Abstract - In this paper, high performance MAC is designed and implemented to support multi-gigabit nomadic access systems. New algorithms and Control channels are introduced for low MAC latency and high MAC throughput. The new multi-gigabit nomadic/local area wireless access, called NoLA, is implemented using the proposed MAC. NoLA demonstrated the multi-gigabit service with full HD video streams where the proposed high performance MAC supports the 84 full HD video streams in real time. The implemented NoLA system shows near 1.8Gbps MAC throughput, which can meet the requirements of the gigabit IMT-Advanced wireless nomadic access. It is proved that the proposed high performance MAC used in NoLA can be one of the promising solutions for the future multi-gigabit wireless communication systems.

I. INTRODUCTION

Recently, the demands for high capacity services such as HDTV and 3D-TV are rapidly increasing in the wireless communication systems. According to the ITU-R, the IMT-Advanced wireless communication systems are defined to satisfy more than 1Gbps data rate service under the nomadic environment and 100Mbps under the mobile environment.

For a high data rate transmission, MAC and PHY frame structures should be designed in efficient way such that a large channel bandwidth system can reduce the frame overhead but enlarge the MAC throughput. This paper will discuss MAC frame structure design mainly for the multi-gigabit IMT-Advanced wireless communication systems under the nomadic environment.

Many papers have been presented to achieve high data rate for the next generation WLAN (Wireless Local Area Network) system. Dual band MIMO-OFDM prototype system in [1, 2] is designed to target over 200Mbps of the maximum PHY data rate in 40MHz bandwidth. They used 2 transmit and 3 receive MIMO antennas for the high spectral efficiency where MAC throughput was more than 50% of the peak data rate. The multiple access scheme of this system is CSMA/CA where STAs (Stations) always sense the carriers status to send data. A high MAC throughput was achieved by aggregating frames with BA (Block ACK) function [3, 4, and 5]. However, the resource wastes due to packet collisions for the large number of STAs are still remained.

Mobile WiMAX [6, 7] compromises the service requirements between WLAN and cellular systems and provides moderate data rate and coverage. The multiple access scheme of this system is OFDMA where resources are allocated in time and frequency domain. Bandwidth is scalable from 1.25 to 20MHz with the maximum spectral efficiency of 2b/s/Hz. Auxiliary information is transmitted with DL/UL MAP in DL frame to help mobile terminal decoding. The MAP overhead rate is not negligible especially when the number of users is large.

MBWA [8] introduced Superframe structure which consists of a preamble frame, DL frames and UL frames. The preamble frame is introduced to reduce the frame overhead, where the preamble frame factors out the common information for users and it is transmitted once per Superframe period.

An efficient MIMO decoder algorithm is proposed in [9] with multiple transceiver antennas at the AP (Access Point) and the STA. A robust channel coding scheme is shown in [10] for the high data rate processing. We propose MAC and PHY frame structures and implement a system having low latency, which cooperate with the algorithms in [9, 10]. The implemented system with the proposed frame structures is satisfied with the multi-gigabit IMT-Advanced local area network service requirements.

The paper is organized as follows. Section II and III describe the proposed PHY and MAC frame format. Section IV explains the hardware implementation employing the proposed frame structures. In Section V, the experimental results are shown. Finally, the concluding remarks are given in Section VI.

II. PROPOSED PHY FRAME FORMAT

The proposed PHY frame structure is shown in Fig.1. The TDD Superframe consists of N numbers of DL and UL frames and k numbers of S-UL frames. The k numbers of S-UL frames are located after UL frames in Superframe. The Superframe starts with the DL frame containing BSR (BW Scheduling Report). IFS (Inter Frame Space) time exists between DL and UL frame.
The proposed PHY frame format is illustrated in Fig. 2. It consists of the training, signal and data field. The training field has p numbers of preamble symbols for the frame synchronization and q numbers of preamble symbols for the channel estimation. The Signal and data field have 1 and L number of symbols, respectively. The DL to UL ratio is determined based on DL to UL data symbol length.

The proposed S-UL frame consists of the same fields with PHY frame format. However, data field has one symbol since this frame is customized to deliver small information such as ACK or BR (BW Request). The optimum number of S-UL frame is carefully designed according to the number of STAs that are trying initial access to the APs.

The signal field contains information for the receivers to decode transmitted frames. It delivers STA numbers, MCS set index, starting symbol number index and length, etc. STAs feedback their CQI (Channel Quality Indication) in signal field to AP for adaptive modulation control.

The proposed system employs multi transmit and receive antennas where the transmit frames from each antenna can be modulated independently with different MCS levels as in [9, 10].

