding, each symbol can carry only 90 or 180 bits for 3.5/5 MHz and 7/10 MHz channels, respectively (360 or 720 carriers * 2 bits * 1/8).

In all, common estimates for MAC layer overhead are at 8 symbols for the downlink sub-frame and 3 symbols for the uplink sub-frame. Later, we describe how the RedMAX 4C base station implements specific scheduling techniques to reduce the amount of overhead and increase capacity.

Table 6 shows an example of MAC layer throughput considering 8 symbols of overhead for the downlink sub-frame and 3 symbols for Mobile WiMAX in PUSC mode with 60:40 traffic ratio (including CP of 1/8 and frame length if 5 msec).

Table 6 Example of MAC layer throughput for Mobile WiMAX assuming 8 symbols of downlink sub-frame overhead and 3 symbols of uplink sub-frame overhead.

Bandwidth (MHz)	3.5		7		5		10	
Modulation \ Path	DL	UL	DL	UL	DL	UL	DL	UL
BPSK ½	0.4	0.3	0.9	0.6	0.7	0.4	1.4	0.9
QPSK ½	0.9	0.5	1.7	1.1	1.4	0.9	2.9	1.8
QPSK ¾	1.3	0.8	2.6	1.7	2.2	1.3	4.3	2.7
16QAM ½	1.7	1.1	3.5	2.2	2.9	1.7	5.8	3.6
16QAM ¾	2.6	1.6	5.2	3.4	4.3	2.6	8.6	5.4
64QAM 2/3	3.5	2.2	6.9	4.5	5.8	3.5	11.5	7.2
64QAM ¾	3.9	2.4	7.8	5.0	6.5	3.9	13.0	8.1
64QAM 5/6	4.3	2.7	8.6	5.6	7.2	4.4	14.4	9.0

Throughput Improvement Techniques

To improve the throughput rate of WiMAX systems, Redline has implemented a number of proprietary techniques following extensive field trials and customer deployments conducted over several years. These techniques fall under a class of cross-layer optimization techniques that optimizes across the whole signal transmit chain and factor in the application services carried over the WiMAX network such as VoIP.

Predictive Scheduling: Polling for traffic requirements of a subscriber station leads to significant overhead and reduces resources available to carry user data. Predictive scheduling algorithms anticipate the traffic demand of a subscriber based on the type of application and schedules subscribers in a manner that reduces polling overhead and increases overall system capacity and throughput. Predictive scheduling was tested and proven to reduce overhead by up to 70%.

Optimal frame building/scheduling techniques: Fine tuning between packet fragmentation and frame structure. This is a combination between a stiff scheduler and frame structure adaptation. This technique allows avoidance or minimization of padding and balancing traffic over the wireless link. This feature is particularly tricky to accomplish when the MAC layer is developed by a vendor and the scheduler by another vendor.

Dynamically combination broadcast/multicast/unicast poling group's function of QoS of active SF's: This feature allows the optimization of capacity over the wireless link particularly for VoIP traffic. For instance, when large number of voice calls is active, a combination of piggyback/unicast/multicast is used to maintain the required latency and keep a large number of sessions active. It is particularly important to match the action of the subscriber station with the base station scheduler in case of GPSS (grant per SS) bandwidth request mode. GPSS can lead to a SS with multiple service flows receiving grants that may be the result of a few cumulated requests (hence the SS is provided with much greater capacity than required) or more critically GPSS can lead to a grant that is smaller than cumulated requests in which case the scheduler needs to weigh the allocations and decide on a how to serve them. Therefore, to optimize the wireless link capacity and respect the QoS metrics, the SS must understand the base station 'language' of granting bandwidth, as otherwise, the service flow may be starved of or overfed with capacity. This applies in a significant manner to multiple host/multiple service flow terminals.