# Emulating GFSK Modulation for Wi-Fi-to-BLE Multicast Communication

Chaeyeong Lee, Moonbeom Kim, Jeongyeup Paek
Chung-Ang University
Department of Computer Science and Engineering
Seoul, Republic of Korea
cxaexeong/mbkim/jpaek@cau.ac.kr

## Abstract

*Cross technology communication* (CTC) facilitates direct communication between heterogeneous wireless technologies in the overlapped frequencies such as the 2.4 GHz ISM band. In this poster, we propose a novel method named *WBMC* for direct multicast communication from a Wi-Fi device to multiple BLE transceivers. This is achieved by making a Wi-Fi signal appear like BLE's *Gaussian frequency shift keying* (GFSK) signal over multiple subcarrier groups of Wi-Fi. Uniqueness of *WBMC* compared to prior Wi-Fi-to-BLE CTC studies is that one Wi-Fi transmission can deliver distinct data to multiple BLE receivers simultaneously. The potential and feasibility of the newly suggested approach is demonstrated through implementation on GNURadio.

## CCS Concepts

• **Networks** → **Physical links**; *Cross-layer protocols.*

## Keywords

Wi-Fi, BLE, Cross Technology Communication, Multicast

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An earlier idea of this poster appeared in the proceedings of the 14th International Conference on Information and Communication Technology Convergence (ICTC) – Workshop on Big Data (IWBD), Oct. 2023 [5]. However, that version only had the initial idea whereas this work has been significantly extended with actual algorithm design and implementation.


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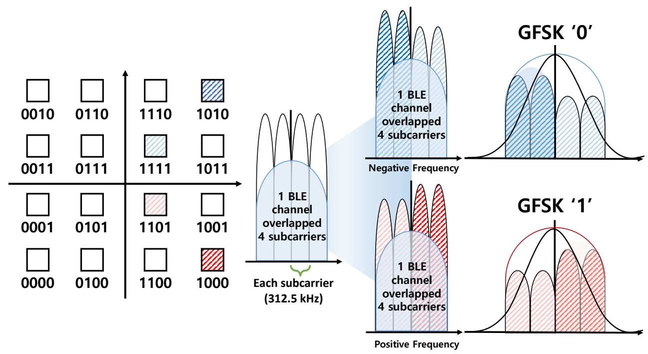



**Figure 1: Symbol Strength-based Subcarrier Manipulation**

## 1 Introduction

The 2.4 GHz ISM band's dense population of heterogeneous devices leads to severe cross technology interference, hindering network scalability and spectrum efficiency. Multi-interface gateways can mitigate the problem to some extent, but are costly and inefficient. For this reason, *Cross Technology Communication (CTC)* that allows direct communication between heterogeneous wireless technologies is gaining attention as a promising solution.

However, research on Wi-Fi to BLE CTC is more limited than that of ZigBee-based research. This is because ZigBee-based CTC relies on the error correction capabilities of direct sequence spread spectrum (DSSS). For example, WeBee [7] can receive only 50% of the CTC frames. Additionally, in cases like WiBle [6], which uses IEEE 802.11b and proposes a *symbol mapping table*, only the phase needs to be considered for PSK modulation. However, quadrature components must also be considered for OFDM, making quantization errors inevitable. While most research aims to minimize these errors by approximating symbol positions, we utilize the symbols' unique geographical location and signal strength. If we can manipulate overlapping subcarriers in multiple BLE channels in this manner, we can repurpose Wi-Fi hardware for Bluetooth functionality. For example, Bluetooth LE Audio [8, 9] can provide content about exhibits in places like museums, stadiums, and tourist attractions. However, in larger venues,

