FREQUENCY HOPPING SPREAD SPECTRUM: HISTORY, PRINCIPLES AND APPLICATIONS

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Abstract:

Introduction/purpose: The frequency hopping spread spectrum (FH-SS) technique assumes the carrier generated by the syntesizer to hop from frequency to frequency over a wide bandwidth, according to a pseudonoise code sequence defined by the code sequence generator. The article presents the history, principles and applications of the FH-SS technique. Both military and commercial applications are discussed.

Methods: This article presents an overview of data from the technical literature, with appropriate comments.

Results: After presenting the history and principles of the FH-SS technique, the article summarizes its use with examples of military and commercial applications. The importance of using FH-SS in the described applications is highlighted.

Conclusion: The FH-SS technique has been successfully implemented in many military and commercial technologies due to its high protection against interference, making communication difficult for reconnaissance and eavesdropping, and its ability to provide code division multiple access.

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Key words: radio communication, spread spectrum, frequency hopping, bluetooth, global system for mobile communication, unmanned aerial vehicles.

Introduction

Spread spectrum is a modulation widely used in military communications. In spread spectrum modulation, the bandwidth of the transmitted signal is much greater than the bandwidth of the original message, and is determined by the spreading code (Yahya et al, 2006). The spreading code is a digital signal that is independent of the message and is known to both the transmitter and the receiver. There are two the most frequently used methods for performing the spreading of the spectrum: frequency hopping (FH-SS) and direct sequence (DS-SS).

Spread spectrum modulations provide high protection against interference, make unauthorized reception (reconnaissance and eavesdropping) difficult, allow the formation of a code multiplex in which all users operate simultaneously in the same frequency bandwidth, and enable selective addressing of individual users (Todorović, 2021).

In this article, the history, principles, and applications of the spread spectrum frequency hopping technique are presented. A review of the military and commercial applications of frequency hopping is given.

After the Introduction, in the second section, the history of frequency hopping is presented. The third section gives the principles of FH-SS. Sections after that present applications of frequency hopping, such as military radio communications, control of unmanned aerial vehicles, the global system for mobile communication, and Bluetooth technology. In the last section, the most important conclusions are made.

History of FH-SS

More than a century separates Nikola Tesla's frequency-based method of signalling from today's widely used spread spectrum data transmissions. In 1901, Tesla considered a method of signalling that consists of two, or more, transmitters operating at different frequencies. The receiver is designed to respond only when both signals are received (Rothman, 2018).

On December 18, 1920, Otto B. Blackwell, De Loss K. Martin, and Gilbert S. Vernam applied for a patent "Secrecy communication system". Successive portions of a message are transmitted on waves of different frequencies. Secrecy is obtained by the transmission of signals on a plurality of waves of different frequencies. A station tuned to one of the frequencies receives only a part of the message. The frequency shifting is not accomplished in a cyclic order, but rather in a random and variable manner (Rothman, 2018).

In 1922, Emory-Leon Chaffee described a system of radiocommunication that proposes rapid changing of the carrier frequency in an "erratic manner" in order to provide secrecy (Price, 1983).

On October 11, 1929, Broertjes submitted a patent application in Germany for a "Method of maintaining secrecy in the transmission of wireless telegraph messages". He said that the known methods of maintaining secrecy operate, in most cases, with codes or cryptograms and with a periodically modified transmission frequency, which is received by means of a receiving apparatus, the tuning of which is modified in synchronism. According to Broertjes, the idea of changing transmission frequencies is already commonplace, but he argues that this approach does not prevent the interception and decipherment of the message because a broadband receiver could pick up all the frequencies. Broertjes proposed a system in which a number of operating frequencies, known to the transmitter and receiver alone, can be varied in a random or variable manner. In a method of this kind, secrecy is ensured by the fact that an unauthorized receiver, which at first is tuned to only a single frequency, picks up only disconnected portions of the message. The transmitter includes a code wheel that selects a new frequency each time a telegraph key is pressed. One can only assume that the receiver contains a duplicate wheel, but Broertjes prefered manual operation, so it remains unclear how he intended synchronization to be effected. Despite its flaws, Broertjes's invention proves that the frequency hopping concept was available in Germany before World War II (Rothman, 2018).

In September 1940, Ellison Purington, who had done graduate work in physics at Harvard University and had worked on torpedo guidance systems at the Hammond Laboratory during World War I, filled an application for a "System for reducing interference" (Rothman, 2018). In this patent, Purington proposes changing the carrier frequency to reduce the ability of other transmitters to interfere with the signal (Scholtz, 1983).

