UWB MAC Protocol Design and Analysis Report 1

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***Abstract*—In this Report 1 we introduced the UWB, MAC protocol and why MAC is important to UWB, then we listed current research areas of MAC protocol for UWB and analyzed three of them CSMA/CA, MACA and MACAW.**

I. Introduction

A. UWB

UWB technology is a short-range radio technology which is ideal for wireless personal area networks (WPANs). As per the specifications of FCC, UWB communications use the spectrum from 3.1 GHz to 10.6 GHz [1]. It provides the needed cost-effective, power-efficient, high bandwidth solution for relaying data from host devices to devices in the immediate area (up to 10 meters or 30 feet).

UWB differs substantially from conventional narrowband radio frequency (RF) and spread spectrum technologies (SS), such as Bluetooth* Technology and 802.11a/b/g[2]. A UWB transmitter works by sending billions of pulses across a very wide spectrum of frequency several GHz in bandwidth. The corresponding receiver then translates the pulses into data by listening for a familiar pulse sequence sent by the transmitter. UWB's combination of larger spectrum, lower power and pulsed data improves speed and reduces interference with other wireless spectra.

B. MAC

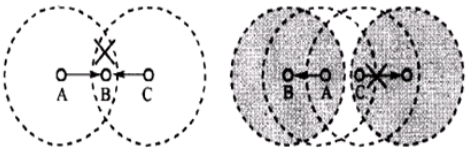
The Medium Access Control (MAC) protocol is used to provide the data link layer of the Ethernet LAN system. The MAC protocol encapsulates a SDU (payload data) by adding a 14 byte header (Protocol Control Information (PCI)) before the data and appending a 4-byte (32-bit) Cyclic Redundancy Check (CRC) after the data. The entire frame is preceded by a small idle period (the minimum inter-frame gap, 9.6 microsecond (?S)) and a 8 byte preamble.

C. MAC for UWB

UWB is a novel wireless short-range technology, which has been the focus of a lot of interest in recent times[4-14].It provides high-speed and reliable supporting of data transmission to the upper link.[3]. In UWB communication systems, there may be more than one wireless devices needed to enter into the channel which leads to collisions between groups. Meanwhile, because UWB has the features such as a wide band, high speed rate and low power spectrum density, it is difficult for the receiver to make out the data it received. Thus, it results in severe channel resource waste and obvious decrease of throughout. Under this circumstance, designing an appropriate MAC Protocol is crucial to UWB.

1) Factors That Should Be Considered In Designing a MAC Protocol : The MAC protocol globally *manages* the interference and medium access on a shared communication channel. Its main goal is to maximize in a fair manner both the overall lifetime of the network and the rate offered to each node. So the design of a MAC protocol on UWB communication system should take the following factors into account.

- Shared Devices: A UWB system transmits impulses with very low duty-cycle and uses *Time Hopping (TH)* modulation in order to make it easy to construct a mobile net such as CDMA system. And the features like high processing gain and *strong distinguishing of multi-path* make the total number of devices in the systems far larger than that in CDMA system [15].Hence, considering the problem of shared devices is a must.
- Coordination between Devices: There is a large variety of devices in a UWB system. Therefore, the design of a MAC protocol should also guarantee the *interaction* between the devices with different working principles in the net. Moreover, it must ensure there are different data rates in the devices with the same working principles and there are correct *exchanges* of information between the devices that have different *QoS* requirements. Most significantly, it should resolve the problems of the communication between the devices with low complexity and low data rate and those with high complexity and high data rate.
- Fixation and Tracing: Fixation technology is inseparable with MAC protocol. Its function is to improve the veracity of time fixation and convert time information to fixation information. What poses a challenge to fixation technology is the hidden terminal problem[16].
  The requirement of tracing technology is that the data rate in each device in the system can be observed and monitored. In a certain range, the data rate is changeable. The implementation will be difficult if the number of devices in the system is large.
- Power Control: The purpose of power control is to *optimize* the transmission power in the net. A good power control should decrease the *leakage*, *interference* and *self-adaptation* in transmission power adjust to adapt well to the link change caused by the change and mobility of channel.



(a) Hidden Terminal (b) Exposed Terminal

Fig. 1. The Problem of Hidden Terminal and Exposed Terminal[17]

2) The Constraints on MAC Protocol of UWB: UWB signal has some advantages which other technologies don't possess. However, in some aspects, UWB system also has some problems which bring about some constraints on the design of a MAC protocol.

- Hidden and Exposed problem [15]: This problem exists in all the UWB systems. In the classic hidden terminal situation, station *Y* can hear both stations *X* and *Z*, but *X* and *Z* cannot hear each other. *X* and *Z* are therefore unable to avoid colliding with each other at *Y* (see figure 1.a); In the exposed terminal case, a well-sited station *X* can hear far away station *Y* even though *X* is too far from *Y* to interfere with its traffic to other nearby stations, *X* will refer to it unnecessarily, thus wasting an opportunity to reuse the channel locally. Sometimes here can be so much traffic in the remote area that the well-sited station seldom transmits. This is a common problem with hilltop digipeaters. (see figure 1.b)
- The effect of the transmission sequences: UWB takes a long time of synchronization establishment. This collides with the high data rate of UWB. So measures should be taken to reduce the synchronization time.
- The ability of impulse wireless carrier frequency sensor: Non-carrier-frequency impulse wireless system is modulated with very narrow impulse signals in order to gain the ultra wide band for data transmission. But it is to implement carrier-wave interception in MAC protocols such as CSMA/CA [18].

