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Efficient Transmission of Multicast MAPs in IEEE 802.16e*

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SUMMARY The institute of electrical and electronics engineers (IEEE) 802.16e is designed to support a wide range of applications with various quality of service requirements. Since MAP signaling overhead can unacceptably be large for voice traffic, IEEE 802.16e suggests the use of multicast sub-MAPs whose messages are encoded according to the channel condition. In this case, it is desirable for the base station to properly choose a modulation and coding set associated with the channel condition. In this letter, we consider the use of an adaptive modulation coding scheme for the multicast sub-MAPs without explicit information on the channel condition. The proposed scheme can achieve the same MAP coverage as the broadcast MAP while minimizing the signaling overhead. Simulation results show that when it is applied to voice-over-internet protocol (VoIP) services, the proposed scheme can significantly enhance the VoIP capacity.
key words: *MAP overhead, sub-MAP, WiMAX, VoIP*

1. Introduction

The institute of electrical and electronics engineers (IEEE) 802.16e standard specifies a new wireless access system, which provides a state of the art solution for the last-mile technology [1]. Mobile worldwide inter-operability for microwave access (m-WiMAX) has been implemented as a commercial IEEE 802.16e based orthogonal frequency division multiple access (OFDMA) system with time-division duplex (TDD). M-WiMAX can support bursty data traffic at high peak rates, while simultaneously supporting streaming video and latency-sensitive voice traffic over the same channel [2]. The use of adaptive modulation and coding (AMC) and hybrid automatic repeat request (HARQ) has also been introduced to m-WiMAX to enhance the coverage and capacity in mobile environments [2].

In IEEE 802.16e (or m-WiMAX), the resource allocation information is conveyed in the MAP message at the beginning of each frame, allowing the scheduler to effectively change the resource allocation on a frame-by-frame basis and so respond to the bursty nature of traffic [1], [2]. The MAP message contains the allocation information on both the downlink (DL) and uplink (UL), called DL-MAP and UL-MAP, respectively. Since the MAP information needs to reliably be delivered to users even near the cell boundary, it is usually encoded by quadrature phase-shift keying (QPSK) modulation at a code rate of 1/2 with six repetitions (i.e., an effective code rate of 1/12), corresponding to the lowest spectral efficiency of IEEE 802.16e [1], [2]. As a consequence, the signaling overhead for the MAP message is not negligible [3]. In particular, in services of data packets with small sizes such as voice-over-internet protocol (VoIP) traffic, the amount of MAP signaling overhead can unacceptably be large [2].

To reduce the MAP overhead, IEEE 802.16e can utilize multicast sub-MAP messages (sub-MAPs) each of which can be encoded according to the operating condition (e.g., the carrier-to-interference plus noise ratio (CINR)) [1], [2]. It is desirable to optimally choose the modulation coding scheme (MCS) level to minimize the signaling overhead for the sub-MAPs. However, most of previous results have been concentrated on the use of broadcast MAP messages, not on the use of sub-MAP messages [3]–[5].

The base station (BS) needs accurate DL CINR of users to determine the MCS levels for the sub-MAPs. The BS can get the DL CINR from the channel quality indicator (CQI) reported by users. However, it is not easy for the BS to get accurate CINR for the sub-MAPs via the CQI which is used for the purpose of AMC for DL data bursts. For instance, users scheduled only in the UL do not have to report the CQI, and users scheduled in the DL need to send the CQI according to the reporting period of CQI, which is associated with the AMC. Moreover, the BS may not be able to obtain accurate DL CINR of users in high mobility even when it receives the CQI [6]. The MCS level for the sub-MAPs can also be determined based on the average CINR (e.g., slow AMC using the average CINR). However, the BS should provide a margin for the CINR threshold by considering the discrepancy between the average and accurate CINR. In fact, this margin depends on the channel condition (e.g., the channel delay profile) [6], [7].

In this letter, we consider an AMC scheme for the sub-MAPs to reduce the MAP signaling overhead without explicit information on the channel condition. The proposed scheme adjusts the threshold for the MCS according to the user response to the sub-MAPs. The BS lowers the threshold by a small step when a user responds to its own sub-MAP. Otherwise, it raises the threshold by a large step to meet desired message error rate (MER). Then the proposed scheme determines the MCS level considering both the spectral efficiency and the amount of these messages. The proposed scheme can considerably reduce the MAP overhead and thus increase the system capacity when

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applied to services such as VoIP services that require a large MAP overhead.

