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A Survey on Technical Aspects of MAC 802.11b and MAC 802.16e

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***Abstract*—** With the increasing use of small and handheld devices, wireless and mobile networks have experienced an unprecedented growth. But their performance significantly depends on the choice of suitable MAC protocol which aims at coordinating access to the shared wireless medium among a number of mobile nodes. Several wireless standards have developed for supporting wireless and mobile networking. Various versions of IEEE 802.11 (Wi-Fi) and IEEE 802.16 (mobile WiMAX) offer physical and MAC layer specifications for WLAN and WMAN respectively. This paper presents a detailed description of the design and technical aspects of MAC 802.11b and MAC 802.16e.

***Keywords*—** MAC 802.11b (Wi-Fi), MAC 802.16e (mobile WiMAX), MAC layer.

I. INTRODUCTION

Because of the extensive use of smaller and mobile devices that are mostly battery-powered such as laptops, smart phones, sensors, etc. and communicate with each other over wireless links, wireless and mobile networking has matured to the point at which it has become an essential part of daily life. Wireless networks may or may not use a fixed infrastructure. Wireless networks operating in an ad-hoc mode do not use fixed infrastructure. Various design constraints of wireless and mobile networks such as limited bandwidth, error-prone and shared channel, mobility, limited power resources impose many challenges to design of MAC protocol that needs to allow fair channel access, minimize packet collisions and deal with packet loss and errors in wireless mobile network. The popular IEEE technical standard 802.11 ("Wi-Fi") wireless protocol enabled high-speed mobile interconnectivity for WLANs. Two configuration modes are supported in WiFi: infrastructure mode where all the communication goes through the central access point and other is ad-hoc mode where mobile stations can communicate directly with each other. Its MAC protocol incorporates coordination functions for accessing shared channel. The IEEE 802.16 is a specification for fixed broadband wireless metropolitan access networks (WMANs) or WiMAX (Worldwide Interoperability for Microwave Access). In 802.16 two major components base station and subscriber stations are defined and base station provide necessary infrastructure for subscriber stations to communicate. The flexibility of wireless technology, combined with high throughput, scalability and long-range features of the IEEE 802.16 standard better facilitates wireless and mobile networking.

II. MAC 802.11b

The IEEE 802.11b MAC layer [2] provides access control functions to the shared wireless medium such as access coordination among a number of users, frame check sequence generation, addressing and security. Interframe spaces (IFS) i.e. time interval between frames play an important role in channel access coordination. Four different IFSs are defined to offer priority levels for accessing shared wireless media as listed in order, from the shortest to the longest:

- Short IFS (SIFS) is used for an ACK frame, a CTS frame, the second or subsequent frames of a fragment burst, and by a STA responding to any polling by the PCF. Duration of SIFS is PHY dependent.
- PCF IFS (PIFS) is used in case of PCF during contention-free operation. Stations in the contention-free period wait for the period of PIFS to transmit data.
- DCF IFS (DIFS) is used by STAs operating under the DCF to transmit data frames. Stations may have immediate access to the medium if it has been free for a period longer than the DIFS.
- Extended IFS (EIFS) is used only in case an error in frame transmission.

Two medium access coordination functions are specified in the 802.11b MAC: an essential distributed coordination function (DCF) and an optional point coordination function (PCF).

A. Basic DCF

The basic DCF employs a carrier sense multiple access with collision avoidance (CSMA/CA) mechanism to control access to the shared wireless medium. Before transmitting each station has to sense the medium for a time interval DIFS (DCF interframe space) and if the has been sensed idle, station defers access to medium for a *backoff time* = *rand*[0;CW] × *slot time*, where CW (contention window) and slot time are physical layer dependent. At the first transmission attempt, CW is set equal to a minimum value, *CWmin*. It is doubled after each failed transmission attempt until it reaches a maximum value, *CWmax*. It is reset to *CWmin* after successful transmission. The backoff timer is decremented by each slot until the medium becomes busy again, or the timer reaches zero. STA stops decrementing the backoff timer if the medium becomes busy, and starts incrementing again after the medium has remained idle during period of longer than DIFS. When the timer reaches zero, the station is allowed to transmit its frame as shown in Fig. 1.