Actress Hedy Lamarr, born Hedwig Kiesler in Austria, soon after the beginning of World War II escaped and ended up in Hollywood where she met George Antheil. Hedy revealed that she possessed a flair for inventing weapons and shared with him an idea for a secure torpedo guidance system that employed a novel technique known as frequency hopping. Hedy lacked the technical expertise to put her idea into practice (Rothman, 2018). George was likewise no engineer, but in the 1920's he had written a concert piece Ballet Mecanique, which included parts for synchronized player pianos (Price, 1983). They had an idea to place a player-piano roll punched with 88 rows of randomly placed perforations in the transmitter to control the hopping among 88 radio frequencies. They would place the identical roll in the receiver, and then they would synchronise them. George and Hedy applied for a patent in June 1941. Despite the novelty of their approach, the pneumatic player-piano mechanism made their system unwieldy and certainly unworkable in a battle. Antheil made strenuous lobbying efforts to get the invention adopted by the Navy, but it was shelved (Rothman, 2018).

Early in January 1943, U.S. army signal corps officer Henry P. Hutchinson applied for a patent on frequency hopping signalling for maintaining the secrecy of telephone conversations or for privately transmitting information (Price, 1983). His scheme utilized cryptographic machines to produce a pseudorandom hopping sequence on demand (Rothman, 2018).

After World War II, another major effort at developing a secure, jam-proof system was put forth by Sylvania with its Buffalo Laboratories Application of Digitally Exact Spectra (BLADES). Its development began in 1955, as a system for communicating with Polaris submarines. It was tested in 1957, and in 1963 it was installed on the flagship U.S.S. Mount McKinley, for operational development tests where It successfully thwarted intentional jamming efforts. Thus, BLADES was quite likely the earliest FH-SS communication system to reach an operational state (Scholtz, 1982).

A practical application of frequency hopping began in the years to follow. Radio systems with FH-SS for battle conditions were developed by Racal, Marconi Communication Systems, Single Channel Ground and Airborne Radio System (SINCGARS) and other companies.

In 1992, the early 2G cellular networks did use a form of frequency hopping. In 1997, Jaap Haartsen patented the Bluetooth technology that employs frequency hopping.

Principles of FH-SS

During the communication using the FH-SS technique, the receiver and the transmitter change their carrier frequency according to a predefined order and rate, which should remain a secret for everyone except for them. The carrier frequency change takes place under the control of the code sequence generator within the transmission bandwidth. The FH-SS technique can be used to transmit messages both in analogue and digital formats (Todorović, 2021).

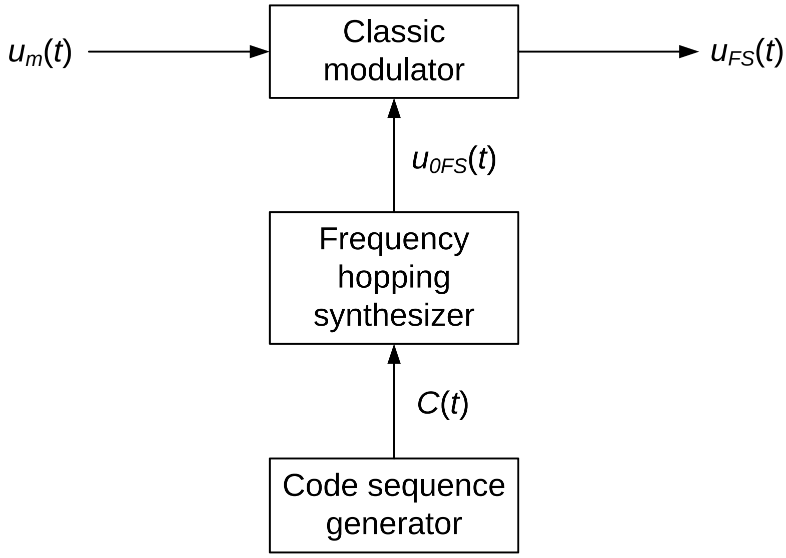

Figure 1 – FH-SS signal modulator
Рис. 1 – Модулятор сигнала со скачкообразной перестройкой частоты
Слика 1 – Модулатор сигнала са фреквенцијским скакањем

A block diagram of the FH-SS signal modulator is given in Figure 1 (Todorović, 2021). The FH-SS signal modulator consists of a code sequence generator, a frequency hopping synthesizer and a modulator, where some of the classic analogue or digital modulations is applied.

The most important block of FH-SS signal modulators is the frequency synthesizer. Under the control of the code sequence generator, a signal $u_{0FS}(t)$ is generated at its output. That signal has a variable carrier frequency. The rate of carrier frequency change varies from a few hops per second to 100000 hops per second. The frequency synthesizer generates the frequency hopping pattern known to both the transmitter and the receiver (Čisar et al, 2020).

When FH-SS is used, the frequency bandwidth for signal transmission is significantly wider than necessary to transmit the message when using some of classic modulations with the carrier at a fixed frequency.