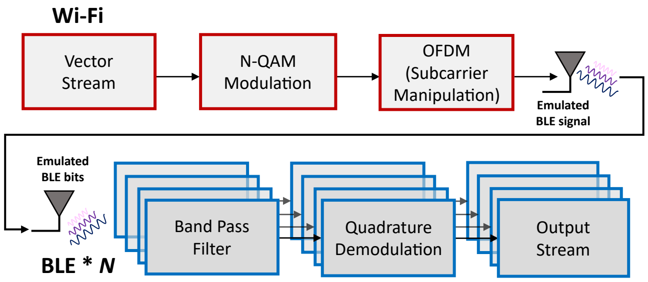
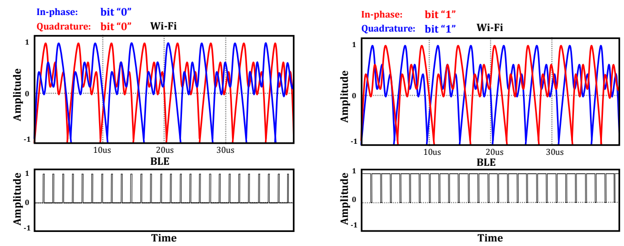



**Figure 2: An overview of *WBMC***




**(a) BLE bit '0'** **(b) BLE bit '1'**

**Figure 3: When transmitting mimicked GFSK signal**

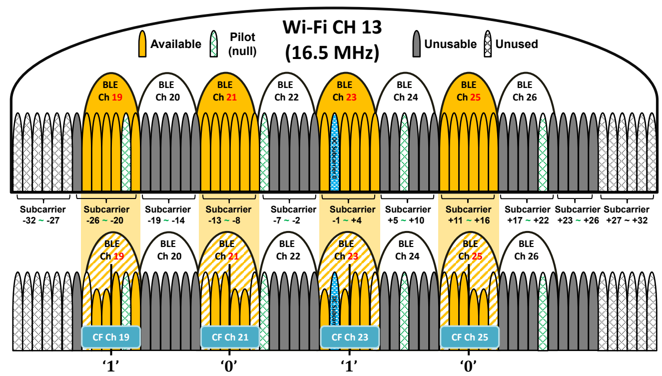



**Figure 4: Multicast different data to 4 BLE channels**

more Bluetooth devices are required, which can lead to increased operational and maintenance costs [3, 4]. For this reason, repurposing Wi-Fi hardware for Bluetooth functionality can leverage its wider coverage to deliver different content to various Bluetooth devices, thereby enhancing interoperability. We thus emulate GFSK modulation to propose "Wi-Fi-to-BLE Multicast Communication (*WBMC*)", and evaluate the performance across 4 BLE channel when transmitting from a single Wi-Fi.

## 2 *WBMC* Design

Wi-Fi and BLE share the same 2.4 GHz ISM band, but have different characteristics. Wi-Fi typically uses orthogonal frequency division multiplexing (OFDM) and quadrature amplitude modulation (QAM), with each channel being 20 MHz bandwidth and containing 64 subcarriers, each with a bandwidth of 312.5 KHz[2]. In contrast, BLE utilizes Gaussian frequency shift keying (GFSK) modulation to encode digital information onto the carrier via frequency deviations, where a higher frequency is termed *mark* and a lower frequency is termed *space* [9]. BLE also operates within a significantly narrower bandwidth of 2 MHz compared to Wi-Fi. Based on these facts, to enable direct communication between two different communication technologies, we emulate GFSK signals by manipulating the subcarriers of Wi-Fi channels that overlap with BLE channels. Fig. 2 illustrates the overall process of the transmitter and receiver sides of *WBMC*, with core part to note being the *subcarrier manipulation* and *band pass filter*.

**One-to-One Communication:** *WBMC*'s key technique is the *subcarrier manipulation*, which utilizes changes in signal strength based on the geographic locations of QAM symbol coordinates to emulate the frequency deviation of GFSK. For instance, as depicted in Fig. 1, *WBMC* transmits by placing external symbols (ES) on subcarriers with lower frequencies relative to the center frequency of BLE, and internal symbol (IS) on subcarriers with higher frequencies within a Wi-Fi bandwidth that overlaps the BLE channel (indicated by blue hatching). Upon receiving this emulated signal, as illustrated in Fig. 3a, BLE detects it as a frequency deviation of GFSK and decodes it as a '0'. Conversely, as indicated by the red hatching in Fig. 1, BLE also detects this as a frequency deviation and decodes it as a '1', as shown in Fig. 3b. By transmitting data on each subcarrier based on combinations such as *ES with IS* or *IS with ES*, it is possible to emulate a GFSK signal. We have further identified symbol combination patterns that facilitate the seamless reception of actual data (*e.g.,* '1010', '0101'). When transmitting consecutive data, it is necessary to use two different symbol combinations with the *same phase* (*e.g.,* '1010, 1111' or '1101, 1000' as illustrated in Fig. 1). The reason is that if symbol combinations with different phases are used (*e.g.,* '1010, 1101'), the frequency deviation of the emulated signal from space to mark or from mark to space could cause distortion in the consecutive signals due to the differing phases, potentially leading to bit errors in GFSK.