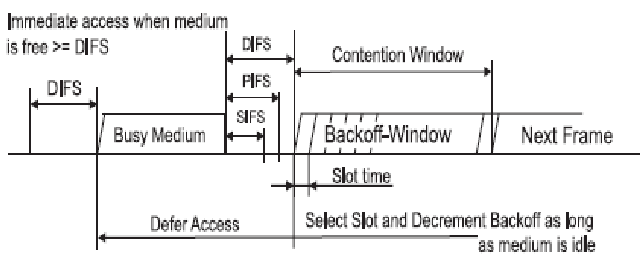

Fig.1. Basic access method of DCF

A collision may occur, if two or more STAs simultaneously finish their backoff procedures and start transmitting simultaneously. A positive acknowledgement ACK is transmitted to sender after a period of SIFS (short interframe space). If an ACK is not received within a specified timeout interval of *ACKTimeout*, the sender assumes it a collision and schedules a retransmission by entering the backoff procedure again until the maximum retransmission limit is reached.

B. DCF with RTS/CTS Clearing Scheme

To deal with hidden terminal problems wherein some STAs cannot hear the transmission from each other and may transmit simultaneously to a common receiver, an optional four-way handshake protocol that employ the exchange of short control frames [request to send (RTS) and clear to send (CTS) frames] between sender and receiver can be associated with the basic DCF [1] when data frame size is greater than the value called the *RTS_threshold*. Before transmitting data frame, a STA senses the medium for the duration of DIFS, if it is sensed as idle; STA enters a backoff procedure as discussed previously. When backoff timer reaches to zero, sender sends a RTS frame to the receiving STA. On the reception of RTS receiver replies with a CTS frame after the duration of SIFS, if medium is idle. MAC header of the RTS, CTS and Data frame carry a duration field which is set by the sender to specify the duration for which the channel is going to be occupied by the proposed data transmission. Upon hearing, all other nodes in the transmission range of sender and receiver update their local timers, called NAVs (Network Allocation Vectors) with this duration and defer their transmission and receptions for this duration to avoid collisions. RTS frames may collide with each other if transmitted simultaneously and collision can be detected by the absence of CTS reply. After receiving CTS frame, DATA frame is transmitted which acknowledged by the receiver, if received successfully. PCF, an optional MAC function was introduce to provide contention-free services and can only be used if a WLAN operates in an infrastructure mode.

C. PCF

If contention-free delivery is required, the PCF may be used. PCF [2] is a polling-based contention-free access scheme, which uses an AP as a point coordinator. With PCF enabled, the channel access time is divided into periodic intervals called *beacon intervals*. A beacon interval is composed of a contention-free period (CFP) and a contention period (CP). Access to the medium in the former case is controlled by the PCF, while access to the medium in the later case is controlled by the DCF. At the beginning of the CFP, a Beacon frame is transmitted by the access point. The maximum duration of the contention-free period, *CFPMaxDuration* is announced in the Beacon frame. On receiving Beacon frame all stations set their NAV to the *CFPMaxDuration* to lock out DCF-based access to the medium. Beacon frame is generated by the AP after the time period called the target beacon transmission time (TBTT). AP announces the next TBTT within the current beacon frame. During a CFP, the AP maintains a list of registered STAs and polls them according to the list. A STA can start transmission, only after it is polled. Contention-free polling frames are called CF-Poll. To make sure that the point coordinator retains control of the medium, it may poll the next STA on its polling list if no response is received after an elapsed PIFS. To give PCF higher access priority than DCF, the AP waits for a shorter interval than DIFS, called the PIFS, before starting PCF. Time in the CFP is valuable, so acknowledgments, polling, and data transfer may be combined to improve efficiency.