The spreading ratio of FH-SS modulations is defined as follows:

$$\eta = \frac{B_{FS}}{B_m} \tag{1}$$

where B_{FS} denotes the frequency bandwidth of the FH-SS transmission, while the bandwidth of one channel is denoted by B_m.

If there is no frequency gap between adjacent channels, the spreading ratio is equal to the number of channels:

$$\eta = N \qquad (2)$$

If another signal is present in any of the channels within the frequency bandwidth B_{FS}, that signal and the FH-SS signal interfere with each other. This interference is of very short duration and occurs in the time interval when the FH-SS signal is present in that channel.

The block diagram of the FH-SS signal demodulator is shown in Figure 2 (Todorović, 2021). The FH-SS signal demodulator consists of a code sequence generator, a frequency hopping synthesizer, a demodulator and a code synchronization block.

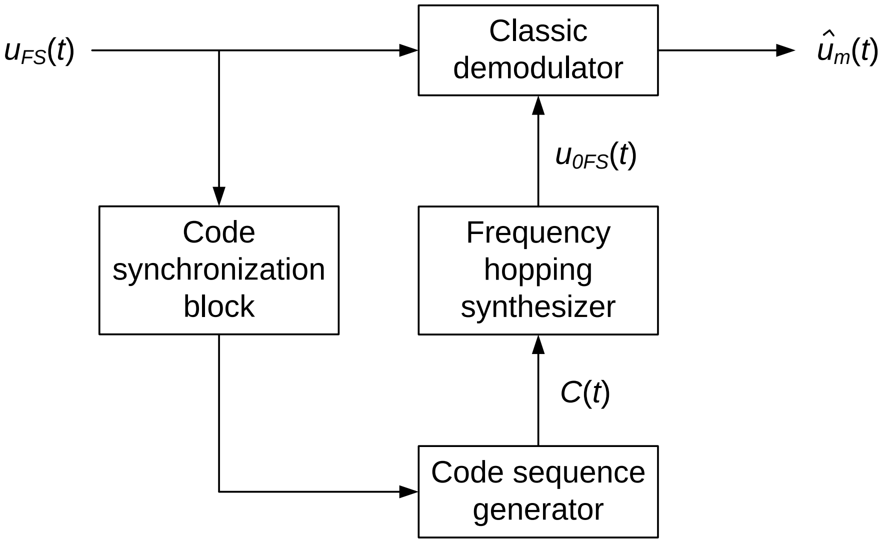

Figure 2 – FH-SS signal demodulator
Рис. 2 – Демодулятор сигнала скачкообразной перестройки частоты
Слика 2 – Демодулатор сигнала са фреквенцијским скакањем

The basic task of the FH-SS receiver is to despread the spectrum of the incoming signal. The process of despreading has to be performed before demodulation. This is accomplished by correlating the incoming signal with a synchronized locally generated code sequence. Code synchronization is a necessary step in order to be able to despread the spectrum of the incoming signal.

The task of the code synchronization block is to ensure that the change of the carrier frequency in the transmitter and the receiver takes place at the same time.

FH-SS systems may be classified as fast or slow. Fast FH-SS occurs if one information symbol is transmitted over several frequency hops. Slow FH-SS occurs if one or more information symbols are transmitted within one frequency hop (Torrieri, 2018).

Applications of FH-SS

FH-SS techniques have been employed intensively for highly secured data transmission in military and commercial wireless communications (Aung et al, 2012). Military applications include HF, VHF and UHF radios, and unmanned aerial vehicles (UAV) control and data signals. Among commercial applications, GSM mobiles and Bluetooth have to be mentioned.

Military radio communications

Spread spectrum signals are highly resistant to unintentional or intentional jamming. Therefore, they are suitable for military applications. FH-SS has a good near-far performance and can be implemented easier than DS-SS (Hasan et al, 2016). It has good resistance to various forms of electronic attacks, and it is a suitable technique for overcoming interception, direction finding, and jamming.

Military radios use the FH-SS technique to transmit messages in the analogue or digital format, with hopping rates from a few hops per second to several hundred hops per second. Military radios generate the FH-SS pattern under the control of a secret transmission security key (TRANSEC) that the transmitter and receiver share in advance. Frequency changes are made in the programmed frequency band that the transceiver selects based on the current conditions of radio wave propagation. The number of programmed bands may vary depending on the manufacturer and the frequency bandwidth in which the radio operates. By analyzing the characteristics of the radio wave propagation at a given time, the control station selects one of these frequency bands. The transceiver uses the best frequencies in the defined frequency band by analyzing the interference. Some radios also allow the entry of forbidden frequency bands, which the transceiver also takes into account when selecting operating frequencies. The best use of these transceiver characteristics depends on a careful selection of frequency bands.

