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# EVALUATION OF LORA WIRELESS TECHNOLOGY FOR MILITARY APPLICATIONS

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***Abstract:*** *The modern military relies on broad information exchange to maintain military competitive advantage, where information is in most cases carried wirelessly, due high mobility of the field units. Among many low-power wireless communication technologies, LoRa (Long Range) wireless technology with high immunity to interference makes it prospecting for use in military applications, such as battlefield monitoring, friendly force identification, field unit localization, etc. LoRa technology is based on a CSS (Chirp Spread Spectrum) which makes it resilient to the Doppler Effect frequency shift caused by the movement of filed units. Furthermore, the variable spreading factor makes this technology adaptable to various interference levels present in the channel. In this paper, we evaluated the properties of the Semtech SX1278 LoRa compliant module to implement frequency hopping spread spectrum operation. Obtained results show that LoRa technology can be successfully adopted for use in a wide range of low-power military applications.*

***Keywords:*** *wireless, low-power, LoRa, CSS, FHSS.*

## 1. INTRODUCTION

Military innovations for a long time have been the primary driving force for mankind's technological advancements. In recent decades rapid revolution in the field of information communication technology became attractive for the military to increase battlefield information awareness [1]. Shared situational awareness is a requirement for efficient decision-making for military forces operating at the tactical level. Collection of information about the friendly force identification, field unit localization, battlefield monitoring and detection of enemy troops is a key enabler for achieving such shared situational awareness [2]. This information is collected using wearable electronic devices that can be worn as accessories or embedded in clothing, or by the sensors planted on the battlefield [3]. Due to mobility requirements, wireless technology is the only practical solution for such devices. Among many design requirements which include low power, low dimensions, security, etc, low-power wireless transmission is the most appropriate. The current low-power wireless transmission provides different modulation schemes, but all of them are limited to short-distance communication. The only way to increase communication distance is the use of a spread spectrum which enables the reception of signals whose power is near or below the channel noise level.

LoRa represents a spread spectrum modulation scheme derived from Chirp Spread Spectrum modulation (CSS) which trades data rate for sensitivity within a fixed channel bandwidth. LoRa provides significant advantages over conventional modulation techniques, solving the traditional design compromise between long-range, immunity to interference and energy consumption.

In this paper, we presented the upgrade of LoRa modulation using the frequency hopping modulation scheme, which further increases interference immunity and adds another level of security that makes this solution practical for military use.

## 2. LORA MODULATION

LoRa represents Semtech's proprietary spread spectrum modulation scheme which is derived from Chirp Spread Spectrum modulation (CSS) [4]. CSS modulation is based on the generation of chirps, a signal which varies continuously in frequency. This signal property eliminates phase and frequency offset between transmitter and receiver, which makes the receiver design very simple since it doesn't require complex synchronization algorithms. LoRa modulation is highly adaptable to various channel conditions thanks to three configurable modulation parameters: Spreading Factor (SF), Bandwidth (BW), and Coding Rate (CR) which define data rate and receiver sensitivity.

LoRa modulation offers configurable forward error correction (FEC) encoding which for every 4-bit data adds a certain number of redundant bits which significantly increases interference resistance. The number of redundant bits is defined by the Coding Rate (CR) parameter, which ranges from 1 to 4 and is adjusted according to the conditions of the channel used for data transmission. In the case of the coding rate of 1, one redundant bit is added to 4 data bits which reduce the useful data rate to 80%. In the case of 4 redundant bit bits, the data rate is reduced to 50%. The coded data blocks are then grouped to form symbols that are SF-bit long. Symbols are represented by an up-chirp signal, which frequency linearly changes in the range starting from $f_{min}$ to $f_{max}$ with supported the chirp bandwidth (BW) up to 500 kHz. The spreading Factor (SF) represents an exponential factor of 2 which defines how many chirps are used to represent one symbol and defines symbol duration. In case of the LoRa modulation Spreading Factor is taking values in the range {7; 8; 9; 10; 11; 12}. Symbols are modulated in the way that symbol value is used to cyclically-shift chirp starting frequency. In the case of the symbol with value 0, starting frequency is equal to $f_{min}$, while with the maximum symbol value of $2^{SF}$-1, starting frequency is equal to $f_{max}$.

The receiver uses unmodulated down-chirp signals, which frequency linearly changes in the range starting from $f_{max}$ to $f_{min}$, to mix with the received up-chirp signals in order to demodulate coded encoded symbols as shown in Fig 1. The longer the chirp duration defined by the spreading factor, the receiver has more processing gain to decode symbols from the received signal with a negative SNR value or in the presence of narrowband interference.