MCS set index represents one of the possible combination of MCS level for all transmit antennas. The AP and STA share the known MCS set table and use the MCS set index to indicate the modulation levels. It is not mandatory to use different MCS for each antenna. By considering the system complexity, they can make the MCS same or partially different for each other as in [9, 10].

The proposed MAC is required to support a physical layer of multi-gigabit data rate. The MAC and physical layer should be tightly coupled to provide the multi-gigabit data rate but reduce the latency and resource overhead. The key attributes and features of the MAC are followings:

- The low MAC frame overhead with the aggregated data frames. The DH (Data Header) control frame removes the common information from the data frames and aggregates them into one.
- The fast MPDU (MAC Protocol Data Unit) reordering at the MAC receiver with the DH control frame that the SSN in the DH subfield helps to make the algorithm implementation to be simple.
- The low scheduling latency during the random access since the BR control frame includes the AC (Access Category) and BW request size information at the same time.
- The efficient usage of the channel capacity with the MS (Multirate Selective)-ARQ. This scheme assigns the optimal rate for the new (or retransmit) data frame and the control frame. The control and data frames are transmitted into the different multiple antennas with different MCS (Modulation and Coding Scheme) levels at the same time. The control frames needs to be sent under the robust channel to have error rates almost zero. However, the common data frames may be sent with the allowable error rates that will be recovered by the robust channel coding or ARQ schemes with fast retransmission.
- Employing the selective ACK bitmap which informs the error information for the each received MPDU. The transmitter knows the exact status of the transmitted MPDUs so that it can retransmit the failed MPDUs only.

In the following subclauses, we will introduce the proposed MAC with overview and explain the MAC frame format in detail.

A. Proposed MAC layer overview

When the proposed MAC layer is viewed as functional blocks, it consists of the BW control function, the PDU control function, the SAR (Selective and Repeat) ARQ (Automatic Repeat Request) function and the scheduling function as shown in Fig. 3. The PDU control function does (de)segmentation, MPDU ordering, numbering, and duplicate detection. The ACK and DH Control frames are generated to control data. The SAR ARQ is applied only for the data MPDU.

The BW control block generates BSR frame to broadcast BW allocation information and BR frame to request BW. The scheduling block decides both the priority and MCS level for the control and data frames, and maps them into the optimal antennas.
The MAC frame format is shown in Fig.4. It consists of the Control Header, Frame body and FCS (Frame Check Sequence). The Control Header consists of several information fields such as Length for the frame length, Pattern for Control Header period, Retry for retransmission, Header bit, FN (Fragmentation Number) for fragmentation notice, SN (Sequence Number) for the sequence number, TID (Traffic ID) for traffic types and FCS for frame check sequence. The MSDU (MAC Service Data Unit) is located in the Frame body field and its length depends on the wireless channel.

The Control frame helps to setup the call. There are the BSR frame to report scheduling information, the BR frame to request BW, the DH frame to inform MPDU sequence number and the ACK frame to feedback information about the transmitted packets. The proposed Control frame format is shown in Fig.5. the MAC ID field consists of many information fields such as Protocol version, Type and Subtype for MPDU type, TA for MAC transmit address and RA for MAC receive address.

The BSR Control frame format is shown in Fig.6. The Superframe number field indicates Superframe index. The DL and UL frame length field informs the frame length in symbol numbers. The S-UL frame number field indicates the number of S-UL frame numbers. The STA number field notices the number of STAs which will receive BSR. The number of BSR STA Info field is proportional to the number of STAs. The STA address in BSR STA Info field helps to find the corresponding STA. The DL and UL frame bitmap fields informs the allocated frames to the corresponding STAs. The UL MCS informs MCS level for UL frame.

The BR Control frame format is shown in Fig.7. It has only BR Control field which consists of AC (Access Category) to indicate traffic type and BW request size.

A new multi-gigabit wireless communication system is implemented for the proposed MAC function.
The functional block diagram for the implemented MAC is depicted in Fig.8. It can be grouped into three parts: the transmitter, receiver, and controller module. The functional blocks for each group are explained in the following subclauses.