The FH-SS technique is used by many companies, especially in the production of military radio communication devices. Some of such companies are Racal, Marconi Communication Systems, SINCGARS, Aselsan, Thales Group and L3Harris Technologies.

Among the first military radio systems with FH-SS was a series of JAGUAR radios, developed by Racal. Racal was a British electronics company founded in 1950. JAGUAR-H, JAGUAR-V and JAGUAR-U were developed for different frequency bands. JAGUAR-H was developed in 1982. It operates in the 2-30 MHz frequency band. It has a 5 W manpack and 100 W vehicle configurations. FH-SS is performed according to the pseudorandom law within the subband. The width of the subband goes from 400 kHz in the lower frequencies and increases in the central and upper part of the HF band. The hopping rate for the JAGUAR-H is 10-20 hops per second (Todorović, 1987). The JAGUAR-V system was developed in 1981. There are a 4 W manpack and vehicular 50 W radio stations. It is designed to hop over a bandwidth of 6.4 MHz, corresponding to 256 channels at 25 kHz spacing. It provides 9 hop subbands in the combat network radio band of 30-88 MHz. The hopping rate for the JAGUAR-V system is in the region of 50-500 hops per second (Munday & Pinches, 1982). The 15 W vehicle radio station JAGUAR-U, developed in 1982, operates within the 225-400 MHz band. FH-SS is performed on 768 channels in 9 subbands of 19.2 MHz (Todorović, 1987).

Marconi Communication Systems is a British company which developed SCIMITAR-H and SCIMITAR-V radios in 1982. The SCIMITAR-H radio operates in the 1.6-30 frequency band. It has a 20 W manpack and 100 W vehicular configurations. FH-SS is performed within the entire frequency band with a hopping rate of 150 hops per second. The SCIMITAR-V radio operates in the 30-88 MHz frequency band. There are a 5 W manpack and vehicular 50 W radio stations. FH-SS is performed on 2320 channels within the entire frequency band with a hopping rate of 150 hops per second (Todorović, 1987).

The SINCGARS is a combat network radio used by the U.S. and other military forces. Among the first SINCGARS radios was the SINCGARS-V radio developed in 1986. It was developed to work in the frequency band from 30-88 MHz. There are a 5 W manpack and vehicular 50 W radio stations. It supports FH-SS which is performed according to the pseudorandom law within the entire frequency band with a hopping rate of 150 hops per second (Todorović, 1987).

Aselsan is a defence electronics company in Turkey. Among others, it is engaged in the production of communication and information technologies (Aselsan, 2022). The 9661 HF radios and PRC/VRC 9661

V/UHF software-defined radios are representatives of military radio communications systems. The 9661 HF radios are software-defined radios covering the HF 1.6-30 MHz band. It is possible to communicate under intentional or unintentional interference by using the frequency hopping mode of operation. The 9661 HF radio family has three configurations for manpack, vehicular and fixed station usage. The 20 W station can be used for manpack and vehicle configurations and the 150 W station can be used for vehicular and fixed station configurations. PRC/VRC 9661 V/UHF software-defined radios are tactical radios capable of communicating in clear, encrypted and frequency hopping voice and data in VHF and UHF bands from 30-512 MHz. There are 5 W handheld, 10 W manpack and 50 W vehicular/base station configurations of 9661 V/UHF radios.

Thales Group is French company that produces HF and VHF radio communications systems for defence (Thales Group, 2022). Both HF and VHF radios provide frequency hopping encrypted voice and data transmission. A digital HF software-defined radio operates in the 1.5-30 MHz frequency band. There are 20 W (TRC 3700), 125 W (TRC 3730) and 400 W (TRC 3740) radio stations. VHF radios operate in the 30-88 MHz frequency band. There are several types of VFH radios: handheld 2 W radio (TRC 9110), manpack 10 W radio (TRC 9210), vehicular 50 W station (TRC 9310 A/AP) and vehicular 2x50 W dual fit station (TRC 9310 B/C).

L3Harris Technologies (L3Harris) is an American technology company. Among others, it is engaged in the production of tactical communications systems (L3harris, 2022). The L3Harris Falcon III AN/PRC-160(V) presents a military radio which uses frequency hopping for transmission. It covers the HF/VHF 1.5-60 MHz band. It provides 20 W output power for HF and 10 W for the VHF frequency band.

Unmanned aerial vehicles (UAVs)

Unmanned aerial vehicles, or drones, are aircraft without a human pilot aboard. UAVs are a component of an unmanned aircraft system (UAS), which includes a UAV, a ground-based controller, and a system of communications between them (Nived Maanyu et al, 2020). There are two versions of UAVs: UAVs controlled from a remote location and UAVs which fly autonomously based on a pre-programmed flight plan (Todorovic & Orlic, 2009). Due to the absence of a pilot, UAVs always have a certain level of autonomy (Vergouw et al, 2016).