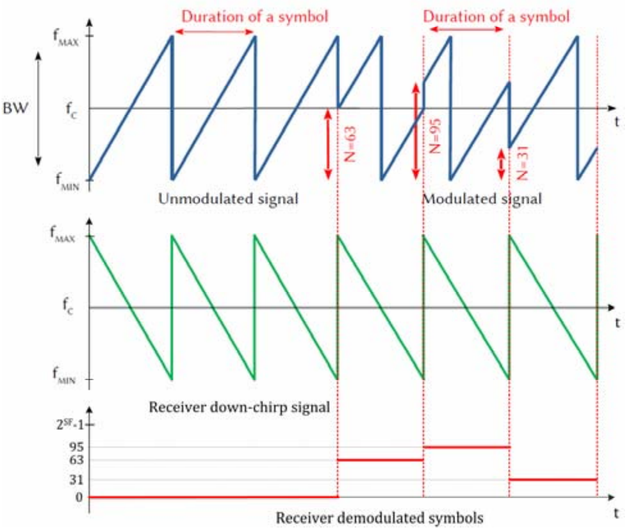


**Figure 1.** LoRa modulation

The duration of a symbol, known as symbol period is dependent on chirp bandwidth and spreading factor as defined by equation 1. The data rate is defined as the symbol rate multiplied by SF bits which represent one symbol. Furthermore, due to the use of FEC effective data rate is dependent on the used coding rate as shown by equation 2.

$$T_s = \frac{2^{SF}}{BW} \quad (1)$$

$$R_b = \frac{4}{4+CR} \cdot SF \cdot \frac{BW}{2^{SF}} \quad (2)$$

Table 1. presents expected data bitrates which can be achieved for different channel bandwidths, with a maximum spreading factor of 12, and 4/5 coding rate. The LoRa packet format consists of the preamble, optional header which is only used in explicit mode, and the data payload as shown in Fig 2. The preamble field is used to synchronize the receiver with the incoming data packet and by default, is configured to the length of 12 symbols. The preamble length is configurable and may be extended up to 65539 symbols in case of the receive intensive applications, but its default value is sufficient for the most typical communication scenarios. The explicit mode uses the short header which is transmitted with a maximum error correction code (4/8). It contains information about the number of bytes, coding rate and whether a CRC is used in the packet and has its own CRC to allow the receiver to discard invalid headers. The packet payload contains actual data coded at the user-selected coding rate and its length is variable with a maximum packet length of 256 bytes. An optional CRC is appended to the end of the payload to check received data for errors at reception.

**Table 1**. LoRa expected bitrates

| Bandwidth (kHz) | Spreading Factor | Coding rate | Data bitrate (bps) |
|---|---|---|---|
| 7.8 | 12 | 4/5 | 18 |
| 10.4 | 12 | 4/5 | 24 |
| 15.6 | 12 | 4/5 | 37 |
| 20.8 | 12 | 4/5 | 49 |
| 31.2 | 12 | 4/5 | 73 |
| 41.7 | 12 | 4/5 | 98 |
| 62.5 | 12 | 4/5 | 146 |
| 125 | 12 | 4/5 | 293 |
| 250 | 12 | 4/5 | 586 |
| 500 | 12 | 4/5 | 1172 |

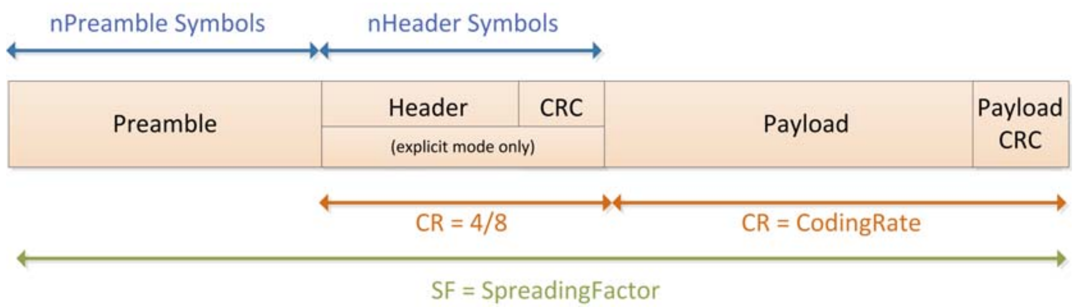


**Figure 2.** LoRa packet format

The total transmission (on-the-air) time of a LoRa packet is dependent on packet length, spreading factor (SF), coding rate (CR) and signal bandwidth (BW). In the case of long data packets transmitted with a high spreading factor, packet transmission could last in order of a second. In this case, LoRa could exceed regulatory requirements relating to the maximum permissible channel dwell time. This is most notably the case in US operations where the 902 to 928 MHz ISM band makes provision that the average time of occupancy at any frequency (dwell time) must not be larger than 0.4 seconds within a 20-second period [5]. To meet these requirements, FHSS (Frequency Hopping Spread Spectrum) is used where a portion of each LoRa packet is transmitted on a separate hopping channel from a look-up table of frequencies managed by the host microcontroller. After a predetermined hopping period has expired the transmitter and receiver change to the next channel in a predefined list of hopping frequencies to continue transmission and reception of the next portion of the packet, as shown in Figure 3. The hopping period is required to be shorter than the maximum channel dwell time and is represented as an integer multiple of symbol periods.

