MATLAB Simulink for Bluetooth Frequency Hopping and Modulation Model

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تاريخ الاستلام 29-01-2024

الملخص

توضح هذه المقالة مكونين أساسيين لمعيار الاتصالات اللاسلكية عبر Bluetooth: تعديل Bluetooth وقفز التردد، باستخدام نموذج Simulink الذي تم إنشاؤه باستخدام برنامج MATLAB. يقدم نموذج Simulink وصفاً شاملاً ومرئيًا لنظام تعديل Bluetooth وعملية التنقل بين الترددات. إنه يسهل إنشاء وتحسين المنتجات التي تدعم تقنية Bluetooth من خلال العمل كأداة مفيدة لفهم وتقييم أداء أنظمة Bluetooth. الهدف الرئيسي من هذه الدراسة هو محاكاة وتقييم وتحسين إشارة إرسال البلوتوث من أجل إنشاء منتجات جديرة بالثقة وفعالة تدعم تقنية البلوتوث. من حيث النتائج، تحقق هذه المقالة سرعة 1 ميجابت في الثانية.

الكلمات المفتاحية: تعديل البلوتوث، نموذج Simulink، التحسين.

Abstract

This article describes two essential components of the Bluetooth wireless communication standard: Bluetooth modulation and frequency hopping, using a Simulink model created with MATLAB software. The Simulink model gives a thorough and visual description of the Bluetooth modulation scheme and the frequency hopping process. It facilitates the creation and improvement of Bluetooth-enabled products by acting as a useful tool for comprehending and evaluating the functioning of Bluetooth systems. The main objective of this study

is to simulate, assess, and improve the Bluetooth sending signal in order to create trustworthy and efficient Bluetooth-enabled products. In terms of the results, this article achieves 1Mbps.

Keywords: Bluetooth modulation, Simulink model, Optimization, MATLAB.

1. Introduction

Bluetooth technology has become ubiquitous in modern wireless communication systems, enabling seamless data transfer between various devices [1]. Understanding the underlying principles of Bluetooth modulation and frequency hopping is essential for designing and implementing reliable Bluetooth systems [2].

The frequency band used by Bluetooth technology is the 2.4 GHz ISM band, which is divided into 40 channels with 2 MHz channel spacing, of which 37 are data channels and 3 are used as advertising channels. The Bluetooth radio employs frequency hopping techniques with the carrier modulated using Gaussian frequency shift keying (GFSK) to mitigate cochannel interference by Bluetooth devices.

Wireless data transfer between devices is made possible by Bluetooth data transfer. A variety of data formats, including files, documents, photos, audio, and video, can be exchanged using it. Common uses for this feature include sharing media between Bluetooth-enabled devices and transferring files between a PC and a smartphone [3].

Furthermore, Bluetooth's IoT connectivity is crucial to the Internet of Things (IoT) ecosystem. Bluetooth Low Energy (BLE) has made it possible for devices to connect and communicate while using less power, which makes it appropriate for Internet of Things (IoT) devices such as smartwatches, fitness trackers, home automation systems, and medical sensors [4].

This article presents a Simulink model that accurately represents these aspects, allowing for in-depth analysis and evaluation. The remining section in this article are classified into five sections. Section 2 discussing the overview of Bluetooth modulation and frequency hopping techniques. Section 3 presented the flowchart operation of Bluetooth. Section 4 considered the methodology. Alog with presenting the original data. Closing the article by the acquired results in Section 5 along with listed of recent cited references.

2. Overview of the Bluetooth modulation and frequency hopping

Bluetooth technology utilizes adaptive frequency hopping (AFH) as a form of frequency-hopping spread spectrum (FHSS) to overcome interference and find a clear transmission path that avoids packet collision [5]. This involves dividing the frequency band into smaller channels and rapidly hopping between those channels when transmitting packets. Additionally, Bluetooth adapts its hopping sequence and dynamically tracks and avoids noisy and busy channels to further reduce the chance of interference [6].

The concept of frequency hopping in Bluetooth technology is often credited to Austrian actress Hedy Lamarr as a co-originator of the patent granted in 1942 based on spread spectrum transmission [7]. Adaptive frequency hopping (AFH) in Bluetooth technology alters the frequency hopping sequence in the Bluetooth basic rate/enhanced data rate (BR/EDR) Physical Layer (PHY) and minimizes the impact of WLAN interference by excluding Bluetooth channels that are sources of interference [8]. The Framework of building Bluetooth modulation and frequency hopping is demonstrated in Figure 1.