This letter is organized as follows. Section 2 describes the DL subframe structure and the MAP overhead in the IEEE 802.16e system. Section 3 presents the proposed scheme to determine the CINR thresholds and the optimum MCS level. Section 4 verifies the performance of the proposed scheme by computer simulation. Finally, Sect. 5 concludes the letter.

2. System Description of IEEE 802.16e

2.1 Downlink Subframe Structure

M-WiMAX has a TDD frame structure where each frame comprises DL and UL subframes. The DL subframe comprises a preamble, a frame control header (FCH), MAP messages and multiple DL data bursts [1], [2]. M-WiMAX has a slot comprising 48 data subcarriers as the minimum unit for the resource allocation. Letting S_{FCH}, S_{MAP} and S_{data} be the number of slots for the FCH, MAP message and data bursts, respectively, it can be seen that

$$S_{\text{FCH}} + S_{\text{MAP}} + S_{data} \leq R_{slot} \tag{1}$$

where R_{slot} is the number of maximally allowable DL slots.

2.2 MAP Overhead

We consider the MAP overhead associated with the broadcast MAPs and multicast sub-MAPs. The MAP overhead is defined by the number of slots for the MAP message. Since the FCH uses a fixed number of slots (e.g., four slots in m-WiMAX), the MAP overhead directly influences the system capacity of the DL. Assume that the MCS levels are represented from 1 to M in an ascending order of the spectral efficiency and ρ_m is the spectral efficiency corresponding to MCS level m, and that each user sends a single data burst at each frame. Consider a compressed format which uses one-dimensional allocation of the UL-MAP message excluding the MAC header because the overhead for this type of message is less than that for a normal type of message [1], [3].

The broadcast MAP comprises the DL- and UL-MAP messages. Each MAP message contains multiple information elements (IEs) in proportion to the number of data bursts. It is modulated with an MCS level of 1 (i.e., with the lowest spectral efficiency). When the broadcast MAP is used, the MAP overhead S_{MAP} can be represented as [1]

$$S_{\text{MAP}} = \left\lceil \frac{h_{BC}(N_d, N_u)}{J \cdot \rho_1} \right\rceil \tag{2}$$

where J denotes the number of subcarriers per slot (i.e., 48), $\lceil x \rceil$ denotes the smallest integer not less than x, N_d and N_u are the number of users scheduled in the DL and UL, respectively, the denominator $J \cdot \rho_m$ represents the number of bits in each slot with MCS level m, and h_{BC} denotes the number of information bits for both the DL- and UL-MAP messages containing the allocation information of DL and UL users, respectively. That is, for the resource allocation of the HARQ users, h_{BC} can be represented by [1]

$$88 + \left\{ 20 + \sum_{i=1}^{N_{H\_DL}} (56 + MC_i \cdot 8) + N_d \cdot 36 \right\}_{DL\_IE} + 48 + \{36 + N_{H\_UL} \cdot 24 + N_u \cdot 40\}_{UL\_IE} + 32 \tag{3}$$

where N_{H_DL} and N_{H_UL} equal $\lceil N_d/15 \rceil$ and $\lceil N_u/15 \rceil$, respectively, MC_i denotes the number of MCS levels of users included in the i-th HARQ-DL-MAP IE, and $\{\cdot\}_{DL\_IE}$ and $\{\cdot\}_{UL\_IE}$ denote the number of information bits for DL-MAP IEs and UL-MAP IEs, respectively.

The multicast sub-MAP messages are encoded with K MCS levels which are chosen among M MCS levels. The DL-MAP message contains K Sub-MAP-pointer-IEs, while the sub-MAPs contain the information on the resource allocation, DL-MAP IEs and UL-MAP IEs [1]. When the sub-MAPs are used, the MAP overhead can be represented as

$$S_{\text{MAP}} = \left\lceil \frac{h'_{BC}(K)}{J \cdot \rho_1} \right\rceil + \sum_{k=1}^{K} \left\lceil \frac{h_{MC}(b_{d,m_k}, b_{u,m_k})}{J \cdot \rho_{m_k}} \right\rceil \tag{4}$$

where h'_{BC} denotes the number of bits in the DL-MAP message, h_{MC} denotes the number of bits in each sub-MAP, m_k denotes the MCS level for the k-th sub-MAP, b_{d,m_k} and b_{u,m_k} and denote the number of users in the DL and UL, respectively, belonging to the k-th sub-MAP message [1]. Here [1]