UAVs were most often associated with the military until a few years ago. They were used initially for intelligence gathering, anti-aircraft target practice, and then, more controversially, as weapons platforms. Their high cost and restricted market meant they were extremely difficult to provide. This situation has changed dramatically in recent years, as UAVs are becoming cheaper, making it easier to provide for ordinary people (Mototolea, 2019).

Commercial UAVs typically are built on a small platform, they are easy to operate and flexible to execute different kinds of missions (Fan & Ala Saadeghvaziri, 2019). UAVs can carry multiple sensors, transmitters and imaging equipment. As the use of UAVs continues to proliferate, they will impact industries ranging from entertainment to agriculture, from construction to delivery markets (Rao et al, 2016).

There are several links for communication with UAVs: control, video transmission, and telemetry links. These links use radio-frequency transmission to transmit and receive information to and from the UAV. These transmissions can include location, remaining flight time, distance and location to target, payload information, airspeed, altitude, and many other parameters.

Table 1 – UAVs types, frequencies they operate on and the used modulation
Таблица 1 – Виды дронов, их рабочие частоты и используемая модуляция
Табела 1 – Врсте дронова, фреквенције на којима раде и модулација коју користе

Brand	Frequency	Modulation
DJI Phantom	2.4/ 5.8 GHz	FH/ DSSS
Futaba	2.4 GHz	FH/ DSSS
Spektrum	2.4 GHz	FH/ DSSS
JR	2.4 GHz	FH/ DSSS
Hitec	2.4 GHz	FH/ DSSS
Graupner	2.4 GHz	FH/ DSSS
Yuneec	2.4 GHz	DSSS
Parrot AR2	2.4 GHz	OFDM
Immersion	433 MHz	FH

The 2.4 GHz band is the most often used frequency for remote control (Šević et al, 2020). The 2.4 GHz systems usually use spread spectrum technology which provides much more resistance to interference. The transmitter and the receiver are paired which eliminates the possibility that another transmitter connects to the receiver in use.

Table 1 (Mototolea, 2019) shows that the majority of controllers use the 2.4 GHz band with proprietary FH-SS modulation, since it is resistant to narrowband interference and is difficult to intercept. Some UAVs use the 2.4 GHz band with DS-SS modulation or with orthogonal frequency division multiplexing (OFDM) modulations.

Video links are used to send information from cameras, microphones, or different sensors. The OFDM is the most popular modulation technique for transmitting video (Mototolea, 2019). Simple frequency modulation is also used for transmitting video information.

The telemetry link is used to send information regarding the voltage of the supply, altitude, vertical and horizontal speed, temperature, and other critical parameters. Using such a module, the controller can receive real-time data from the UAV. DS-SS, FH-SS, and OFDM modulations are used to transmit the telemetry data (Mototolea, 2019).

While most popular UAV brands use only one type of modulation in their proprietary technology, some brands combine DS-SS and FH-SS to make the communication more robust.

Global system for mobile communication (GSM)

The GSM is a digital mobile network that is widely used by mobile phone users in Europe and other parts of the world. It is a standard that specifies how second generation (2G) cellular networks operate. When the GSM was first introduced in Europe in 1991, these 2G networks created faster, more secure wireless connections. For the first time, voice communications became encoded into digital signals before being transmitted through the network. For years, the GSM reigned as the world’s most widely used standard for mobile communications. But today, 2G networks are significantly slower than other cellular networks, and in several countries, 2G networks are being switched off.

Two frequency bands are defined for the GSM: the band from 890 MHz to 915 MHz is used for the uplink and the band from 935 MHz to 960 MHz is used for the downlink. Besides these 900 MHz bands, there are two bands in the 1800 MHz, from 1710 MHz to 1785 MHz and from 1805 MHz to 1880 MHz (Wigard et al, 1996).

The GSM system combines time division multiple access (TDMA) and frequency division multiple access (FDMA) for effective use of the frequency band. FH-SS is a feature of the GSM system used to decrease the simultaneous usage of the same frequencies and in this way averages the interference level. The GSM system divides the carrier frequencies into eight timeslots, according to TDMA. Each time slot is used to handle the call of one subscriber (Mishra, 2007).

The slow FH-SS method is implemented in the GSM system (Ivanov et al, 1996). The frequency can be changed after every TDMA frame. By changing the frequency after each 4.615 ms (length of one TDMA frame), in one second the TDMA frame makes 217 hops per second (Mishra, 2007).