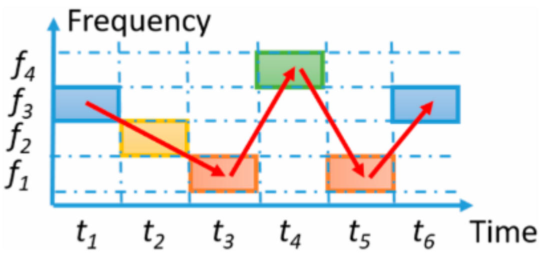


**Figure 3.** FHSS operation

## 3. LORA FHSS TRANSCEIVER

Semtech's SX1278 LoRa transceiver provides long-range communication and high interference immunity with minimized current consumption [6]. The transmitter part of this chip has a maximum transmitting output power of +20 dBm (100 mW), while receiver sensitivity of -148dBm provides a 168 dB maximum link budget making it optimal for any application requiring range and/or robustness. The main field of applications is automated meter reading, home and building automation, wireless alarm and security systems, industrial monitoring and control, and long-range irrigation systems. SX1278 transceiver is designed for battery-powered devices operating at 3.3V, with 12 mA current consumption if reception mode and 200 nA consumption in low-power register retention mode. Transmitter current consumption for different output power levels is shown in Table 2.

**Table 2**. Current consumption in transmit mode

| Transmitting power | Current consumption |
|---|---|
| + 20 dBm | 120 mA |
| + 17 dBm | 87 mA |
| + 13 dBm | 29 mA |
| + 7 dBm | 20 mA |

Besides LoRa modulation this transceiver also supports FSK, GFSK, MSK, GMSK, and OOK modulation. It can operate in the frequency range from 137 to 525 MHz, concerning the country's regulatory constraints on the permissible occupied bandwidth. For maximum flexibility the user may decide on the LoRa spread spectrum modulation bandwidth (BW), spreading factor (SF) and error correction rate (CR). The SX1278 chip offer bandwidth options ranging from 7.8 kHz to 500 kHz with spreading factors ranging from 6 to 12. Using the higher spreading factors will increase receiver capability to demodulate very low SNR signals, as shown in Table 3.

**Table 3**. LoRA Demodulator SNR

| Spreading factor | Chirps per symbol | LoRa Demodulator SNR (dB) |
|---|---|---|
| 6 | 64 | -5 |
| 7 | 128 | -7.5 |
| 8 | 256 | -10 |
| 9 | 512 | -12.5 |
| 10 | 1024 | -15 |
| 11 | 2048 | -17.5 |
| 12 | 4096 | -20 |

The SX1278 transceiver is equipped with a 256-byte dual port data FIFO buffer which is accessible through an SPI interface. The content of the packet is written to the FIFO buffer by the host microcontroller after which the transceiver is switched to transmit mode, and automatically adds the preamble, and header to the packet, after the successful packet transmission the content of FIFO is cleared. In case the transceiver is in reception mode, any valid packet after reception will be stored in FIFO and the host microcontroller will be informed using the appropriate interrupt line.

SX1278 transceivers are connected to their host microcontrollers which are programmed to periodically exchange data, using regular LoRA modulation operating in the fixed channel in 433 MHz band, with 125 kHz channel bandwidth, spreading factor set to 12 and coding rate of 4/8. Figure 4, represents the spectral waterfall diagram of occupancy of the 433 MHz band during the data exchange between transmitter and receiver where modulated frequency chirps can be observed.

