Design Approach for MAC Design in Vehicle Safety System Using Dedicated Short Range Communications (DSRC)

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Abstract
Dedicated short range communication (DSRC) system is the key technology of intelligent transportation system (ITS), and the associated service information and control commands of ITS can transmit via DSRC. In this paper, we propose design approach of DSRC MAC in ARM embedded systems and FPGA chips, including both the DCF and PCF for vehicle safety system. This paper presents design aspects of the technical requirements for Internet Protocol (IP) and Medium Access Control (MAC) protocol to support Dedicated Short Range Communications (DSRC) which is a critical element of the Intelligent Transportation System (ITS). This paper also analyzes various optional procedures in the 802.11 standard where these procedures should be considered requirements in DSRC. A major contribution of this study is to introduce a new feature, bridging with layer-3 forwarding, to support multi-hop DSRC communications.

Key Words: DSRC, DCF, FPGA, PCF.

I. Introduction

Intelligent Transportation System (ITS) involves applying advanced information, networking, and other technologies to improve the economic and safety of the transportation system [1][2], which includes, but not limited to highways, railroads, and rural/urban/suburban roads. The foundation of ITS is a communication system for real-time information gathering and analysis where such a system shall use radio frequency (RF) for wireless communications. This paper discusses the technical requirements of a new wireless standard, Dedicated Short Range Communications (DSRC), and its applications in supporting ITS. In recognition of this need, Federal Communication Commission (FCC) allocated 75 MHz spectrum in the 5.9GHz band for DSRC in 1998 [3], which is above the Unlicensed National Information Infrastructure (UNII) band used by the IEEE 802.11a standard [4], as shown in Figure 1.

![Figure 1. DSRC Spectrum band](image)

This new spectrum is different from the legacy DSRC spectrum as shown in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Legacy</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>909-928 MHz</td>
<td>5.850-5.925 GHz</td>
</tr>
<tr>
<td>Spectrum</td>
<td>12 MHz</td>
<td>75 MHz</td>
</tr>
<tr>
<td>Data Rate</td>
<td>0.5 MHz</td>
<td>1-54 MHz</td>
</tr>
<tr>
<td>Max. Range</td>
<td>100 m</td>
<td>1,000 m</td>
</tr>
<tr>
<td>Min. Separation</td>
<td>500 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Non-Overlapping</td>
<td>1 or 2</td>
<td>7</td>
</tr>
<tr>
<td>Channel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The DSRC standard supports vehicles with an on-board device (OBD) to communicate with a roadside unit (RSU), or other traveling vehicles.
In general, DSRC applications should meet the following requirements:

1. **Low Latency** – Real-time information should be received by traveling vehicles or RSU with low or minimum latency. If the latency is too long, the vehicle may be out of the RF range before the communication is complete.

2. **High mobility** – Study has shown that signal to noise ratio goes up and throughput goes down as traveling speed increases [6]. As a result, applications in a fixed wireless environment may not work properly in a mobile environment. We need to consider the factor of high mobility in DSRC application development.

3. **High reliability** – Information from emergency vehicle or RSU has impact on public safety, so their reception by the traveling vehicle should be guaranteed. The distance and data rate requirements for the DSRC applications are given in Table 2.

**Table 2. Range and Data Rate Requirements**

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Data Rate</th>
</tr>
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<tbody>
<tr>
<td>Toll Payment</td>
<td>30 m</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Emergency Vehicle</td>
<td>1000 m</td>
<td>6 Mbps</td>
</tr>
<tr>
<td>Roadside Safety Message</td>
<td>300 m</td>
<td>18 Mbps</td>
</tr>
<tr>
<td>V2V Private Voice and Data</td>
<td>100-1,000 m</td>
<td>6-54 Mbps</td>
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DSRC specifications and ranges of values related to RF link testing are given in Table 3; these specifications and values are based on ASTM E2213-03.

**Table 3. DSRC specifications**

<table>
<thead>
<tr>
<th>DSRC spec. Item</th>
<th>DSRC-defined Values</th>
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<tr>
<td>DSRC channels</td>
<td>172, 174, 176, 78,180, 182, 184</td>
</tr>
<tr>
<td>ITS band</td>
<td>5.85 - 5.925GHz</td>
</tr>
<tr>
<td>RF link range</td>
<td>Up to 1,000 Meters</td>
</tr>
<tr>
<td>Average LOS Packet error rate</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Ave. NLOS Packet error rate</td>
<td>Not defined</td>
</tr>
<tr>
<td>TX output power Class</td>
<td>0, 10, 20, 29dBm (Class A, B, C, &amp; D)</td>
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**II. IEEE 802.11 MAC Protocol**

