Design and Implementation of Error Control Algorithms for Bluetooth System: Open-loop and Closed-loop Algorithms

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Abstract—We propose open-loop and closed-loop link quality control (LQC) algorithms using the correlation output of the access code for a short-range radio network. The new schemes can decrease the number of retransmission and data overhead which result in improving the throughput of the Bluetooth system without extra hardware burden.

1. Introduction

Industries are heavily taking interest in a personal area network (PAN) and developing PAN systems such as HomeRF and Bluetooth [1][2]. In the Bluetooth system, using a frequency hopping (1600 hops/s) and error control algorithms such as a forward error control (FEC) and unnumbered automatic repeat request (ARQ), the interference protection can be achieved. However, inappropriate FEC error control will give unnecessary overhead and increases the retransmissions of packet which result in degradation of throughput and data rate of Bluetooth system [3].

In this paper, two link quality control (LQC) algorithms which use a sliding correlator output are proposed in a short-ranged Bluetooth system. The open-loop and closed-loop LQC algorithms decide the FEC error control scheme by monitoring the sliding correlator output reflecting the link quality of the Bluetooth radio.

2. LQC Algorithms for Bluetooth

2.1 Open-loop LQC Algorithm

A Bluetooth device in the receiving mode activates a sliding correlator against the access code and triggers a control signal when the correlator's output exceeds a threshold. The trigger control signal wakes up the device [3]. The sliding correlator output can be used as an indicator of the radio channel environment with noise and interference. The existing Bluetooth system uses the sliding correlator only for the receiving slot timing and link acquisition [3]. However, the proposed LQC algorithm uses the sliding correlator to reduce the data overhead and packet retransmission. The open-loop LQC scheme utilizes the received ARQ state and the sliding correlator.

Fig. 1 describes the structure of the proposed open-loop LQC block. In the open-loop LQC, the classification block and error control block are implemented by software of the existing Bluetooth baseband processor which makes no extra hardware burden. In Fig. 1, The sliding correlator output \( \Lambda(k) \) can be expressed as

\[
\Lambda(k) = \sum_{n=1}^{N_w} c(n)r(k-n), \quad r(n) = 0 \text{ if } n < 1 \quad (1)
\]

where \( N_w \) is the length of the access code, \( c(n) \) is the stored bipolar access code, and \( r(n) \) is the received data in the searching window. According to the value of \( \Lambda(k) \), the classification block categorizes three classes as follows:

\[
C_M \in \{2/3 \text{ FEC class } | \lambda_M \leq \Lambda(k) < \lambda_H \}
\]

\[
C_L \in \{1/3 \text{ FEC class } | \Lambda(k) < \lambda_M \}
\]

\[
C_H \in \{\text{no-FEC class } | \Lambda(k) \geq \lambda_H \}
\]

(2)

where \( \lambda_M \) and \( \lambda_H \) are the boundary thresholds for three classes. The maximum sliding correlator output in the additive white Gaussian noise (AWGN) and multipath fading channel is shown in Fig. 2. We use the lower address part (LAP) of the general inquiry access code (GIAC) '0x929b33' to generate access code [2]. It is shown in Fig. 2 that the quality of the link environment can be estimated by monitoring the maximum output of correlator.

During the initial link setup, the proposed algorithm can guide an appropriate FEC, which makes the probability of the packet retransmission to be reduced. In the
connection state, on the other hand, the algorithm with received ARQ state monitors the quality of the Bluetooth link, which results in the decrease of the packet retransmission and data overhead. Through the simulation, however, it is observed that the fast error control scheme can lead to the vibration of the FEC error control. This can be circumvented by designing a hysteresis curved error control classes for the classification block. Fig. 3 presents the generation of the hysteresis curved error control classes. In this hysteresis curve, the threshold value $\lambda_M$ is set to 51 as a default.

The LQC block of Fig. 1 can be described as a finite-state machine as shown in Fig. 4. In the state transition trigger $(a, b)$, $a$ represents the state of the ARQ and $b$ displays the error control class. The error control classes are generated by the hysteresis curved generator of Fig. 3. The LQC scheme monitors the ARQ state to prevent the FEC error control vibrations.

The open-loop LQC algorithm can be used efficiently in the initial link set-up state of Bluetooth system and has the excellent capability of the omni-directional communication mode.

2.2 Closed-loop LQC Algorithm

In the open-loop LQC algorithm, each Bluetooth device only utilizes the correlation information from its own received radio link. The open-loop LQC algorithm is based on the assumption that the radio links between two Bluetooth devices are same. However, the radio link environments are different when the direction of the Bluetooth link changes. For the compensation of the quality loss due to the different radio links, a closed-loop LQC algorithm which takes into account the other sliding correlator of the linked Bluetooth device is designed. Fig. 5 shows the proposed closed-loop LQC architecture.

The closed-loop LQC algorithm utilizes the error control classes of the other linked Bluetooth device in the connection mode. In Fig. 5, Bluetooth unit A uses the error control classes of Bluetooth unit B. Therefore, the error control classes of Bluetooth unit B indicate the quality of the radio link from Bluetooth unit A to Bluetooth unit B. Using the reciprocal link informations, the closed-loop LQC algorithm provides more accurate information for the error control. The structure and implementation of the closed-loop algorithm are same as those of the open-loop algorithm described in the previous section.

The closed-loop LQC algorithm can be used in the connection mode of Bluetooth system. It shares information about each Bluetooth radio environment by exchanging the error control classes. This algorithm has the best performance in the broadcast mode or bi-directional communication.

REFERENCES