$$h'_{BC}(K) = 88 + \{12 + K \cdot 16 + 4\}_{DL\_IE} + 32 \tag{5}$$

and

$$h_{MC}(b_{d,m_k}, b_{u,m_k}) = 40 + \left\{ 20 + \sum_{i=1}^{N'_{H\_DL,k}} (56 + MC'_{k,i} \cdot 8) + b_{d,m_k} \cdot 36 \right\}_{DL\_IE} + \{36 + N'_{H\_UL,k} \cdot 24 + N_{u,m_k} \cdot 40\}_{UL\_IE} + 32 \tag{6}$$

where $N'_{H\_DL,k} = \lceil b_{d,m_k}/15 \rceil$ and $N'_{H\_UL,k} = \lceil b_{u,m_k}/15 \rceil$, and $MC'_{k,i}$ denotes the number of MCS levels of users included in the i-th HARQ-DL-MAP IE of the k-th sub-MAP message. It can be seen that the more the sub-MAPs are used, the more the amount of MAP information is required. To reduce the MAP overhead, it is desirable to consider the number of sub-MAPs and associated MCS levels.

3. Proposed AMC for Multicast Sub-MAPs

In this section, we consider an AMC scheme for the sub-MAPs, where the BS adjusts the CINR threshold for the MCS and chooses the MCS level to minimize the MAP overhead.

IEEE 802.16e users who receive a HARQ-DL-MAP IE in the sub-MAPs should send an ACK signal after a certain amount of delay. However, when users do not successfully receive the sub-MAPs, they do not send an ACK signal through the UL. By detecting the ACK signal, the BS can confirm whether the sub-MAPs are successfully delivered. Users cannot transmit their data bursts without receiving a HARQ-UL-MAP IE in the sub-MAP. In this case, by detecting the data bursts in the UL, the BS can confirm whether the sub-MAPs are successfully delivered. The proposed scheme can adjust the CINR threshold $th_{u,m}$ of user u with MCS level m by monitoring the user response to the sub-MAP as

$$th_{u,m} = th\_init_m + \delta_u \tag{7}$$

where

$$\delta_u = \begin{cases} \delta_u - \Delta_{Dn}; & \text{detection of ACK or UL data} \\ \delta_u + \Delta_{Up}; & \text{otherwise} \end{cases} \tag{8}$$

where th_init_m denotes the initial CINR threshold for user u with MCS level m and δ_u is a threshold margin of user u. Here, Δ_{Dn} and Δ_{Up} denote the step size for the down and up to satisfy desired MER, respectively [8]. Note that the threshold margin is upper-limited by Δ_{max} to avoid unusual large values due to detection errors. The upper limit Δ_{max} corresponds to the largest fade margin for desired MER among possible channel conditions [7]. Thus, the proposed scheme enables the BS to adjust the CINR threshold to satisfy desired MER without explicit channel information. The MCS levels for the sub-MAPs have an effect on the spectral efficiency and the amount of MAP messages. It can be seen from (4) that the MAP overhead is associated with the output from the combination of these two factors. From user-specific CINR threshold $th_{u,m}$ determined above, an AMC function $f_u(\varphi)$ can be defined as

$$f_u(\varphi) = \max\{m | \gamma_u \ge th_{u,m}, \quad m \in \varphi\} \tag{9}$$

where $\varphi = \{m | 1 \le m \le M\}$, γ_u is the CINR of user u and $\max\{\cdot\}$ denotes the maximum value of elements. Thus, the AMC function of user u chooses the maximum MCS level whose the CINR threshold is less than or equal to the CINR (i.e., the largest MCS level achievable in φ). It is possible to generate candidate sets of MCS levels from the distribution of CINR of all users. The minimum and maximum MCS level, defined by x and y, respectively, can be found as

$$x = \min_u f_u(\varphi) \quad \text{and} \quad y = \max_u f_u(\varphi) \tag{10}$$