802.11 was approved by IEEE as an international standard for wireless local area networks (WLAN), including the detail of medium access control (MAC) and physical layer (PHY). The medium access is controlled by the coordination functions, the fundamental DCF and optional PCF in 802.11 standards. We take brief descriptions in the following. DCF is a random access scheme based on carrier sense multiple accesses with collision avoidance (CSMA/CA). Before data transmission, it will detect the channel state in clearance or not. There are two basic principles of DCF transmission:

1. If the channel is idle longer than DCF inter frame space (DIFS), the transmission can start, and the carrier sensing could use the physical detection and the network allocation vector (NAV),

2. If the channel is sensed in busy, the transmission should wait until the channel is free, called as access deferral in 802.11, then the exponential backup procedure starts.

Flow chart for CSMA is as shown in figure 2

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**Figure 2. Flow chart of CSMA**
IEEE 802.11 Distributed Coordination Function

In IEEE 802.11 DCF, a node reserves the channel for data transmission by exchanging RTS/CTS messages with the target node. When a node wants to send packets to another node, it first sends an RTS (Ready to Send) packet to the destination. The receiver, on receiving RTS, replies by sending CTS (Clear to Send) packet to the sender. RTS and CTS packets include the expected duration of time for which the channel will be in use. Other hosts that overhear these packets must defer their transmission for the duration specified in the packets. For this reason, each host maintains a variable called *Network Allocation Vector* (NAV) that records the duration of time it must defer its transmission. This whole process is called *Virtual Carrier Sensing*, which allows the area around the sender and receiver to be reserved for communication, thus avoiding the hidden terminal problem. Fig. 3 illustrates the operation of IEEE 802.11 DCF.[13]

![Fig. 3. Operation of IEEE 802.11 DCF.](image)

When B is transmitting a packet to C, A overhears the RTS packet and sets its NAV until the end of ACK, and D overhears the CTS packet and sets its NAV until the end of ACK. After the transmission completes, the stations waits for DIFS and then contends for the channel.

If a node has a packet to send but observes the channel busy, it performs a *random back off* by choosing a back off counter no greater than an interval called *contention window*. Each host maintains a variable $cw$, the contention window size, which is reset to a value $cw_{min}$ when node is initiated. Also after each successful transmission, $cw$ is reset to $cw_{min}$.

After choosing a counter value, the node will wait until the channel becomes idle, and start decrementing the counter. The counter is decremented by 1 after each “slot” time, as long as the channel is idle. If the channel is busy, the node will freeze the counter until the channel is free again. When the back off counter reaches 0, the node will try to reserve the channel by sending RTS to the target node. Since two nodes can pick the same back off counter, the RTS packet may be lost because of collision. Since the probability of collision is higher as the number of nodes increase, a node will interpret the absence of CTS as a sign of congestion. In this case, the node wills double its contention window to lower the probability of congestion.

Before transmitting a packet, a node has to wait for a small duration of time even if the channel is idle. This is called *inter frame spacing*. Four different intervals enable each packet to have different priority when contending for the channel. SIFS, PIFS, DIFS, and EIFS are four *Inter frame spacing*, in an increasing order. A node waits for DIFS before transmitting RTS, but waits for SIFS before sending CTS or ACK, which is shorter. So an ACK packet will win the channel when contending with RTS or DATA packets.

PCF adopt the infrastructural access scheme, that only the point coordination unit can manage the medium access. This function is specially implemented in access points (AP), so that the associated stations can only transit under the admissions of point coordination unit. As the PCF used, the medium will be partitioned into contention-free period (CFP) and contention period (CP) that CFP is coordinated by PCF and CP is DCF. The CFP and CP will exchange in a fixed cycle. As the CFP start, AP will send a beacon frame which includes the CFP Max Duration field to indicate the time of CFP continuity. All station received the beacon will set their NAV in this value, then DCF stop. When the AP owns the medium coordination, it will poll each associated station to send data according to polling list. The CF polling frame is called CF-poll, one CF-poll means the station is licensed to transmit one frame. If the polled station has no response longer than PIFS, AP
will assume the polled station has no frame to transmit and poll next station in polling list.

III. Design and Implementation

This section will separate into two subsections, one is the implemented MAC scheme arrangement and the other one is the hardware implementation.

III.1 MAC Schemes

From the associating literatures and our points of view, DSRC is inherently not the same to the wireless LAN (WLAN). The conventional WLAN is dominated in distributed coordination function (DCF), so that it can realize the carrier sense multiple access with collision avoidance (CSMA/CA) Such MAC scheme is effective in media distribution but not efficiency in utilization rate due to the high overhead. The alternative point coordination function (PCF) in IEEE 802.11 standard is the more efficient scheme than DCF [4]. There are many kinds of mixed frame formats and channel distributions to improve the media utilization rates. So in our plan of DSRC AMC implementations, we use the new type MAC scheme, PCF dominated and DCF assistant, but not the conventional one. We summary the reasons into two terms; one is the application providing that DSRC:

Mainly provide the channel to transmit the ITS service information and control commands, not arbitrary data transmission in WALN. In PCF dominated infrastructure type can guarantee the access of necessary information and commands.