A. MAC transmitter module

The MPFB (MPDU Formatting Block) reads the MSDU from the service data interface, constructs the MAC frame (or MPDU) format, and stores them in the external memory. The MPFB also makes the descriptor for each MPDU. The TMMB (Tx MPDU Memory Block) stores the transmit MPDU descriptor in the FPGA internal dual-port memory block. The TMCB (Tx MPDU Control Block) reads the descriptors from the TMMB and the retransmit queue list to make a new transmit queue list. The retransmit queue list is made of the descriptors of the failed MPDUs. The scheduler in the TMCB decides the priorities where the retransmit MPDU has higher priority than the new transmit MPDU. The TFSB (Tx FIFO Selection Block) receives the new transmit queue list and decides the proper FIFO queue for the transmit MPDUs. The implemented MAC employed two FIFOs to support two different data rate (or MCS level). The control MAC frames and the retransmit data MPDUs are assigned to the FIFO queue for lower data rates. The TFIB (Tx FIFO Interface Block) reads out the MAC frames (or MPDUs) from the external memory to write on two transmit FIFOs. The TFMB (Tx FIFO Memory Block) controls the MAC frame transferred to the physical layer module.

B. MAC receiver module

The decoded MAC frame is sent to the RSCB (Rx Signal Control Block). The RSCB finds the Control Header field first for the identity check. Then, the received MAC frame can be classified by the MAC ID field in the Control frame. The RSCB performs the de-aggregation and validation check with FCS. The received DH Control frames informs the first data MPDU sequence number (SSN). The RSCB makes the ACK bitmap for the received data MPDUs and delivers it to the MPFB with the SSN. For the received ACK Control frame, the RSCB delivers the ACK bitmap information for the TMCB to update the retransmit queue list. The RMCB (Rx Memory Control Block) reorders the received MPDUs in the sequence number and de-fragments for the fragmented MSDU. The restored MSDU is sent to the external memory. The RFMB (Rx FIFO Memory Block) delivers the MSDU to the service data interface.

C. MAC controller module

The timing is controlled by the TSGB (Timing Signal Generation Block) and the TSCB (TX Signal Control Block). The TSGB controls IFS and symbol timing. The TSCB generates the transmit timing synchronized with the TSGB. The TSCB also controls the signal field information delivery to the physical layer and the transmit signal power. The system parameters and configuration control is done by the MRCB (MAC Register Control Block).

V. EXPERIMENTAL RESULTS

The implemented multi-gigabit wireless communication system employed OFDM-TDMA/TDD scheme with 120MHz channel bandwidth and 5.25GHz carrier frequency. To demonstrate large video streams from AP to STA, DL to UL ratio is customized to 10:1 where DL data symbols are 60 and UL data symbols are 6. The retransmission scheme is applied for QoS and the maximum retransmission numbers are set to 4. NoLA-AP is connected with 4 video stream servers where each video server sends 21 full HD video channels using UDP protocol. The system transmits and receives the signal with 8 antennas in wireless. STA is connected with clients to display the video streams into the monitors. Total 84 full HD video streams are transmitted at the same time in wireless where each monitor/client can display 7 different video contents. The protocol stack for the demonstration system is depicted in Fig.11.

The MAC throughput is measured in two different environments. The test environment 1 and 2 provide more open space than environment 3. The test environment 1 has no walls around the systems while the test environment 2 has a wall behind the systems. The test environment 3 is isolated with three walls around the systems. The distance between the AP and STA is about 5 meters.
The received MAC data is measured for a few minutes at the STA to check the MAC throughput as shown in Fig. 12. The traffic monitoring equipment is connected to the STA through Gigabit Ethernet ports. The total measured MAC throughput is about 1.6Gbps for DL only. If we consider the UL data rate together since the implemented NoLA system uses TDD, the total MAC throughput of NoLA system is about 1.8Gbps. The throughput of test environment 1 and 2 has larger variation than test environment 3 since the worse delay profile causes the inter symbol interference. The test environment 3 results showed robust performance and less sensitive to the moving people near the system.

A multi-gigabit nomadic local area wireless access system (NoLA) employing the proposed high performance MAC is implemented and demonstrated. The proposed MAC frame formats are designed to support multi-gigabit data service. The MAC latency is reduced by improving ACK feedback and MPDU reordering time. The BR Control frame is also formatted to reduce scheduling latency. The MS-ARQ is designed and implemented to enhance the channel efficiency where different MCS levels are applied to the different types of transmit data. The DH Control frame is introduced to reduce MAC overhead but increase the MAC throughput by introducing the aggregated data MPDU format.

The NoLA system showed total 1.8Gbps MAC throughput including DL and UL data traffic. The 84 full HD video streams are transmitted in wireless and displayed with 12 clients/monitors where each client receives 7 video streams. This paper shows the proposed high performance MAC can meet the service requirements of the gigabit IMT-Advanced nomadic wireless communication systems, and it can be one of the promising solutions for the future multi-gigabit wireless communication systems.

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