An Implementation of the TDMA Baseband Modem for Voice Relay

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Abstract - *This paper presents an implementation of the TDMA baseband modem to support M:N voice communications by using ad-hoc method. The designed baseband modem is applied to communicate a 14-node relay network. Each node can send and receive signals by its assigned time slot. When odd-numbered nodes of 14 nodes can transmit signals at the same time, even-numbered nodes can receive signals, and vice versa. To implement the relay function, the baseband modem has a cycle network controller, a priority dual-port I/O controller with an asynchronous serial device and data buffer memories, and has been programmed on Xilinx Spartan-6 FPGA with Verilog HDL. Since the baseband modem configures a network for maximum 14-hop relay in serial, the communication distance is extended up to 1.4 Km. The baseband modem is tested and verified its functions for voice communications, and its measured maximum delay time is less than 230.4msec for the end-to-end voice transmission.*

Keywords: Wireless Ad-hoc Network, Relay Protocol, Baseband Modem, WPAN

1 Introduction

Wireless personal area networks(WPANs) are used in many places such as small group meetings, short distance multi-way communications, remote speakers and so on. Typically WPANs do not have a function to join the networks or relay voices using ad-hoc function. Also WPANs are very limited distance and outputs because of sharing ISM bandwidth. For small group communications, it is much efficient to use TDMA technology than CDMA technology since TDMA increases the efficiency of the channel.

To implement ad-hoc function for voice communications, there are several technical challenges in ad-hoc networks. First, ad hoc networks have by high bit error rates and path breaks due to changing network topology. High bit error rates reduce the quality of the network service. Second, the transmission frame of the wireless network are included not only preamble for synchronization but also a payload of limited length. Therefore the length of the data packets that are available in an ad-hoc network is short in the wired network. There is also a disadvantage in a multi-hop wireless networks the throughput of data is reduced as the number of nodes increases. In particular, the transmission delay of wireless network communication is increased as the number of hops is increased. There are no products to support the relay protocol and ad-hoc function among groups.

As the processors speeds are increased, it is possible to overcome the above technical challenges. Ahn has proposed a relay protocol based on TDMA technology with ad-hoc function[1]. This paper presents an implementation of the baseband modem for voice communications using the protocol

2 Related Work

There are many researches for ad-hoc networks. For real-time speech on wireless ad-hoc is studied by Kargl, Kwong and Venkat[4][5][6]. Frank Kargl *et al.* have discussed voice transmission over Bluetooth and presented a new routing protocol called Bluetooth Scatternet Routing(BSR)[4]. But they have discussed the possibility, and the chip of BSR has not been implemented. Kwong *et al.* have used multi-path routing protocol called MSDR in order to speech quality[5]. But processing overheads have not been solved. G. Venkat Raju *et al.* have proposed a Localized Distributed heuristic for Minimum number of Transmissions(LDMT)[6]. In order to reduce transmission delay, this algorithm minimizes voice retransmission only.

Several researches have studied to solve the problem of capacity reduction in multi-hop wireless networks[11][12]. They have observed that the performance degrades quickly as the number of hops increases due to using a single radio for transmitting and receiving packets. A good way to improve the capacity of wireless is to use more network interfaces or to use speech compression in the case of voice applications. Some researches have used only one network interface due to cost. Another way to improve the capacity of wireless is to use schedule transmission slots in time and to use multiple non-interrupting frequency channels[13]. Chen *et al.* have observed transmission traffic is decreased as the number of hops increases when single frequency is used in wireless networks[12].

There are no related papers which have been implemented the baseband modem with the relay and ad-hoc functions. This paper presents an implementation of the TDMA baseband modem using Xilinx Spartan-6 FPGA and Verilog HDL. The basic protocol is described in Section 3 and the design of baseband modem is described in Section 4 and 5.