III. MAC 802.16e

This section is oriented towards the functionality of MAC layer of IEEE 802.16e in point-to-multipoint (PMP) mode wherein a single base station (BS) serves multiple subscriber stations (SS). This MAC protocol [8] is purely connection oriented and all the transmission, be it uplink (form SS to BS) or downlink (form BS to SS) is carried on a connection. Each connection is identified by a unique Connection ID (CID), is associated to a service flow (uniquely identified by a SFID) whose characteristics provide the QoS requirements to apply for the PDUs (Protocol Data Units) exchanged on that connection. The MAC layer comprises three sublayers: the service-specific convergence sublayer (CS), MAC common part sublayer (MAC CPS), and security sublayer.

A. Service Specific Convergence Sublayer

The main task of the CS is to classify packets received from the higher layer and from peer stations to appropriate CID and so to a SFID associated to that connection and finally maps these packets into a from compatible with WiMAX MAC traffic type that is MAC Service Data Unit (MSDU). This allows the MAC CPS to identify the QoS parameters associated to a transport connection and to ensure the QoS The classification procedure is performed based on criterion, such as destination or source IP-address. The capability of Payload Header Suppression (PHS) is optional and is used to remove repetitive or redundant information from higher layer packets headers.

B. MAC Common Part Sublayer (CPS)

Common part sublayer provides the core MAC functionality such as SS initialization and registration, generation of MAC management messages, generation of MAC PDU (Protocol Data Unit), framing, addressing, service flow management, bandwidth management and scheduling services.

1) Framing: In the IEEE 802.16, the physical medium is devided into fixed-length frames. MAC module [8] implements frames as a fixed duration of time, each frame is further subdivided into UL (Uplink to carry uplink traffic) and DL (Downlink to carry downlink traffic) subframes which carry a number of uplink and downlink bursts, respectively as shown in Fig. 2.

