Voice Transmission over Wireless Sensor Networks

Lin-Huang Chang, Chao-Chieh Chen, Tsung-Han Lee

Department of Computer and Information Science,
National Taichung University, Taichung, Taiwan
lchang@mail.ntcu.edu.tw

Abstract. There is a growing need to support voice communication in wireless sensor networks for use in emergency scenarios. In this paper we develop an end-to-end rescue communication voice gateway to provide a stable voice transmission over Bluetooth and Zigbee networks for mountain climber. The performance analyses, in terms of end-to-end throughput, packet loss rate, jitter and delay, show that our implementation can efficiently support voice transmission over wireless sensor networks.

Keywords: Zigbee, Bluetooth, Xbee, Arduino, Speex, Voice over Zigbee.

1 Introduction

Traditional wireless sensor network (WSN) has focused on sensing and reporting physical phenomenon or environmental parameters, such as temperature, sound and pressure etc. Currently, using WSN for emergency response has gained significant attention due to the development of WSN technology. The data types transmitted over WSN becomes diversity. There are many hazard scenarios, such as emergency response, rescue, and disaster during mountain climbing, which need to support voice transmission over WSN (VoWSN).

Several standards are currently under developed for WSN. The Institute of Electrical and Electronics Engineers (IEEE) approved the 802.15.4 Standard [1] to define the physical and media access control (MAC) for Low-Rate wireless Personal Area Network (LR-WPAN). Upper layer are defined by Zigbee Alliance [2]. The features of Zigbee include the standard specified operation in the unlicensed 2.4 GHz worldwide, low power consumption, low transfer rate (default rate: 250kbps), short-range communication capability, (maximum: 300m), limited computational capacity and memories.

The research from Brunelli et al. [3] has investigated and analyzed the performance of Zigbee network for voice transmission. They adjusted the sensor network deployment to maximize transmission performance. Their simulation and experimental results have demonstrated that by adjusting the input and output queue size properly, WSN is capable of providing most common voice streaming applications. Several voice transmission mechanisms and architectures for communication over WSN have been studied in [4-7].

On the other hand, the usage of Bluetooth as the direct access of voice transmission has been prevalent. Therefore, transmitting voice data via Bluetooth and then over limited Zigbee bandwidth is very attractive for many applications. However, the voice transmission from Bluetooth via Zigbee and then back to Bluetooth wireless technology was not paid too much attention and the flow control mechanisms in personal area network (PAN) have not been clearly explored. The bandwidth difference between these two wireless transmissions may require an effective flow control mechanism. Accordingly, designing a flow control and traffic management to maintain a balanced traffic flow between Bluetooth and Zigbee would be an important research issue.

In this paper, we will design and implement a Bluetooth and Zigbee voice gateway (BZVG) with flow control mechanism to provide voice transmission from Bluetooth via Zigbee and back to Bluetooth. The rest of this paper is organized as follows. We review related works in section II. In section III we describe the system architecture of BZVG followed by the Section performance analysis presented in section IV. Finally we address the conclusion in section V.

2 Related Works

The researches in [4-7] have developed several voice communication protocols for voice transmission. In [5], authors developed a real-time emergency rescue communication system for mine tunnel over Zigbee networks. They use embedded system named Atmel ATmega32 [8] to implement on-board audio sampling, ADPCM encoding and packet transmission. However, voice packet due to the stochastic transmissions of voice packets, a burst of voice packets may cause micro-controller unable to afford encoding and to handle packet transmission simultaneously. Their study did not provide any flow control mechanism, to reduce the significant packet error rate due to the burst voice packets.

The researches in [6,7] evolved from [5] tried to resolve some problems addressed above. They modified and improved previous implementation for voice communication over Zigbee. They adopted non-acknowledgement mode and G.729.A codec to transmit 127B voice data every 100ms. They achieved higher bandwidth utilization. Nevertheless, the flow control mechanism for burst traffic was not taken into account. When the communication range increases, the packet loss rate may increase.

The research in [9] presented a hybrid Zigbee/Bluetooth grid infrastructure. The authors proposed a packet format conversion mechanism for heterogeneous wireless network which equipped wireless nodes with both wireless interfaces. Their system allowed a widespread diffusion between 2 Mbps Bluetooth data rate to inter-transfer with 250 kbps Zigbee data rate.