3) Some Existed MAC Protocols based on UWB: The MAC protocol can be categorized into several groups:

- synchronized MAC protocol and asynchronized MAC protocols
- sender-driving protocols and receiver-driving protocols
- single-band protocols and dual-band protocols and multi-band protocols
- Peer-to-Peer protocols and non peer-to-peer protocols

With the development of the networks, many more MAC protocols have been proposed in order to resolve particular problems such as improving the throughput of the network, decrease the cost of energy and mitigating the interference.

a) CSMA/CA: **Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)**[17].A CSMA protocol works as follows: CSMA/CA as used by localtalk works as follows. When a station wants to send data to another, it first sends a short *Request To Send (RTS)* packet to the destination. The receive responds with a *Clear to Send (CTS)* packet. On receipt of the CTS, the sender sends its queued data packet(s). If the sender does not receive a CTS after a timeout, it resends its RTS and waits a little longer for a reply. This three-step process (not counting retransmissions is called a dialogue. Since a dialogue involves transmissions by both stations, I will avoid confusion by referring to the station that sends the RTS and data packets as the initiator, and the station that sends the CTS as the responder. The RTS packet tells a responder that data follows. This gives the responder a chance to prepare (see figure 2), e.g., by allocating buffer space or by entering a "spin loop" on a programmed-I/O interface. This is the main reason localtalk uses the CSMA/CA dialogue.

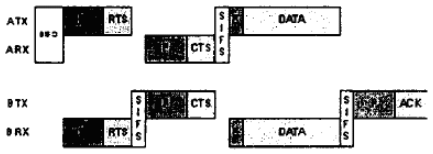


Fig. 2. Transmission from node A to node B using CSMA/CA [18]

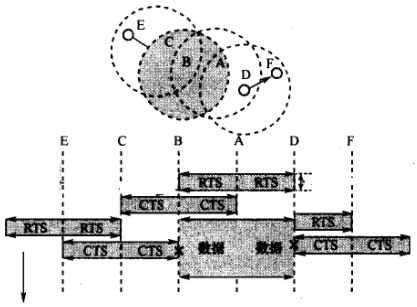


Fig. 3. MACA protocol[17]

b) MACA: MACA [19]is also based on the RTS/CTS mechanism. Different from the CSMA/CA, MACA does not adopt the technology of carrier sensing. Before transmitting the data, the sender and the receiver exchange control information to get the access to channel. The sending station first transmits a packet of RTS to the receiver and when the receiver receives that packet, it return a CTS message. If the CTS reaches the station which is willing to transmit information, the station begin to send data packets. RTS and CTS both include the information about the size of data packet which will be transmitted by the sender. It is guaranteed that other senders will defer the transmitting for a time which is estimated by the RTS they have sensed until the original sender receives the CTS. Similarly, other senders who have sensed the CTS will also defer the transmitting to assure following data packets could be received successfully (see figure 3).

c) MACAW: This protocol[20] adds to the link-level confirmation message(ACK)on the basis of MACA. The basic operation is similar to MACA. The differences lie

on that when the receiver receives the data packets, it will send back a ACK to confirm. If the sender does not receive the ACK message, it will retransmit the RTS. When receiver receives the RTS message, rather than transmit a CTS, it will send a ACK to reconfirm. Additionally, before transmitting data, the transmitter would send a DS message to inform its neighbor nodes that a RTS-CTS conversation is done.

II. Related Works

Though the Mac protocols discussed above perform well in the l wireless networks such as ad hoc network and WLAN, they don't appear excellent in the network based on the UWB. Because these MAC protocols are not designed according to the feature of UWB such as high data rate, low transmitting power, the direct use dose result in bad performance in terms of packet delay, the throughput and efficiency of channel.

While physical layer technologies on UWB communication have been developed to some extent, the traditional MAC protocols are unable to match. So some new designs of MAC protocols have been developed which could be better synergetic with the underlying physical layer. One is the multiband MAC protocol for UWB ad hoc networks proposed by Broustis, I., Krishnamurthy, S., Faloutsos, M.,Molle, M.. Foerster, J in their paper, A multiband mac protocol for impulse-based UWB ad hoc networks. [21] The concept of this MAC protocol is the use of different bands for control and data transmission. That is to say, two nodes first use a control channel to facilitate a rendezvousing, another band for a data exchange. The protocol implementation at each node can be represented by a finite state machine.

(1) IDLE: a node is in this state initially.
(2) REQUEST: a node enters this state when it needs to send data.
(3) TALK: if the request of sending data is to succeed, the node enters this state, switches to a data band.
(4) BACK-OFF: If the request were to fail, the node enters this state and tries again at a later time.
(5) DECLARE: In this state, the node periodically announces that the specific data band being used is occupied.

There are several advantages of this approach. When multiband is used, each transmitter could send longer pulses in one of many narrower frequency bands without worrying about the inter-symbol interference (ISI) caused by delay spread. Second, the collision could be reduced without resorting to long time-hopping sequences which exist on a single channel. Thirdly, the throughput of this scheme is significantly higher compared to a single-band approach that comats delay spread by increasing the spacing between pulse transmissions.

Also, the MAC protocol takes into account the regulations imposed by the FCC proposed in Federal Communications Commission: Evision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems [22]. Accordingly, this approach is conjoined with the UWB physical layer and performs well in the whole system.

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