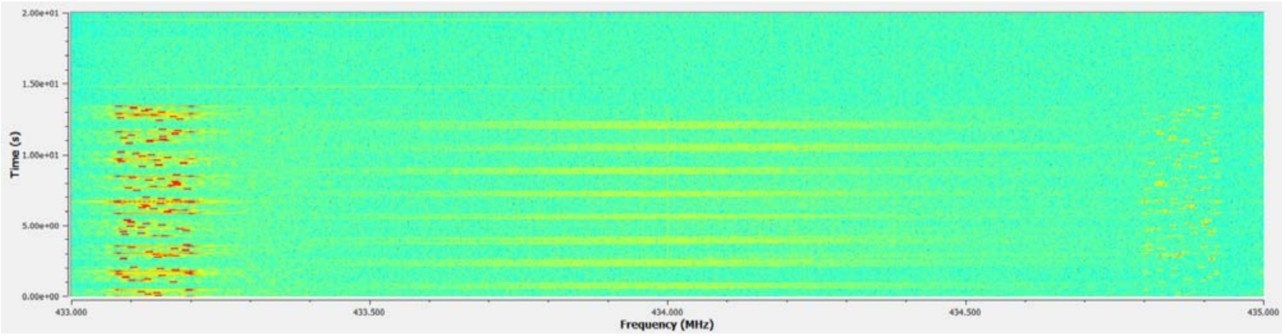


**Figure 4.** Regular LoRa modulation transmission in 433 MHz band

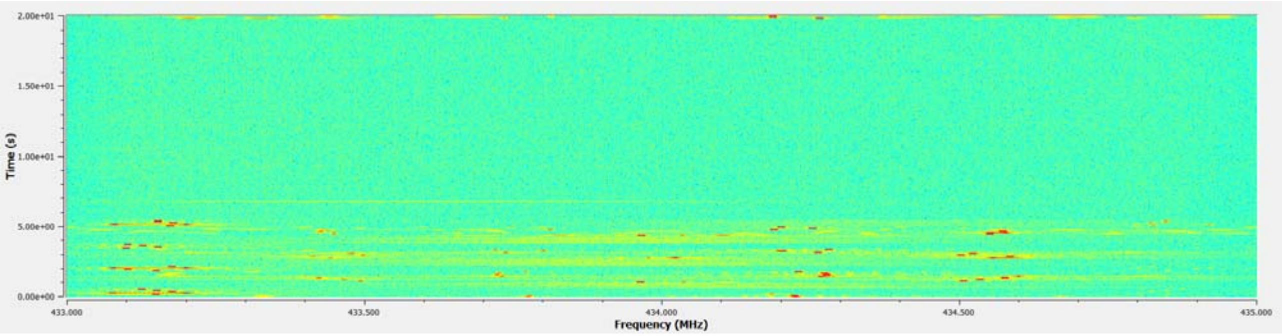


**Figure 6.** LoRa FHSS modulation transmission in 433 MHz band

The frequency hopping operation of LoRa modulation is managed by the host microcontroller which generates a channel look-up table using the pseudorandom generator fed by the pre-shared 32-bit key which is the same for the transmitter and the receiver. The frequency hopping mode starts at channel 0 from the look-up table, as shown in Figure 5. The transmitter sends the preamble and header on channel 0, while the receiver waits for a valid preamble detection at the same channel 0. At the beginning of each hopping period, the channel counter register in the transmitter and receiver is incremented and the interrupt signal is generated. Host microcontroller needs to service generated interrupt within the hopping period, where it programs new channel frequency from the look-up table to ensure it is taken into account for the next hop and clears generated interrupt.

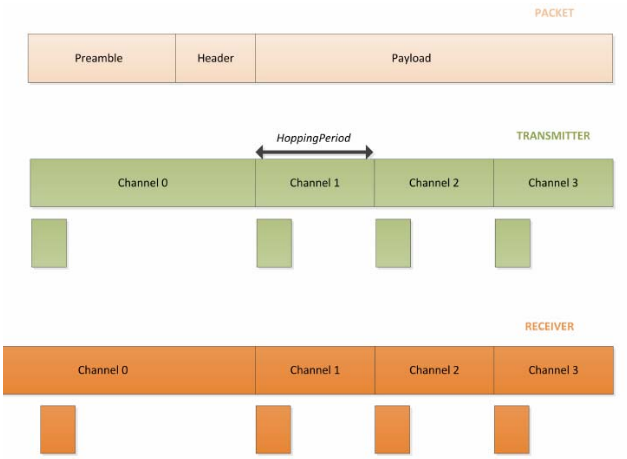


**Figure 5.** LoRa FHSS operation

SX1278 transceivers are configured by their host microcontrollers to a frequency hopping period of 10 symbols. At the beginning of every hopping period, the transceiver will generate an interrupt using digital pin DIO2, which will be processed by the host microcontroller in an interrupt service routine. The microcontroller will read the index of the next operating channel from the FhssPresentChannel register, and it will set the transceiver center frequency by the value indexed in the channel look-up table. Figure 6, represents the spectral waterfall diagram of occupancy of the 433 MHz band during the data exchange between transmitter and receiver with employed FHSS where we can observe chirp distribution to the entire 433 MHz band.

## 5. CONCLUSION

The modern military relies on robust wireless communication technologies to improve situational awareness on the battlefield. In this paper, we presented the use of frequency hopping spread spectrum implemented on regular LoRA modulation. By using a 32-bit shared key, security and resistance to jamming are significantly improved compared to the original LoRA modulation. Further research will be focused on LoRa communication based on FHSS between multiple nodes in a wireless sensor network.

## ACKNOWLEDGEMENTS

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