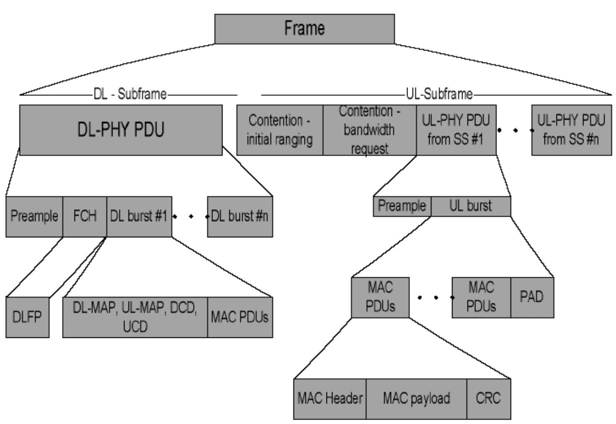

Fig.2. MAC 802.16 frame structure with TDD

Packet burst is the unit of data transmission at the MAC layer. DL and UL channels are duplexed using either TDD (Time Division Duplex) or FDD (Frequency Division Duplex) where TDD separates UL and DL in time and FDD separates them by frequency. BS basically broadcasts a TDM signal, with individual SSs allocated time slots serially. Each SS is required to capture and process only the traffic intended to itself or explicitly intended for all SSs. Access in the uplink direction is controlled through time-division multiple access (TDMA). While using TDD, the UL subframe and DL subframe durations vary within the same shared frame. Downlink and Uplink subframes are separated by two guard spaces: Transmit/receive Transition Gap (TTG) and Receive/transmit Transition Gap (RTG). These gaps allow the BS to switch from the transmit to receive mode and vice versa. The DL subframe consists of a number of physical bursts of different modulation/coding and where the bursts are sent in decreasing robustness. DL subframe starts with synchronization preamble and then comes FCH that contains DLFP field which describes the location and profile of the first downlink bursts. In the first burst of DL subframe BS broadcasts a set of control messages DL-MAP, UL-MAP, DCD and UCD. DL-MAP and UL-MAP are sent in every frame, while DCD and UCD are sent periodically where definitions of burst profiles may update with time. The DL-MAP describes the location and profile of the other downlink bursts. It contains BS identifier and a special data structure called IE (Information Element) one for each upcoming DL burst that contains information about each DL burst like CID identifying SS to which this burst is addressed and a DIUC (Downlink Interval Usage Code) indicating a burst profile to be used to receive the burst. UL-MAP contains information including channel identifier, the starting time of the UL subframe, relative to the beginning of the DL subframe and IE containing notification of an upcoming UL grant. This notification include the a Start Time and duration of the grant and a UIUC (Uplink Interval Usage Code) that maps to a UL burst profile in the UCD message. DCD/UCD messages contain a burst profile data structure containing a combination of modulation and FEC code and a DIUC/UIUC uniquely identifying the burst profile. UCD message contains important parameters including the backoff limits for the contention ranging and bandwidth request processes, and size of the ranging and the bandwidth request transmission opportunities. DCD message contains information including the size of the TTG and RTG, a number indicating the current frame, and the duration of the frame. After receiving a DL-MAP message, SS iterates through the DL-MAP IEs to check whether a DL burst is directed towards it following the current broadcast burst. If so, than it receives the burst by decoding it using the parameters in the corresponding burst profile. In the same way, as SS receives a UL-MAP indicating an UL grant for it, the SS starts sending its pending data as the start time of the grant elapses. In UL subframe two initial contention slots are reserved for initial ranging and bandwidth request. First slot is reserved for contention based initial rangin and used when subscriber stations need to perform ranging with a base station to achieve synchronization and appropriate signal strengths for further communication. The next slot is for contention based bandwidth requests, where subscriber stations can send request messages without waiting for individually allocated bursts. As these two periods are contention based, collisions may occur between subscriber stations transmitting at the same time during this period.

2) Network Entry and Initialization: This phase is divided into two sub phases:

a) Scanning and Synchronization: To join the network, an SS first scans the downlink frequencies to search for a suitable channel. After detecting a PHY frame, the search becomes complete. Then synchronization with the BS is to be established. Once SS receives a DL-MAP message the synchronization phase is complete and it remains synchronized as long as it keeps receiving DL-MAP and DCD messages. After the synchronization is established, SS waits for a UCD message to acquire uplink channel parameters. Once acquired, the first sub-phase of the network entry and initialization is complete.

b) Initial Raging and Registration: Once synchronization is achieved, the SS waits for a UL-MAP message to locate a special grant, called initial ranging interval, in the UL subframe. This grant is allocated by the BS at regular intervals. Initial ranging interval is composed of one or more transmission opportunities. The size of a opportunity is fixed, it is determined by the BS and allows sufficient time to send a RNG-REQ message including the overhead (SS learns its size from UCD message). Once located, the SS sends a RNG-REQ message after performing a backoff based contention resolution process. The BS upon receiving a RNG-REQ responds with a RNG-RSP message indicating if the ranging is accepted or not, or indicating the SS to adjust its timing offset/power parameters. The exchange of RNG-REQ and RNG-RSP messages continues until the ranging is accepted or rejected. Initial ranging is initially performed on the predefined initial ranging connection until BS allocates the Basic and Primary management connections to the SS through the RNG-RSP message. From this point onwards SS is allocated an invited (or unicast) ranging opportunity (basically a UL grant), to continue ranging process.

3) Connection and Addressing: All communication at the MAC layer is carried in terms of connections. A connection is a unidirectional mapping between the SS and BS's MAC entities for the transmission of traffic. Two types of connections are defined: management connections for transmitting control messages and transport connections for data transmission. A 16-bit Connection Identifier (CID) is assigned to every connection. Note that each connection maintains its own transmission queue where packets to transmit on that connection are queued. The BS creates and manages connections for all SSs. The two management connections, namely the Basic and Primary management connections are created and allocated to the SS during the ranging process. All (unicast) DL and UL grants are directed towards SS's Basic CID. An SS may have one or more transport connections to transmit data packets. A management connection is bidirectional, i.e., a pair of downlink and uplink connection is represented by the same CID. Downlink connection is created by the BS and upon receiving the CID, SS creates an identical uplink connection with the same CID.