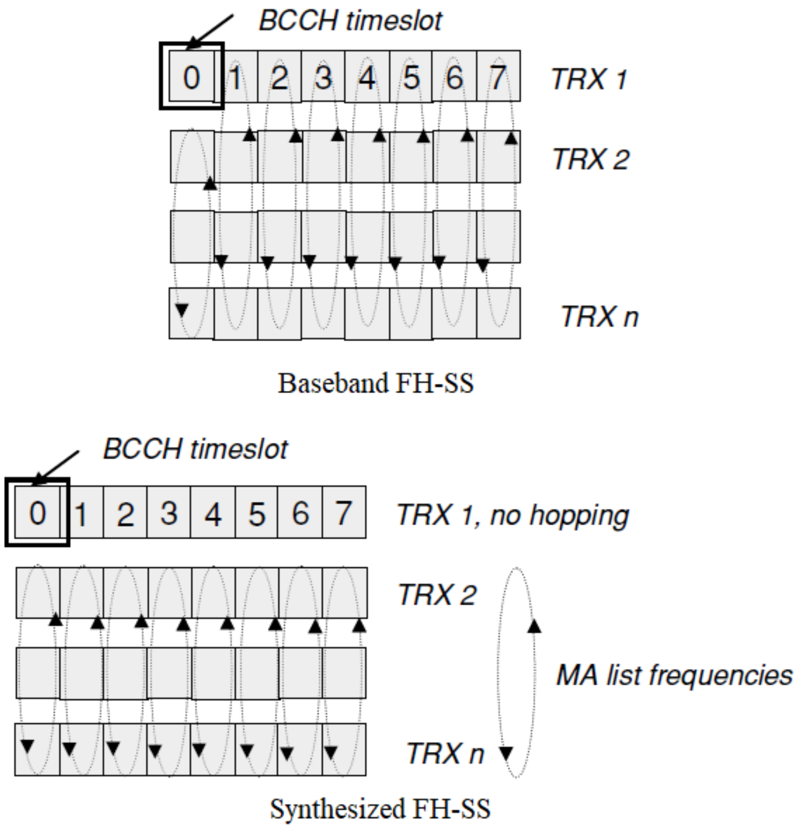

Figure 3 – Baseband FH-SS and synthesized FH-SS
Рис. 3 – Скачкообразная перестройка частоты основной полосы и синтезированная скачкообразная перестройка частоты
Слика 3 – Фреквенцијско скакање основног опсега и синтетизонавно фреквенцијско скакање

A base station contains one or more cells. Each cell may contain one or more transceivers (TRXs). The first time slot in the first transceiver of a cell is used as the broadcast control channel (BCCH). The remaining time slots in that transceiver and the time slots in the other transceivers are used as traffic channels (Bourjolly et al, 2002).

Figure 3 (Mishra, 2007) presents the FH-SS types of the GSM system, baseband FH-SS and synthesised FH-SS. This depends on the type of equipment installed at the transceiver.

In baseband FH-SS, the transceivers actually have fixed frequencies and frequency hopping operates so that bursts are shifted from one transceiver to another according to the hopping sequence. The number of hopping frequencies, therefore, comes from the number of transceivers. The length of the mobile allocation (MA) list is the number of transceivers. The broadcast control channel in the first transceiver does not hop and therefore is excluded from the hopping groups. With baseband FH-SS there are two actual hopping groups, one for the first timeslots of each transceiver excluding the BCCH transceiver and another for all the other timeslots. The first hopping group has TRX-1 frequencies, due to the dedicated BCCH frequency (Mishra, 2007).

In synthesized FH-SS, the frequency of the transceiver changes. Any call goes through one transceiver, but the frequency is changing over time. This allows the number of frequencies in the mobile allocation to be larger than the number of transceivers (Mishra, 2007). A maximum of 64 hopping frequencies is allowed (Olofsson et al, 1995). The synthesized FH-SS pattern can be either random or cyclic. In random frequency hopping, the frequencies are randomly selected from the available set of frequencies. Cyclic hopping has a defined cycle for the frequencies in the mobile allocation list (Mishra, 2007).

Bluetooth

Bluetooth technology is a standard for short range radio links between personal computers, mobile phones, and other portable devices (Đukić et al, 2012). The name Bluetooth comes from the Danish king Haruld Blitund (Bluetooth). King Bluetooth is credited with uniting the Scandinavian people during the 10th century. Similarly, the Bluetooth wireless technology aims to unite personal computing devices. The name was chosen temporarily to describe the yet unannounced development project. However, the search for a new name never came to a successful fruition and the temporary name became permanent (Bisdikian, 2001).