The number of available MCS levels for the sub-MAPs can be updated according to x and y, i.e.,

$$K' = \min(y - x + 1, K). \tag{11}$$

It may be desirable to include the minimum MCS level for safe delivery of MAP messages. Then, the rest (K' - 1) MCS levels can be chosen from values between (x+1) and y. Consider L candidate sets $\{\phi_{K',i}\}$ each of which comprises K' MCS levels, where

$$\phi_{K',i} = \{q_{i,1}, \cdots, q_{i,K'}\} \tag{12}$$

where $L =_{y-x} C_{K'-1}$ and $q_{i,k}$ denotes the k-th MCS level of the i-th candidate set. Let $b_{d,q_{i,k}}$ be the number of users using MCS level $q_{i,k}$ among N_d scheduled users in the DL and $b_{u,q_{i,k}}$ be the number of users using MCS level $q_{i,k}$ among N_u scheduled users in the UL. That is, they can be obtained from,

$$\begin{array}{ll} \#(u | q_{i,k} \le f_u(\varphi) < q_{i,k+1}) & 1 \le k \le K' - 1 \\ \#(u | f_u(\varphi) \ge q_{i,k}) & k = K' \end{array} \tag{13}$$

for the DL and the UL, respectively, where #(A) denotes the number of users corresponding to condition A.

The optimum set can be determined among the candidate sets by finding the number of MCS levels $\hat{K}$ and the candidate set index $\hat{\imath}$ that minimize the MAP overhead as

$$\arg\min_{K',i} \left(\left\lceil \frac{h'_{BC}(K')}{J \cdot \rho_1} \right\rceil + \sum_{k=1}^{K'} \left\lceil \frac{h_{MC}(b_{d,q_{i,k}}, b_{u,q_{i,k}})}{J \cdot \rho_{q_{i,k}}} \right\rceil \right) \tag{14}$$

where argmin(f) denotes the values of argument parameters minimizing function f. Finally, the MCS level of each sub-MAP can be determined as

$$f_u(\phi_{\hat{K},\hat{\imath}}) = \max\{m | \gamma_u \ge th_{u,m}, \quad m \in \phi_{\hat{K},\hat{\imath}}\} \tag{15}$$

Thus, the AMC function of the sub-MAP selects the largest MCS level achievable in set $\phi_{\hat{K},\hat{\imath}}$.

4. Performance Evaluation

The performance of the proposed scheme is verified by computer simulation in a regularly placed 19-cell environment (with 3 sectors per cell). It is assumed that users are uniformly distributed in the cell while being at least 35 meters away from the BS, and that the user gets the strongest received power from the serving sector and interference from other sectors. It is also assumed that the minimum geometry for a call admission is set to −5 dB, and that the shadow correlation between the sectors in the adjacent cells is 0.5, while that between the sectors in the same cell is 1.0. The frame error rate (FER) is related to the CINR of all subcarriers comprising the data bursts of each user via an effective SINR mapping method in [9]. It is also assumed that G.729 codec generates a voice frame of 20 bytes at every 20 msec at a bit rate of 8 kbps and a conventional real-time transport protocol (12 bytes)/user datagram protocol (8 bytes)/IP (20 bytes) header size (40 bytes) is compressed to a 2-byte data [10]. We consider the international telecommunication unit (ITU) multi-path power delay profile environments comprising 40% Pedestrian-A, 30% Pedestrian-B and 30% Vehicular-A at a user speed of 30 km/h. The BS performs the AMC based on the average CINR for the data bursts due to the user speed. The maximum number of MCS levels for the sub-MAPs is set to 4. The largest-weighted-delay-first scheduling is used to satisfy low delay quality of service (QoS) requirements for the VoIP service [11]. Table 1 summarizes the simulation parameters, where $\Delta_{Dn} = 0.01$, $\Delta_{Up} = 0.99$ and $\delta_{max} = 8.9$ dB. Note that the value of δ_{max} corresponds to the fade margin required for an MER of 1% in Pedestrian-A environments and is determined by

Table 1 Simulation parameters.

Parameters	Values
Carrier frequency	2.3 GHz
Frame duration	5 ms
Number of DL OFDM symbols	27
FFT size	1024
Channel bandwidth	8.75 MHz
Subcarrier allocation	partial usage of subchannels
Cell radius	0.5 km
HARQ	Chase combining 3 retransmission
MCS	QPSK-1/12, QPSK-1/8 QPSK-1/4, QPSK-1/2 QPSK-3/4, 16QAM-/2 64QAM-1/2
Path loss model (d: meters)	28.6+35*log10(d) dB
Shadowing model	Log normal std. dev 8 dB
Antenna configuration	Tx: 1, Rx: 2
BS antenna pattern	70° (−3 dB) with 20 dB front-to-back ratio
Receiver algorithm	Maximal ratio combining