Basically, their system did not support real-time audio streaming. In addition, the design and implementation of Bluetooth and Zigbee voice gateway need to resolve the problem due to wireless communication bandwidth difference. Our research adopted non-acknowledgement mode to Zigbee networks for voice packet transmission. Our gold is to accomplish highest bandwidth over Zigbee network and reduce packet loss rate to enhance the overall transmission performance. Therefore in this paper we will design and implement flow control mechanism in the voice gateway for voice transmission between Zigbee and Bluetooth wireless network.

3 System Design and Architecture

In this paper we propose a real-time voice transmission system over WSN for mountain-climbing scenario as shown in Fig. 1. Mountain-Climber will carry a BZVG device, with the same battery capacity, memory, CPU clock rate and communication capacity as well as being able to send and receive packet via Bluetooth and Zigbee, for voice communication. If the BZVG devices are within the signal coverage, they can communicate via peer-to-peer for voice data transfer.

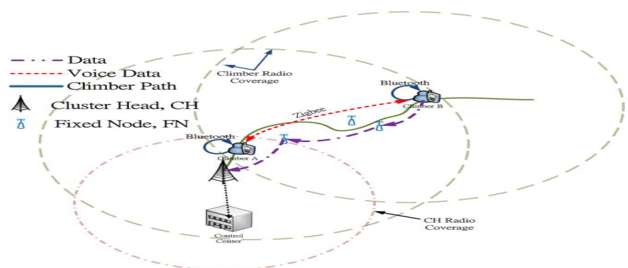

Fig. 1 Voice communication in mountain-climbing scenario

We adopted Xbee [10] wireless transmission module, with up to 250 kbps transmission data rate, for our experiments. The maximum Xbee packet size is 117B, including 100B payload. Xbee have a Universal Asynchronous Receiver/Transmitter (UART) interface for data and control flows. We adopt non-ACK mode without retransmitting packets when an error packet occurs to meet the voice transmission requirements.

Due to the limitation of Zigbee bandwidth and the sensitivity of real-time transmission with delay, jitter and packet loss, as well as the experimental analysis in the [11], we adopted Speex [12] to implement the BZVG device. Speex is an open-source software with audio compression format designed for speech. Speex can encode and decode in narrowband mode. According to [11], it has been implemented with sud-mode 4 and 11 kbps data rate to provide the best tradeoff between speech quality and computational complexity.

The BZVG system architecture is shown in Fig. 2. The codec converts the analogue signal to digital data. It then compresses these data to 11 kbps data with Speex algorithm. The Bluetooth headset transmits data to BZVG gateway. Voice packets are managed via flow control mechanism and transferred to Xbee for Zigbee communication. Each Speex frame contains 20ms of voice data with 28 bytes. Bluetooth transmits a voice data with 1440B every 20ms. Therefore Bluetooth is able to support Speex process speed.

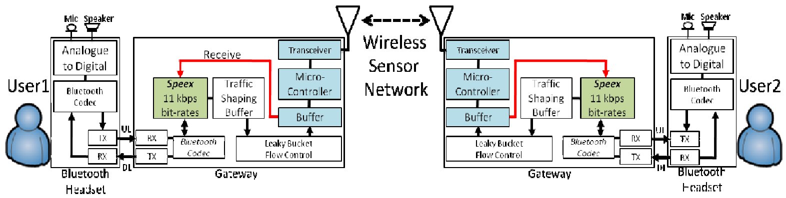

Fig. 2 BZVG system architecture

This paper has implemented BZVG device which combined Bluetooth and Zigbee. It consists two different data rates which are 576 kbps and 106 kbps respectively. We also implemented efficient flow control mechanism to make sure voice data can be transfered over Zigbee network without trouble. The architecture of flow control mechanism in BZVG is shown Fig. 3. Flow control mechanism is composed by Traffic Shaping Buffer (TSB), Leaky Bucket [13] and Xbee internal flow control.

When voice is encoded, data will be sent via Bluetooth to BZVG device. When Bluetooth receiver in BZVG device receives a large amount of voice packets, it stores these packets in the TSB. This will avoid congestion or packet loss when the connection is incomplete or Xbee is busy. When data is stored in TSB, it will trigger the Leaky Bucket to read 100B of data every 3ms and send them out via Zigbee network. We set an Upper Bound and Lower Bound of the buffer in TSB. If the stored data reaches TSB Upper Bound, data will be dropped randomly to prevent packets collapse due to burst congestion.