The PCF has more efficient channel utilization to suit the capacity of high mobility. We arrange the implemented DRSC MAC as a PCF dominated scheme that is based on PCF and assisted with DCF. PCF mainly manager the media access with polling list which included all authenticated and associated stations in the base service set (BSS) coverage. And we open periods of time cyclically in DCF to allow the non-associated and non-authenticated stations to send the management frames and even the v2v transmission. Under the infrastructure architecture, the channel can properly suit the requirements of ITS applications.

III.2 Hardware Implementations

We utilize the ARM integrator as the hardware platform, shown in Figure 4.

![Fig. 4. Hardware platform](image)

ARM integrator mainly includes four modules, that the basic one is Integrator/AP, and it act as a mother-board which has system controller, flash memory, external bus, RS-232, PCI, Compact PCI, and etc. The second module is core module, CM920T, which can be mounted on the Integrator/AP or used independently. CM920T integrates ARM920T microprocessor, FPGA ASIC (includes SDRAM controller, bus bridge, interrupt controller and etc.), expendable SDRAM (up to 256MB), SSRAM, SSRAM controller, clock generator, Multi-ICE interface, and etc. The third one is logic module, LT-XC2V6000, which mainly has a Xilinx FPGA XC2V6000 on it. The FPGA XC2V6000 has 6M system gates that are why so called 6000 series. The logic module connectors of LT-XC2V6000 are not in the type of Integrator/AP, so we further need an interface module, IM-LT1, for bridging them. That’s the forth module in our hardware platform. We use RS-232 serial port to communicate between host PC and ARM development board, so we need to establish the RS-232 decoder to translate the RS-232 information to SSRAM controller compatible ones and to configure the register band. The communications between FPGA and ARM use the AHB bus, and we specify a specific bus to connect the lower MAC and Baseband.
shows the global design architecture of DSRC MAC, it includes the design of driver and upper share memory management (SMM) in host PC, and lower SMM, upper MAC, and lower MAC in network interface card (NIC).

**Fig. 5. MAC implementation architecture**

We first specify the interface between each segment:
1. Between driver and upper SMM, we use the type of function call, that upper SMM provides several interface functions for driver,
2. Between upper SMM and lower SMM, we use the type of I/O mapping, that control information is in register band and data transmission is in SSRAM,
3. Between lower SMM and upper MAC, we use the type of function call, that lower SMM provides functions for upper MAC,
4. Between upper MAC and lower MAC, we use the type of I/O mapping, that use register band in FPGA to transmit the information to each other,
5. Between lower MAC and baseband, we use the register in FPGA to transmit the data and control signals. And the functions of each segment can be described as following:

**Driver:**
1. Interface between OS and upper SMM.
2. Translation of frame format, between 802.3 and 802.11.
3. Fragment and defragment.
4. Duplication detection and recovery.
5. Uni-cast and multicast.

**Upper MAC:**
1. Set register for lower MAC, including TX queue address, IFS, back off CW, RTS/CTS flag, RX queue address.
2. Scheduling algorithm.
3. Retry counter.

**Lower MAC**
1. Set TX rate.
2. Provide the interface to baseband.
3. CCA scheme.
4. Beacon scheme.
5. NAV scheme.
6. FCS generation.
7. Check CRC.
8. Count IFS.
9. Run back off.
10. Send RTS/CTS.
11. Fill time stamp field.
12. Fill Duration field.
13. Answer ACK.
14. Send data.
15. Set TX rate according to RX rate.

The proposed DSRC MAC includes OS driver design in host PC, ARM microprocessor firmware design, and FPGA circuit design. The integration is successfully running under RS-232 transmission rate 115Kbs. We design several demonstrations of MAC schemes, and get correct responses in output points with logic analyzer.

**V. Conclusions**

In this paper, we propose a examine prototype of DSRC MAC for vehicle safety system. For concerning the DSRC applications and high mobility capacity, we utilize the DCF & PCF infrastructure type of MAC to accomplish the safety role in vehicles. And In this paper, we consider each OBD operates in a single RF channel which helps in securing the messages. In theory, an OBD could operate in multiple frequency channels and support more than one application simultaneously. In the future works, we plan to add some inter access point functions and compact handshaking method to deal with
the high mobility issues in vehicles and their safety.

VI References