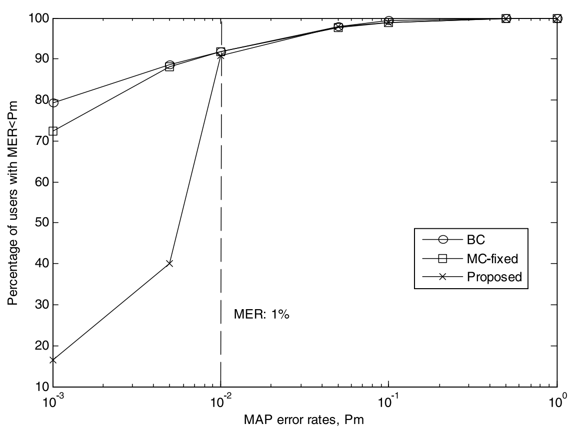

Fig. 1 Percentage of active VoIP users satisfying MER.

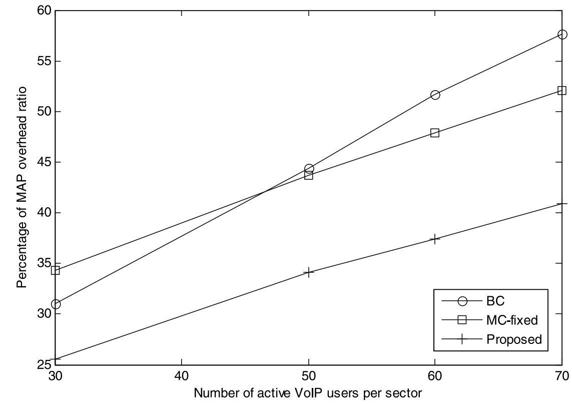

Fig. 2 Percentage of MAP overhead ratio according to the number of active VoIP users per sector.

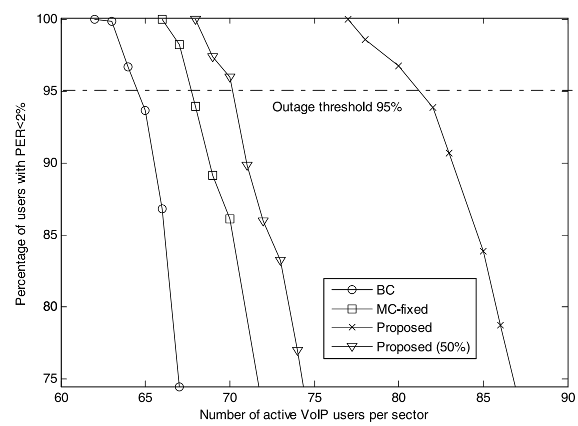

Fig. 3 Percentage of users with FER 2% according to the number of active VoIP users per sector.

simulation.

For performance comparison, two conventional mapping methods are considered; broadcast MAPs (denoted by BC), and multicast MAPs with four MCS levels and one margin for the threshold (denoted by MC-fixed). It is assumed that the MC-fixed uses the threshold margin corresponding to the upper limit since the BS should satisfy desired MER without the information on the channel condition. It is also assumed that the MC-fixed uses the sub-MAPs which contain at least one user, among four sub-MAPs each of which uses QPSK-1/12, QPSK-1/8, QPSK-1/4 and QPSK-1/2, respectively.

Figure 1 depicts the percentage of users in terms of desired MER. The MAP coverage is defined as the percentage of users satisfying an MER of 1% [2]. Since the BC scheme sends the MAP to all users by QPSK-1/12, it can be seen that most of users except users near the cell boundary have an MER less than 1%. The MC-fixed scheme sends the sub-MAPs with different MCS levels while using a conservative threshold margin for the MCS. It also has a high probability of having an MER less than 1%. This implies that the BC and MC-fixed schemes increase the MAP overhead due to the use of low MCS levels. It can be seen that the proposed scheme has MAP coverage similar to the BC scheme at an MER of 1%, but it has lower probability than the others at an MER less than 1%. This is mainly because the proposed scheme adjusts the threshold for the MCS to meet desired MER 1% in response to the receiving status, which reflects the channel condition and chooses the optimum MCS levels according to these thresholds.