3 Network Protocol

Figure 1 shows the TDMA network cycle for the relay protocol for voice communication. One network cycle has 15 slots. The time length of each slot is 15.36*msec* and one network cycle time is 230.4*msec*. Each slot has 15 frames. Each frame is 1.0*msec*. Each node uses one of its own control section assigned in its frame. Slot 0 is used for the start of the network cycle(SoC) and used for contention slot. If a new node requests to join the network, it should use this contention slot. If there are collisions, random back-off time is used to join the network. The first frame of the other slots is used for the control frame, which is used by the master node and all slave nodes to exchange network information. The other 14 slots are used for transmitting voice data.

The basic structure of each frame as shown in Fig 2 consists of five sections, which are preamble, SyncWord, Header, Payload and EoF(end of frame). The length of the frame is 1024-bit(128B). The preamble is used for stabilizing time of the frequency generator for RF modules and users can specify the length of preamble for specific RF chips. SyncWord is 4-byte synchronous and has a special pattern in order to synchronize the payload data. The Header has the addresses of the sender and the parent node.

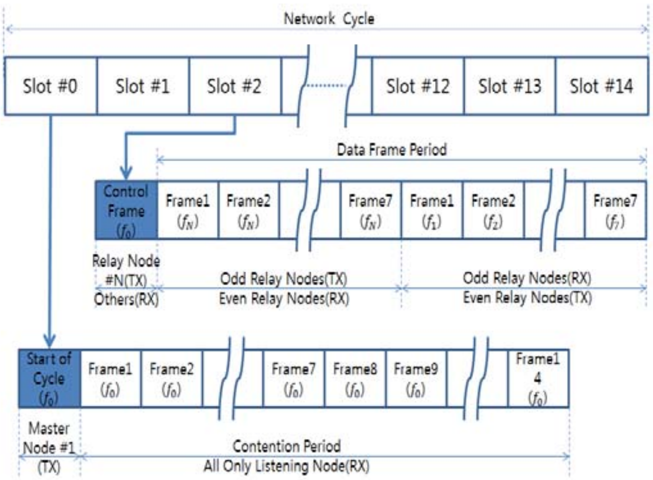

Figure 1. Network Cycle of Relay Protocol

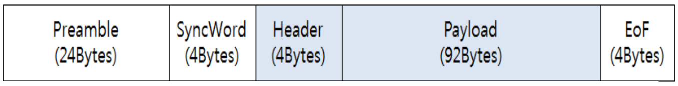

Figure 2. Basic Structure of a Frame

3.1 Start of Cycle

The SoC is generated and transmitted by the master. It indicates the start of the network cycle and all slave nodes should synchronize this signal to work with the network. This includes special codes for security, which are group code and message security code. To synchronize this cycle, the frequency is a designated frequency or default frequency to all slave nodes.

The contention frames followed by the SoC are used to request to join the network and total contention frames are 14 frames. The slave which joins the network sends the message “connection request (JoinREQ)” to the master and the master replies the message “connection permission (JoinACK)” with its node number and network address for routing. For this purpose, the designated frequency is used. After new connection is set up, the frequency hopping is used.

3.2 Control Frames

The control frame is generated and sent by the master and all slave nodes participated in the network. The control frame is used to manage the network using the designated frequency. This frame synchronizes the network, transmits and receives data. The master node and relay nodes use the payload of the control frame to exchange routing information to relay data and ad-hoc function.

3.3 Data Frames

Data frames are divided into 14 small frames to transmit and receive voice data. As shown in Figure 1, 14 data frames are divided into two sections to relay voice data. Two sections have different roles upon hop number from the master. If hop numbers are odd number, the first section (Frame1 ~ 7) is used to transmit voice data generated by odd numbered nodes with designated frequency. The second section (Frame8 ~ 14) is used by even numbered nodes and used to receive voice data. After this stage, odd numbered nodes are changed to the reception mode and even numbered nodes are changed to the transmission mode. The frequency hopping is used for this operation.