Robustness, low consumption, and low price are the key features of Bluetooth. The Bluetooth specifications were established by the joint effort of over two thousand industry-leading companies, including 3Com, Ericsson, IBM, Intel, Lucent, Microsoft, Motorola, Nokia, Toshiba, etc.

under the umbrella of Bluetooth Special Interest Group (Chlamtac et al, 2003). Bluetooth is standardized within the IEEE 802.15 Working Group for Wireless Personal Area Networks formed in early 1999 (IEEE 802.15, 2022). The IEEE 802.15.1 standard defines the basics of Bluetooth wireless technology.

Bluetooth technology supports both point-to-point and point-to-multipoint connections. Several piconets can be established and linked together ad hoc, where each piconet is identified by a different FH-SS sequence. All users participating on the same piconet are synchronized to this FH-SS sequence. A piconet supports up to 8 devices, where one device acts as the master. The master controls the traftic up to a maximum of 7 units, defined as slaves in a piconet (Nusser & Pelz, 2000). Inside a piconet, Bluetooth stations can establish up to three 64 Kbps synchronous (voice) channels or an asynchronous (data) channel supporting data rates of maximal 723 Kbps asymmetric or 433 Kbps symmetric (Chlamtac et al, 2003).

The Bluetooth radio channel frequency hopping rate is about 1600 hops per second for data/voice links and 3200 hops per second during page and inquiry scanning. A channel is used for a very short period (e.g. 625 microseconds for data/voice links), followed by a hop designated by a pre-determined pseudo-random sequence to another channel. This process is repeated continuously according to the FH-SS sequence (Scarfone & Padgette, 2008).

Bluetooth also provides radio link power control, where devices can negotiate and adjust their radio power according to signal strength measurements. Each device in a Bluetooth network can determine its received signal strength indication and request the other network device to adjust its relative radio power level. This is performed to conserve power and to keep the received signal characteristics within a preferred range (Scarfone & Padgette, 2008). Transmit power goes from 1 mW to 100 mW. The designed operating range is from 1 to 100 m.

Figure 4 (Bluetooth, 2022) presents the types of Bluetooth radios. There are two designs of Bluetooth radios: the Bluetooth Classic radio and the Bluetooth Low Energy (LE) radio.

The Bluetooth Classic radio, also referred to as Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR), is a low-power (less than 100 mW) radio that streams data over 79 channels with 1 MHz spacing in the 2.4 GHz unlicensed industrial, scientific, and medical (ISM) frequency band (2.402 – 2.480 GHz Utilized). The data rate can be from 1 to 3 Mbps. Bluetooth versions 1.1 and 1.2 only support transmission speeds of up to 1 Mbps, which is known as the Basic Rate (BR), and can achieve throughput of approximately 720 Kbps. Introduced in Bluetooth version 2.0, the Enhanced Data Rate (EDR) specifies data rates up to 3 Mbps and throughput of approximately 2.1 Mbps. The BR uses Gaussian Frequency-Shift Keying (GFSK) modulation to achieve a 1 Mbps data rate. The EDR uses π/4 rotated Differential Quaternary Phase Shift Keying (DQPSK) modulation to achieve a 2 Mbps data rate, and 8 phase Differential Phase Shift Keying (8DPSK) to achieve a 3 Mbps data rate (Scarfone & Padgette, 2008). Supporting point-to-point device communication, Bluetooth Classic is mainly used to enable wireless audio streaming and has become the standard radio protocol behind wireless speakers, headphones, and in-car entertainment systems. The Bluetooth Classic radio also enables data transfer applications, including mobile printing.

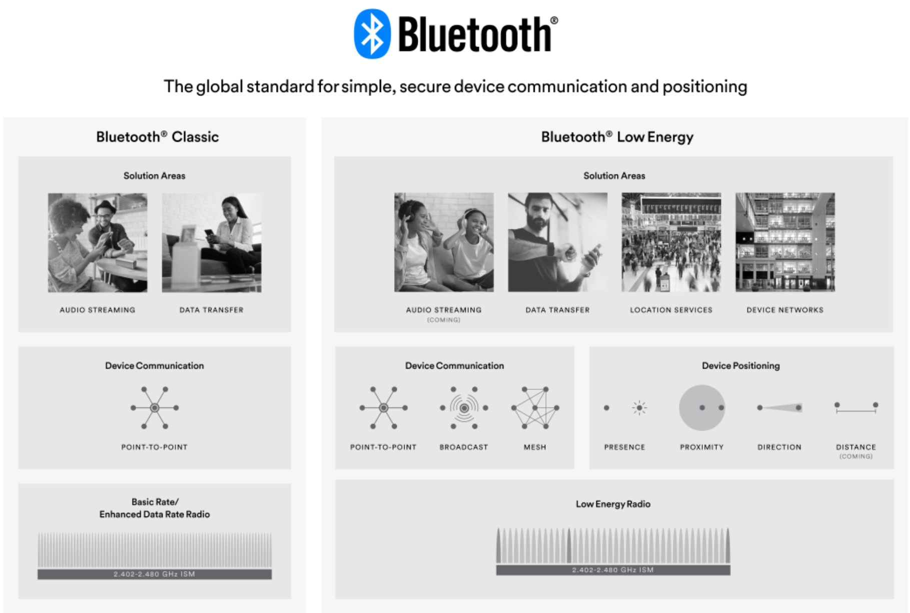

Figure 4 – Bluetooth technology
Рис. 4 – Bluetooth технология
Слика 4 – Блутут технологија