2.1 Bluetooth Modulation

The Simulink model includes the Bluetooth modulation scheme, which employs a combination of Gaussian minimum shift keying (GMSK) and phase shift keying

(PSK) techniques [9]. GMSK is used for transmitting data efficiently, while PSK is utilized for synchronization and control purposes [10]. The model demonstrates the generation and encoding of Bluetooth symbols using these modulation techniques [11].

2.2 Frequency Hopping

Frequency hopping is a core feature of Bluetooth, used to mitigate interference and enhance security [12]. The Simulink model incorporates the frequency hopping mechanism, which involves the rapid switching of the carrier frequency within the designated Bluetooth frequency band [10]. The model demonstrates the generation of the hopping sequence and its application to the transmitted signal [13].

3. MATLAB code Simulink Model of Bluetooth Modulation and Frequency Hopping

Creating the complete Simulink model of Bluetooth modulation and frequency hopping is beyond the scope of a text-based conversation [2]. However, It can provide you with a basic outline and key components that you can use to build your Simulink model [12].

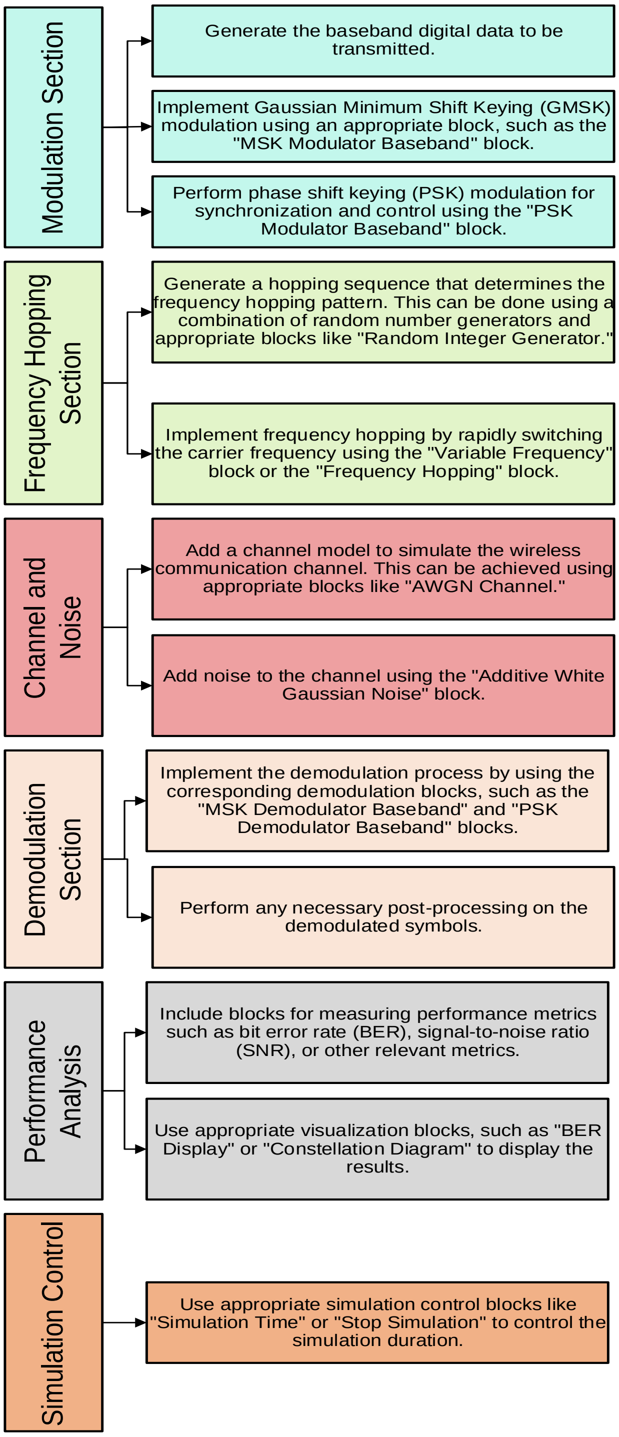

Figure 1: Framework of building Bluetooth modulation and frequency hopping.

This outline provides a general framework for building a Simulink model of Bluetooth modulation and frequency hopping [14]. It can be further customized and expanded the model based on the designer specification requirements and research objectives. Additionally, it may need to explore the available Simulink blocks and functionalities to implement more advanced features and optimizations.

4. Methodology

Simulation and Analysis model allows for the simulation and analysis of Bluetooth communication scenarios. Users can modify parameters such as symbol rate, hopping sequence, transmission power, and interference sources to evaluate system performance under various conditions. The model provides valuable insights into the effects of different parameters on signal quality, interference rejection, and overall system robustness.