4 Baseband Modem Design

The baseband modem for the relay protocol is implemented on Xilinx Spartan-6 using Verilog HDL. The baseband modem block diagram is shown in Figure 3. The modem has a network cycle controller, a priority dual-port I/O controller, an asynchronous serial transceiver, and data buffer memories.

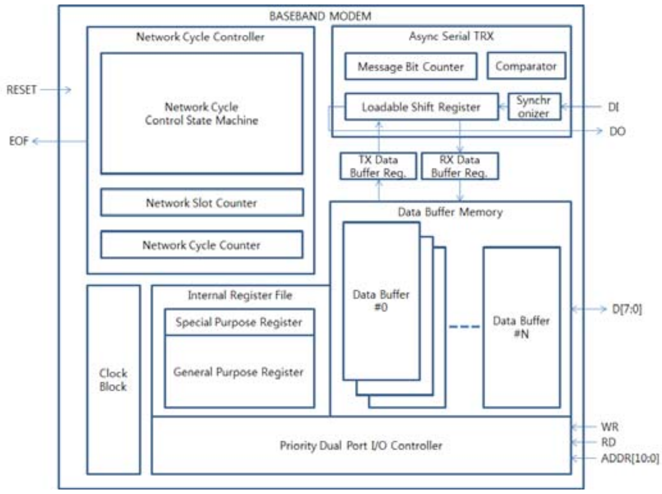

Figure 3. Block Diagram of the Baseband Relay Modem

4.1 Asynchronous Serial Tranceivers

The Baseband modem is designed to communicate asynchronous RF module chip. The RF frequency is ISM(Industrial Scientific and Medical) band. The asynchronous serial transceiver uses a message-bit counter and a comparator to detect a SyncWord and a shift register is used to convert serial data to parallel data or vice versa.

4.2 Buffer Memory

To interface the baseband modem with a processor, buffer memories are implemented. The buffer memories store voice data from the processor to the RF module or store data from the RF module to relay or play voice data. Therefore, seven 512-bit buffers are implemented to handle data simultaneously. Each buffer is assigned to one of seven data frames and each buffer is used to a dedicated relay node participating in the voice relay. In order to reduce the size of logic gates, the data buffer memory is implemented by a single port memory. When a dual-port memory is implemented for fast data access, the power consumption and the number of logic gates increased dramatically.

4.3 Priority Dual-Port I/O Controller

To meet the processing time of the baseband modem, a priority I/O controller is implemented. The priority I/O controller has designed to give higher priority to a network cycle controller when both the network cycle controller and the processor access the buffer memories at the same time.

4.4 Network Cycle Controller

The network cycle controller controls the basic cycle function of the baseband modem. It enters a state of frequency search after it is initialized. In this state, the modem determines whether it is the master node or not. If the master mode is set, immediately it transmits the SoC to provide a network service for slave nodes to join TDMA network cycles. If the slave mode is set, it searches the SoC with the designated frequency. After it receives the SoC, it sends out the message “connection request (JoinREQ)” and searches the control frame of the master and retrieves its unique address assigned by the master. If a slave node receives all information from the master, it synchronizes the network cycle times and operates for transmitting and receiving voice data. The slave node decodes the control frame of the master and compares the SoC continuously, and compares the state of the internal current modem continuously. If the address of slave node is not match the address received from the master, the slave node changes its state to searching mode again since it considers that it is not synchronized to the master. This means that it must be initialized and rejoin the network and performs synchronization process again.

5 Experiment

In order to evaluate relay protocol functions of the baseband modem, it has been assembled on a system board shown in Figure 4. The system board has a Cortex-M4 processor from ST Micronics, a XC6SLX9 FPGA chip from Xilinx, a CC2400 chip from TI and a WM8976 audio codec chip from Wolfson Microelectronics. The baseband modem is programmed on Xilinx FPGA using Verilog HDL. The CC2400 chip is 2.4GHz RF module and the WM8976 chip is used for encoding and decoding voice data. Cortex-M4 processes routing function to relay voice data and controls the system.