Figure 2 depicts the MAP overhead ratio which is defined as the ratio of the MAP overhead to the number of DL slots. It can be seen that the MC-fixed scheme requires overhead ratio larger than the BC scheme when the number of users is small, since it chooses many sub-MAPs compared to the number of users. It can also be seen that the proposed scheme significantly reduces the MAP overhead ratio over the other schemes. This is mainly because the proposed scheme chooses the number of sub-MAPs and associated MCS levels to minimize MAP overhead based on the distribution of the CINR for all users.

Figure 3 depicts the VoIP capacity associated with the outage, which is defined as the number of users in a sector experiencing an outage less than 5%. A user is said to be in an outage if 98% tail latency is larger than 100 msec. It can be seen that the proposed scheme can accommodate more users sending VoIP packets due to the reduction of MAP overhead. Note that the proposed-50% corresponds to the performance when the detection error rate for the ACK signal or data burst in the UL reaches to 50%. In this case, since the threshold margin for the MCS is close to the upper limit, the proposed scheme cannot obtain a gain by adjusting the threshold for the MCS, but it can choose the optimum MCS level corresponding to this threshold. In fact, the proposed-50% can be interpreted as the low limit of the performance of the proposed scheme since the UL CQI is modulated to provide high reception reliability [12]. Thus, it can be inferred that the proposed scheme can provide the best performance in case of no detection error, and it outperforms the BC and MC-fixed schemes even when the detection error rate is high.

5. Conclusions

We have proposed an AMC scheme for the multicast sub-MAPs in the IEEE 802.16e system. The proposed scheme adjusts the threshold for the MCS to satisfy desired MER without explicit information on accurate DL CINR and channel condition, and then determines the optimum MCS level to reduce the MAP overhead. The simulation results show that the proposed scheme achieves the same coverage as the broadcast MAP while significantly enhancing the VoIP capacity. They also show that the proposed scheme works well even in the presence of high detection error in the UL.

References

[1] IEEE Std 802.16e, "Part 16: Air interface for fixed and mobile broadband wireless access systems," Dec. 2005.
[2] WiMAX Forum, "Mobile WiMAX-Part I: A. Technical over-view and performance evaluation," Feb. 2006.
[3] J. So, "A downlink performance analysis of VoIP services over an IEEE 802.16e OFDMA system," IEEE Commun. Lett., vol.11, no.2, pp.155–157, Feb. 2007.
[4] F. Wang, A. Ghosh, R. Love, K. Stewart, R. Ratasuk, R. Bachu, Y. Sun, and Q. Zhao, "IEEE 802.16e system performance: Analysis and simulations," Proc. IEEE PIMRC 2002, pp.900–904, Sept. 2005.
[5] A.E. Xhafa, S. Shantanu, and X. Lu, "MAC performance of IEEE 802.16e," Proc. IEEE VTC 2005-Fall., vol.1, pp.685–689, Sept. 2005.
[6] Intel, Samsung Electronics, Alvarion, Wi_LAN, Wavesat Wireless, Airspan, and Proxim, "OFDMA PHY enhancements using Hybrid ARQ," IEEE 802.16d-04/44, IEEE 802.16 BWA working group, March 2004.
[7] 3GPP TSG RAN R1-062900, "Scheduling for VoIP," Siemens, Oct. 2006.
[8] A. Goldsmith, Wireless Communications, First ed., Cambridge University Press, 2005.
[9] J. Lee, R. Arnott, K. Hamabe, and N. Takano, "Adaptive modulation switching level control in high speed downlink packet access transmission," Proc. IEE 3G Mobile Commun. Technology Conf., pp.156–159, May 2002.
[10] Ericsson, "System-level evaluation of OFDM — Initial evaluation," 3GPP TSG-RAN WG1, R1- 031304, Nov. 2003.
[11] H. Lee, T. Kown, and X. Lu, "An efficient uplink scheduling algorithm for VoIP services in IEEE 802.16 BWA systems," Proc. IEEE VTC 2004-Fall, vol.5, pp.3070–3074, Sept. 2004.
[12] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, R. Vijayakumar, and P. Whiting, "CDMA data QoS scheduling on the forward link with variable channel conditions," Bell Labs Tech. Memo., April 2000.
[13] Samsung Electronics, "UL ACK channel enhancement," IEEE 802.16e-04/127, IEEE 802.16 BWA working group, June 2004.
[14] C. Liu, "On the design of OFDM signal detection algorithms for hardware implementation," Proc. IEEE Globecom 2003, vol.2, pp.596–599, Dec. 2003.