In terms of system model, it is demonstrated in Figure 2 which is consist of the main two section (transmitter and receiver) [2].

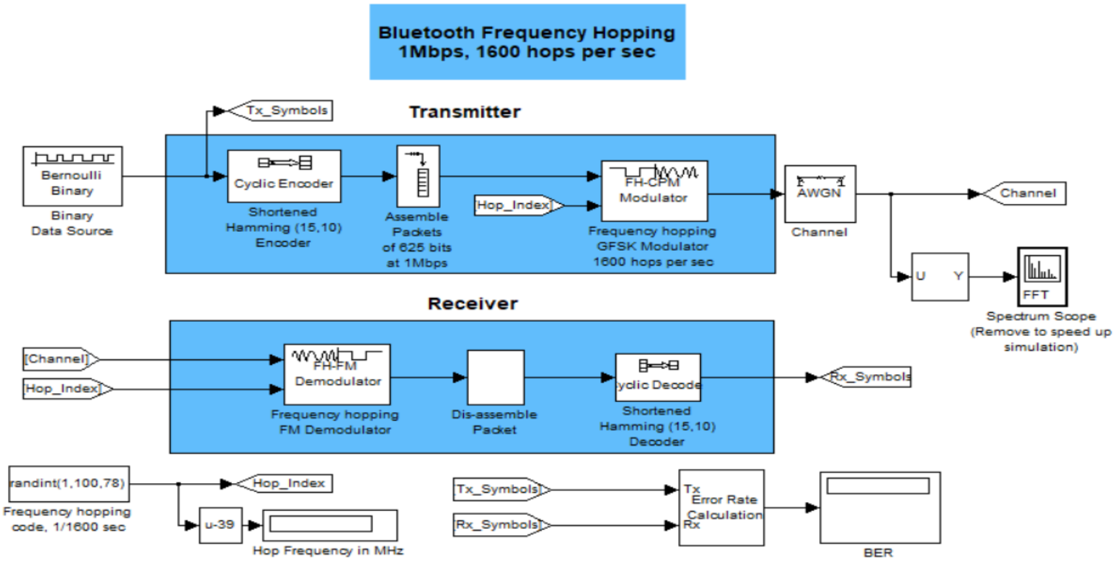

Figure 2: Proposed diagram using Malab Simulink for Bluetooth transceiver.

The previous model has been implemented with the help of the mathematical equation in order to gain the results as presented in Eq. (1) considering Bernoulli distribution that refers to the probability q=$1-p$ that ranges between random variable (0 and 1). While the work operation of the model is shown in the flowchart that presented in Figure 3. Additionally, the f represents mass function of the distribution. The arbitrary message polynomial is mathematically demonstrated in Eq. (2) [2]. The polynomial is generating is shown in Eq. (3).the created code word is demonstrated in Eq. (4).

$$f(k;p)=\begin{cases} p & if\ k=1, \\ 1-p & if\ \ k=0 \end{cases} \quad (1)$$

$$m(x)=c_0+c_1x+\cdots+c_9x^9 \quad (2)$$

$$g(x)=x^5+x^4+x^2+1 \quad (3)$$

$$c(x)=m(x)\times g(x) \quad (4)$$

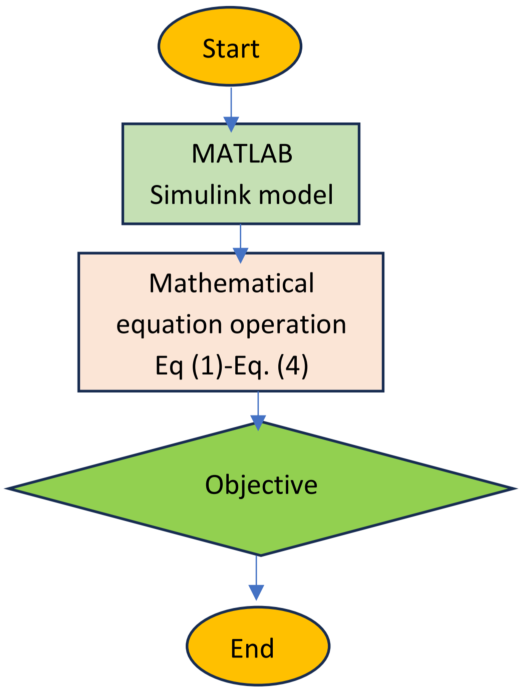

Figure 3: Flowchart

Bluetooth enables the connection of peripheral devices to a host device as shown in Figure 4. For example, Bluetooth can be used to connect wireless keyboards, mice, game controllers, and other input devices to a computer or a gaming console. This functionality provides a cable-free and convenient way to interact with devices.