The Bluetooth Low Energy (LE) radio is designed for very low power (less than 100 mW) operation, transmitting data over 40 channels (3 advertising channels and 37 data channels) in the 2.4 GHz unlicensed ISM frequency band. The data rate can be from 0.125 to 2 Mbps via GFSK modulation. Bluetooth LE was introduced in the Bluetooth 4.0 specification. The key technology goals of Bluetooth LE (compared with Bluetooth BR/EDR) include lower power consumption, reduced memory requirements, efficient discovery and connection procedures, short packet lengths, and simple protocols and services (Scarfone & Padgette, 2008). Bluetooth LE supports multiple communication topologies, expanding from point-to-point to broadcast and, most recently, mesh, enabling Bluetooth technology to support the creation of reliable, large-scale device networks. While initially known for its device communications capabilities, Bluetooth LE is now also widely used as a device positioning technology to address the increasing demand for high accuracy indoor location services. Initially supporting simple presence and proximity capabilities, Bluetooth LE now supports Bluetooth Direction Finding and, soon, high-accuracy distance measurement.

Conclusion

The FH-SS technique is based on a change of the carrier frequency in a wide bandwidth according to a sequence defined by the code sequence generator. The FH-SS technique has been successfully implemented in many military and commercial applications, due to its high protection against interference, making communication difficult for reconnaissance and eavesdropping, and its ability to provide code division multiple access. The history, principles and applications of the FH-SS technique are presented in this article.

Military radio communications require a technique that has good resistance to various forms of electronic attacks. Communication links for the control of UAVs are very important, so they need to use technology that is difficult to interfere with. Mobile personal computers, mobile phones, and other portable devices use Bluetooth technology. The FH-SS technique is used for all these needs.

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РАСПРОСТРАНЕНИЕ СПЕКТРА СО СКАЧКООБРАЗНОЙ ПЕРЕСТРОЙКОЙ ЧАСТОТЫ: ИСТОРИЯ, ПРИНЦИПЫ И ПРИМЕНЕНИЕ

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РУБРИКА ГРНТИ: 49.27.00 Система передачи,
49.43.00 Радиосвязь и радиовещание
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Скачкообразная перестройка частоты основана на скачкообразном изменении несущей частоты в очень широком диапазоне, которое происходит под управлением кодовой последовательности. В статье представлены история, принципы и применение метода скачкообразной перестройки частоты.

Методы: В данной статье представлен обзор данных из технической литературы с соответствующими комментариями.

Результаты: После представления истории и принципов метода скачкообразной перестройки частоты в статье подводятся итоги по ее использованию на примерах военного и коммерческого применения. Подчеркнута важность использования скачкообразной перестройки частоты в описанных приложениях.

Выводы: Метод скачкообразной перестройки частоты успешно применяется во многих военных и коммерческих технологиях, благодаря наличию высокой защиты от помех, успешно противостоящей разведке и прослушиванию.

Ключевые слова: радиосвязь, расширенный диапозон, скачкообразная перестройка частоты, Bluetooth, глобальная система мобильной связи, беспилотные летательные аппараты.

ПРЕНОС У ПРОШИРЕНОМ СПЕКТРУ – ФРЕКВЕНЦИЈСКО СКАКАЊЕ: ИСТОРИЈА, ПРИНЦИПИ И ПРИМЕНА

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КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Фреквенцијско скакање се заснива на скоковитој промени фреквенције носиоца у врло широком опсегу, која се одвија под контролом кодне секвенце. У раду су представљени историјат, принципи и примена технике фреквенцијског скакања.

Методе: Приказан је преглед података из техничке литературе, уз одговарајуће коментаре.

Резултати: Након представљања историје и принципа технике фреквенцијског скакања, сумира се њена употребу са примерима војне и комерцијалне примене. Истиче се важност употребе фреквенцијског скакања у описаним апликацијама.

Закључак: Техника фреквенцијског скакања је успешно имплементирана у многим војним и комерцијалним технологијама јер пружа већу заштиту од сметњи, што отежава извиђање и прислушкивање.

Кључне речи: радио-комуникације, пренос у проширеном спектру, фреквенцијско скакање, блутут, глобални систем за мобилну комуникацију, беспилотне летелице.

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