**Multicast Communication:** Theoretically, approximately 10 BLE channels overlap with a single Wi-Fi channel. However, considering the unused subcarriers within the Wi-Fi channel, 8 BLE channels overlap. To leverage this multiple BLE channel overlap and utilize the wide bandwidth more efficiently, we propose a multicast method for one-to-many

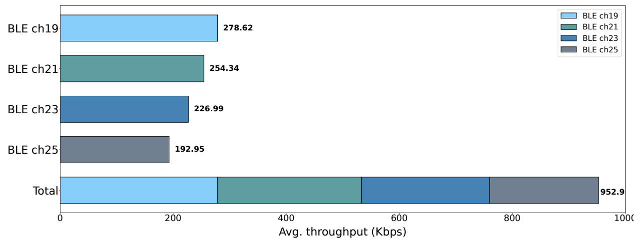



**Figure 5: Aggregate Throughput of 4 BLE channels**

communication. To eliminate interference from Wi-Fi subcarriers that overlap with adjacent BLE channels, we choose 4 nonadjacent channels (for example, BLE channels 19, 21, 23, and 25) out of the 8 overlapping BLE channels, as illustrated in Fig. 4. After that, *WBMC* employs *subcarrier manipulation* to transmit data on the subcarriers, excluding those designated for non-data transmission purposes such as the pilot subcarrier (in BLE channel 19) and the DC subcarrier (in BLE channel 23). At this time, we apply *band pass filter* to each of the 4 selected channels, enabling them to independently receive data on their respective BLE channels. As a simple example, suppose that we transmit data with a value of 1 on BLE channels 19 and 23, and a value of 0 on channels 21 and 25. *WBMC* transmit combinations based on the center frequency of each BLE channels shown in the bottom part of Fig. 4, sending *ES with IS (representing '1')* to BLE channels 19 and 23, and *IS with ES (representing '0')* to channels 21 and 25. This approach enables *WBMC* to simultaneously transmit different data to various BLE devices.

## 3 Evaluation

We assess the potential applicability of *WBMC* and evaluate the performance of this in a multicast communication scenario. We implemented the PHY layers of each other, which are Bluetooth 5.4 standard [9] and WiFi based on the IEEE 802.11g [2], in GNURadio. The subcarrier manipulation on the Wi-Fi side is modified to control each subcarrier for *WBMC*. Experiments are conducted in four scenarios using different datasets ('0,0,0,0', '0,1,0,1', '1,0,1,0', and '1,1,1,1'), and each experiment is carried out for 60 seconds.

Fig. 5 plots the individual throughput of each of the 4 utilized BLE channels, along with the aggregate throughput. BLE channels 19, 21, 23, and 25 achieve throughput averages of 278.62, 254.34, 226.99, and 192.95 Kbps, respectively. Given that the maximum PDU size from the preamble to CRC of the BLE standard is 261 bytes, it is enough to apply in not only common applications but also audio streaming applications requiring a throughput of about 192 Kbps [1]. Furthermore, *WBMC* achieves parallel simultaneous transmission, while resulting in an aggregate throughput of 952.9 Kbps for all BLE, which is a result close to the throughput of 1 Mbps for the BLE 1M PHY.

## 4 Summary

We proposed a *WBMC*, a novel approach for Wi-Fi-to-BLE multicasting that has not been previously attempted. *WBMC* achieves the parallel transmission of individual data to multiple BLE devices and high throughput, leveraging the symbol strength-based subcarrier manipulation. Specifically, our preliminary experiments show the *WBMC* possibility and applicability that can be applied to diverse BLE systems from common applications to LE-Audio. In future work, we plan to enhance *WBMC* to accommodate as many BLE devices as possible and achieve higher performance. We also will advance the extensive study by utilizing software-defined radio (SDR) and commercial BLE devices in real environments and conducting comparative experiments against prior studies.

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