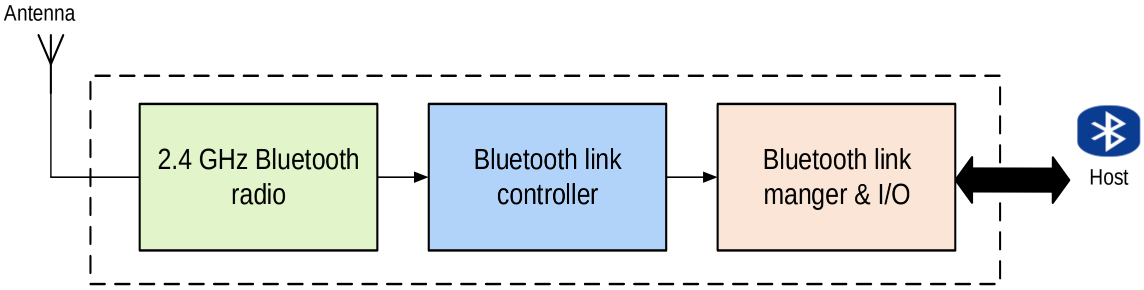

Figure 4: General artiticture of bluetooth module.

4.1 Performance Evaluation:

The Simulink model facilitates the evaluation of important performance metrics of Bluetooth systems. By analyzing the Bit Error Rate (BER), Signal-To-Noise Ratio (SNR), and other relevant measures, researchers and engineers can optimize system design, select appropriate modulation parameters, and assess the impact of interference sources on system performance.

4.2 Design Optimization

The Simulink model serves as a powerful tool for optimizing the design of Bluetooth-enabled devices. By simulating and analyzing different design choices, such as filter characteristics, modulation indices, and hopping patterns, engineers can fine-tune their designs for optimal performance, reliability, and power efficiency [2].

4.3 Educational and Research Purposes

The Simulink model is also valuable for educational purposes and research endeavors as presented the original input data in Figure 5. It provides a clear and intuitive representation of Bluetooth modulation and frequency hopping, enabling students and researchers to explore the fundamental concepts of Bluetooth communication systems and investigate novel algorithms and techniques.

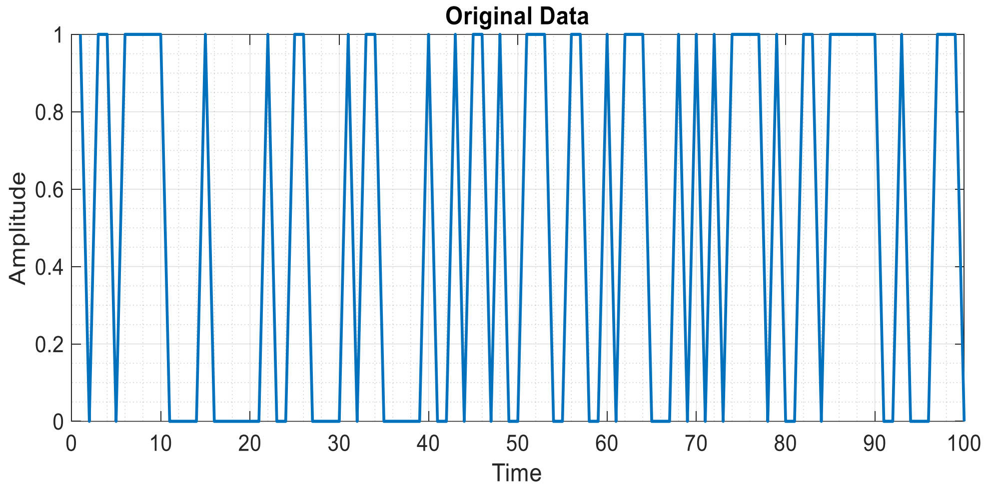

Figure 5: Original input data.

In the context of Bluetooth technology, the term "channel condition" refers to the quality and characteristics of the communication channel used for transmitting Bluetooth signals between devices [2]. Bluetooth operates in the 2.4 GHz frequency band and uses frequency-hopping spread spectrum (FHSS) to minimize the effects of interference and improve reliability. The channel condition in Bluetooth can be influenced by several factors, included in Table 1.

Table 1: Influenced factors of channel condition in Bluetooth transformation [15].