4) Service Flow Creation: A service flow is identified by a 32-bit Service Flow ID (SFID) and is associated to exactly one transport connection and QoS parameter set to ensure the QoS requirement of the traffic on exchanged on that connection. There are three types of service flows: (a) provisioned SFs for which the QoS parameters are provisioned for example by the network management system, (b) admitted SFs for which resources, mainly bandwidth, are reserved and (c) active SFs which are activated to carry traffic using resources actually provided by the BS. Each service flow is uniquely identified by a SFID; admitted and active service flows have also a CID. Service flows may be dynamically managed; they may be created, changed or deleted using DSA, DSC and DSD MAC management messages, respectively. Once the SS is registered, to create a service flow it sends a request (a DSA-REQ message) to the BS, along with the predefined QoS parameter set, to create the service flow. The BS examines the parameters and assuming that all parameters are supported, creates a service flow (and transport connection) and responds with a DSA-RSP message. The SS may now start using the service flow to send/receive data. All DSA messages are sent on the Primary management connection. Multiple service flows per SS are allowed and the above message exchange is invoked for each service flow. Note that a pair of service flows must be created with the same QoS parameters for both sender and receiver.

5) Scheduling Services: Each service flow [6] is associated to exactly one scheduling service, and the QoS parameter set associated to a service flow actually defines the scheduling service it belongs to. Five scheduling services are defined: UGS (Unsolicited Grant Service) is designed for real-time applications with fixed packet size. It guarantees bandwidth on real-time basis, by allocating the flow UL grants on regular basis. rtPS (Real-Time Polling Service) is designed for real-time applications with variable packet size, and is ensured UL grants on periodic basis. The only difference between rtPS and nrtPS (Non-Real-Time Polling Service) is that the latter is designed for non real-time applications. nrtPS flows are not polled on periodic basis and instead only when sufficient bandwidth is available. BE (Best Effort) service, as the name suggests, is designed for the low priority best effort applications. For a BE flow, the scheduler allocates bandwidth only when sufficient bandwidth is available after servicing higher priority flows. No minimum bandwidth is guaranteed for this service. ertPS (extended real time Polling Service) scheduling service is introduced in the 802.16e draft and is a combination of UGS and rtPS. Like UGS data traffic is allocated bandwidth without solicitation but, unlike UGS, nrtPS can make this allocation on a dynamic manner. It thus has less overhead than rtPS that requires unicast request opportunities, but retains the flexibility of variable size grants.

C. Privacy Sublayer

IEEE 802.16's privacy protocol [7] is based on the Privacy Key Management (PKM) protocol enhanced to fit seamlessly into the IEEE 802.16 MAC protocol and to better accommodate stronger cryptographic methods, such as the recently approved Advanced Encryption Standard. PKM is built around the concept of security associations (SAs). The SA is a set of cryptographic methods and the associated keying material; that is, it contains the information about which algorithms to apply, which key to use, and so on. Every SS establishes at least one SA during initialization. Each connection, with the exception of the basic and primary management connections, is mapped to an SA either at connection setup time or dynamically during operation.

IV. CONCLUSION

This paper presented a detailed description of technical aspects of MAC 802.11b (Wi-Fi) and MAC 802.16e (mobile WiMAX) protocols by focusing on the basic overview and architecture design. Both the protocols offer MAC layer features in two different environments. MAC 802.11b protocol is used coordinate channel access in WLANs, while MAC 802.16e protocol is used to coordinate channel access in WMANs. Still, we can say MAC 802.16e is a promising protocol for wireless and mobile networking as it represents a whole new dimension in terms of contention free channel access, QoS provisioning and security. WiMAX is not intended to replace Wi-Fi in its applications but rather to supplement it as WiMAX can bring the underlying internet connection needed to service local Wi-Fi networks.

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