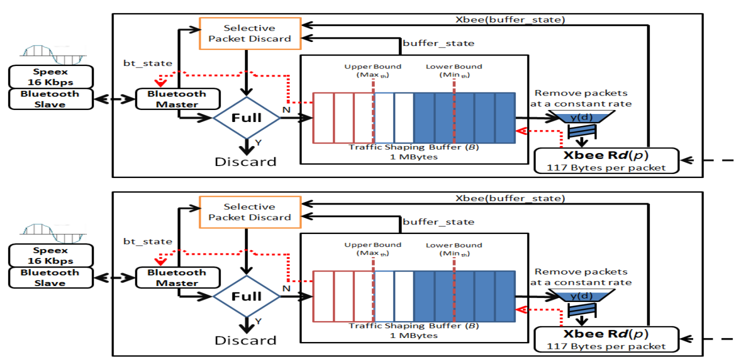

Fig. 3 Architecture of BZVG flow control

The implemented flow control mechanism will optimize the voice data transmission between Bluetooth and Zigbee. If Zigbee network is unavailable, data will be stored in TSB, until Zigbee network recovered.

4 Performance Analysis

In this paper, we implemented a BZVG device to study the capacity of voice transmission over wireless sensor networks. In order to evaluate Zigbee's capability for voice transmission, it is necessary to measure the maximum throughput, packet loss rate, delay and jitter between two Xbee nodes. We apply three different payloads, 60B, 80B and 100B, to analyze the impact of different packet sizes on transmission throughput over Zigbee network. From the experimental results, shown in Fig. 4, we discover that in fixed packet inter-arrival time, the throughput decreases with the reduction of payload. Furthermore, when the transmission distances increases, resulting in unstable signal and possible packet loss, the throughput reduces simultaneously. However, the maximum throughput with 300m distance can be kept about 83.68 kbps.

Next, we conduct the delay measurements for different distances by transmitting the voice packets at the source to the destination with received packets. Experimental result for 100m transmission delay is shown in Fig. 5. From the experimental results, the delay varies from 5 to 8ms for 100m distances.

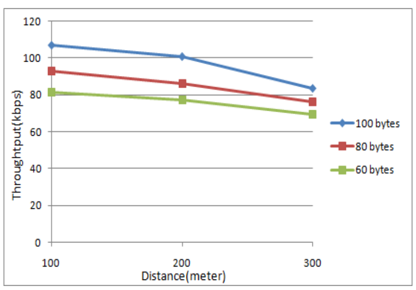

Fig. 4 Transmission throughput

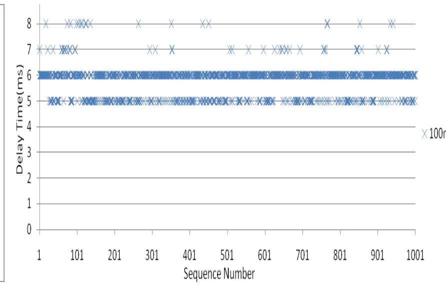

Fig. 5 Transmission delay for 100m

The overall performance analysis include delay, jitter and packet loss of the experiments is summarized in Table 1. For 100m transmission distance, the one-way mean delay, mean jitter and packet loss rate is 5.7ms, 0.006ms and 0.65%, respectively, which are within the Good category defined in ITU-T G.711[14]. The delay increases for 300m transmission distance, however, it is still within the Acceptable category.

TABLE 1 Analysis of The Measured Value

Distance	Mean Delay (ms)	Mean Jitter (ms)	Packet Loss Rate (%)
100m	5.7	0.006	0.65
200m	10.9	0.01	1.32
300m	47.2	0.09	3.88

5 Conclusions

The BZVG gateway, with several flow control mechanism to balance the difference of wireless transmission data rates, was designed and implemented in this paper to provide a stable voice transmission over Bluetooth and Zigbee peer-to-peer networks. With the testbed, we conducted experiments to realize the voice transmission over Zigbee and the performance results for communication distance within 200m experience the acceptable level in terms of delay, jitter and packet loss.

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