Influenced Factors	Features
Signal Strength	• The strength of the Bluetooth signal between devices affects the channel condition. A stronger signal generally results in better communication quality and a more reliable connection.
Interference	• Bluetooth operates in the same frequency band as many other wireless devices, such as Wi-Fi routers, cordless phones, and microwave ovens. • Interference from these devices can degrade the channel condition and impact Bluetooth performance.
Noise	Noise in the 2.4 GHz band, such as background radio frequency noise, can affect the channel condition and introduce errors in the Bluetooth communication
Distance	• The distance between Bluetooth devices can impact the channel condition. • As the distance increases, the signal strength decreases, which may lead to a weaker channel condition and lower data rates.
Obstacles	• Physical obstructions, such as walls or other objects, can attenuate or block • Bluetooth signals, affecting the channel condition and reducing the communication range.
Multipath Effects	• Similar to other wireless communications, Bluetooth signals can experience multipath propagation, where the signals take multiple paths and can interfere constructively or destructively at the receiver. • Multipath effects can cause fading and impact the channel condition

Bluetooth devices continuously monitor the channel condition and adapt their transmission parameters to maintain a reliable connection. Bluetooth uses adaptive frequency hopping (AFH) to dynamically select the best available frequency channels and avoid congested or noisy channels. This adaptive approach helps mitigate the effects of interference and improve the channel condition. In summary, the channel condition in Bluetooth refers to the quality of the communication channel, which can be influenced by factors such as signal strength, interference, noise, distance, obstacles, and multipath effects. Bluetooth technology employs techniques like AFH to adapt to the channel condition and optimize communication performance.

5. Results and discussion

Based on the input data using MATLAB code for Bluetooth modulation using Gaussian Frequency Shift Keying (GFSK) modulation scheme. The presented result in Figure 6 shows the behavior of Bluetooth modulation data.

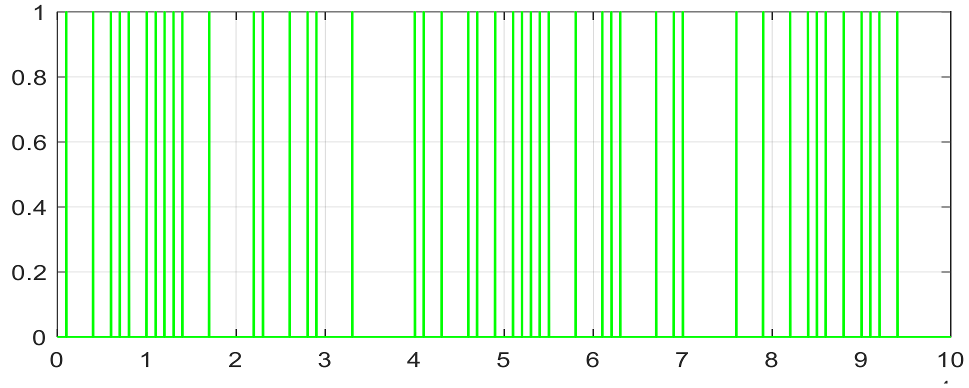

Figure 6: Bluetooth Modulation data.

At the same time, utilizing MATLAB code for implementing Frequency Hopping Spread Spectrum (FHSS) for Bluetooth as presented in Figure 7.

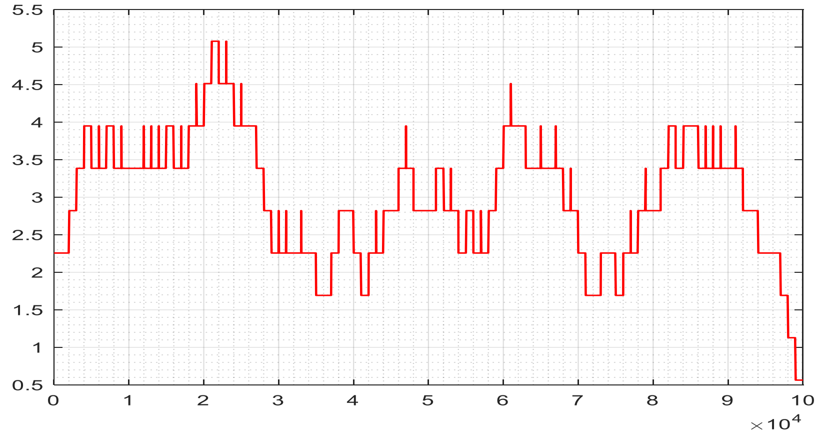

Figure 7: Frequency hopping result.

Conclusion

This article provides a thorough and illustrated explanation of Bluetooth modulation and frequency hopping using the Simulink model. It makes it easier to design dependable and effective Bluetooth-enabled devices by allowing users to simulate, evaluate, and optimize Bluetooth communication systems. Based on the used technology for transmitting and receiving (TX and RX) the signal, the acquired result are rated at 1 Mbps. The model advances Bluetooth technology and its uses in wireless communication, making it a useful tool for research and education.

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