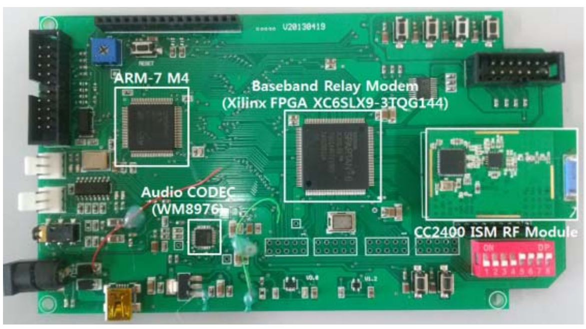

Figure 4. Evaluation Board

In order to evaluate the performance of the modem, experiments have been carried out as shown in Figure 5. First, the master node sends the first frame with the SoC and the control frame according to the network cycles. Slave nodes are joined the network one by one. In Figure 5, a relay node

#2 is connected to the master and a relay node # 4 is connected to the relay node # 2.

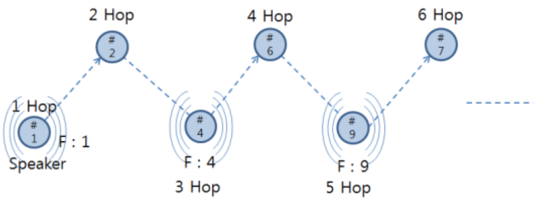

Figure 5 Network topology to test voice relays

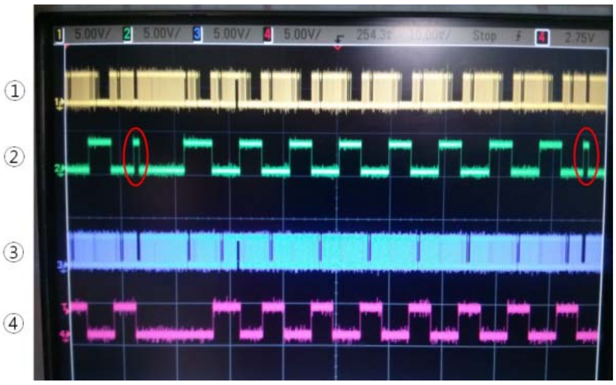

Figure 6. Output Signals of Network Cycle Controller

Figure 6 shows the output signals measured on FPGA pins when the master node transmits data to relay node #2 at Figure 5. At Figure 6, the number ① shows the audio data signal to be transmitted and received by the master. The number ② shows the transfer mode of the master node. The high state of pulses means that master node is a transmission mode and the low state of the pulses means that the master node is a receive mode. The narrow pulses with a circle illustrate the SoC of the first frame of the network cycle. Audio data signals received by the relay node #2 are shown at the number ③**.** The number ④ shows that the relay node #2 is operating in the communication mode.

When the RF module is set to the maximum power, the radius of RF reaches about 100*m*. Experiment results show that the maximum distance using the implemented baseband modem reaches about 1.4*Km* when 14 nodes are connected in serial. When the data bit rate is 1Mbps, the end-to-end delay time from the first node to the 14th node is about 230.4*msec*. The average node-to-node delay time is about 17.7*msec*. When this baseband modem is applied to the personal wireless communication, the delay time guarantees the QoS.

6 Conclusion

In this paper, a TDMA baseband modem has been implemented on FPGA and tested its performance to relay voice data for WPAN environment. The maximum relay nodes are configured up to 14 nodes with ad-hoc function. Experiment results show that the maximum end-to-end delay time of 14 nodes is 230.4 *msec* with the data rate of 1Mbps. The PWAN network can be configured as various topology such as line, start or tree and so on. Also the modem can be used with various RF modules for specific applications with different data rates. It requires to re-design in a chip to apply to WPAN applications.

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