



HAL
open science

Optimized Reception Sensitivity of WBAN Sensors Exploiting Network Coding and Modulation Techniques in an Advanced NB-IoT

El Miloud Ar-Reyouchi, Kamal Ghoumid, Reda Yahiaoui, Omar Elmazria

► **To cite this version:**

El Miloud Ar-Reyouchi, Kamal Ghoumid, Reda Yahiaoui, Omar Elmazria. Optimized Reception Sensitivity of WBAN Sensors Exploiting Network Coding and Modulation Techniques in an Advanced NB-IoT. IEEE Access, 2022, 10, pp.35784 - 35794. 10.1109/access.2022.3163314 . hal-03917074

HAL Id: hal-03917074

<https://hal.science/hal-03917074>

Submitted on 31 Dec 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

Received March 11, 2022, accepted March 23, 2022, date of publication March 30, 2022, date of current version April 7, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3163314

Optimized Reception Sensitivity of WBAN Sensors Exploiting Network Coding and Modulation Techniques in an Advanced NB-IoT

EL MILOUD AR-REYOUCHI¹, (Member, IEEE), KAMAL GHOUMID², (Member, IEEE), RÉDA YAHIAOUI³, AND OMAR ELMAZRIA⁴, (Senior Member, IEEE)

¹Department of Telecommunication and Computer Science, E.T.S, 28014 Madrid, Spain

²Department of Electronics, Informatics and Telecommunications, ENSAO, Mohammed First University, Oujda 60000, Morocco

³NanoMedicine Laboratory, Therapeutic, Imagery, Franche-Comte University, 25000 Besançon, France

⁴CNRS, Institut Jean Lamour, University of Lorraine, 54000 Nancy, France

Corresponding author: Kamal Ghoumid (k.ghoumid@ump.ac.ma)

This work was supported in part by the FEDER “European Regional Development Fund” Project “Reper@ge” (The Reper@ge project is developed at the Nanomedicine, Imaging and Therapeutics Laboratory, Franche-Comté University), and in part by the Engineering Sciences Laboratory (LSI) of the ENSAO, Mohamed Premier University of Oudja, Morocco.

ABSTRACT The sensitivity of the maximum useable data is the most significant characteristic that describes the quality of the Narrowband Internet of Things (NB-IoT) of Medical sensors (MS) receivers. It becomes the most important performance factor in mobile wireless communication networks, particularly wireless body area networks (WBAN). Our interest is in level sensitivity using modulation techniques and subcarrier spacing(SS) to achieve good Bit Error Rate (BER) performance, throughput, and power efficiencies for WBAN communication Systems in an advanced NB-IoT. We propose an efficient coding technique using Linear Network Coding (LNC) to improve sensitivity by considering several factors without affecting the human body. We also present an experimentally analyzed overview of the reception sensibility. Our research has revealed that the receiver sensitivity (minimum detectable signal level) and throughput of the proposed approach (PA) are much better than the conventional approach (CA), achieving more than 14.3% and 55%, respectively, compared to the CA. Also, the PA has improved the modulation types by approximately 45% to provide more throughput and reliability.

INDEX TERMS Sensibility, narrowband Internet of Things, modulation techniques, wireless medical sensor networks, linear network coding.

I. INTRODUCTION

Within the scientific field, the WBANs [1] type are becoming more popular. These networks are aimed at various uses, spanning medicine to sports and multimedia. Consequently, they must meet particular standards regarding flow flexibility, low consumption, and low power usage. Given the environment of WBANs and the applications envisaged [2], these networks are forced to certain requirements:

- Very reduced radiated power due to contact with the human body.
- Very low consumption for long battery life, high variability in flow rates to meet the different applications [3] of WBAN networks.
- Resistance to electromagnetic wave propagation phenomena in a very intimate environment or direct contact with the human body.

The associate editor coordinating the review of this manuscript and approving it for publication was Giovanni Pau¹.

The Green Communication for WBANs appealed to energy-efficient. In [4], [5], the authors propose an energy-efficient fault-tolerant strategy to increase dependability and extend network lifetime in WBANs. The suggested approach reduces faults, bit error rate, and energy consumption by reducing channel degradation and body fading. The body-centric area network presented in [6] discusses wearable low-power wide-area network devices for remote monitoring. On the other hand, medical devices within WBANs highlight major security. In [7], the authors present an efficient and secure attribute-based encryption architecture with outsourcing intense encryption and decryption operations under the elliptic curve decisional Diffie-Hellman assumption.

Today, in the medical field, interest is focused on this category of networks carried on the human body and allowing wireless communication between various electronic equipment, such as *MSs*, for applications in the medical sector and sporty. The introduction of low-cost wearable sensors that can measure heart rate, body temperature,

blood sugar, and metabolic levels has changed the world.

In NB-IoT WBAN, *MSs* and medical devices *MDs* [8], [9] play a pivotal role in connecting to the cloud services or external networks. To perform this task, *MSs* must have the minimum level of the received signal that the *MD* receiver must be able to demodulate with a given error probability in the absence of any interfering or spurious signal other than thermal noise. In other words, their receiver sensitivity will correspond to the minimum signal level to achieve the required performance. Essentially, receiver sensitivity is determined by the desired BER level and signal data rate.

In the design of a radio link, the sensitivity of the receiving equipment is a parameter of great importance since it fundamentally determines the scope of the system [10],[11]. This sensitivity value, or minimum signal level that is needed for correct operation, can be defined in terms of power (dBm) and voltage ($\text{dB}\mu\text{V}$) at the RF or electric field ($\text{dB}\mu\text{V}/\text{m}$) incident on the antenna. The signal quality is defined in terms of the error rate or BER. Thus, the manufacturer usually provides a table with different sensitivity values for different BER values (usually 10^{-3} , 10^{-6} or 10^{-9} , with forwarding error correction (FEC) capability, modulation schemes [12], and bandwidths. While transmitting low-bit-rate medical data (case of our application), it is imperative to determine the perceptual importance of each packet and group them according to their sensitivity to errors. Depending on their perceptual significance, packet in each patient is provided with different levels of error protection through different FEC codes or the number of retransmission in Automatic Repeat reQuest (ARQ)[13].

The sensitivity value of the receiving equipment depends on various parameters [14], but above all, on the noise level at the input of the demodulator, both thermal noise generated in the equipment itself and external noise captured by the antenna. Thus, logically, any external interference that affects the antenna will also influence the quality of the system and the sensitivity value. On the other hand, the receiver sensitivity specification does not explicitly mention signal waveform distortion or optical SNR.

In actual terms, the receiver sensitivity measurement presupposes that the receiver's noise is the primary limiting factor in receiver performance. Inter-system interference can reduce receiver sensitivity, lowering the quality of received signals. As a result, receiver sensitivity is frequently utilized as a protection requirement for interfering systems. Generally, there are two ways to express sensitivity:

- Microvolts (μV), provided impedance specify on which this voltage is measured.
- A power, or rather a level in decibels relative to decibel-milliwatt (dBm). In this paper, the received sensitivity values are rated in dBm.

In our context, the NB-IoT [15] is a low-power, longer network radio infrastructure standard established by 3GPP to support a wide variety of MDs in medical wireless networks. The *MS* quality is defined in numerous parameters

such as co-channel rejection, adjacent channel selectivity, desensitization. But in reality, the maximum sensibility is the most significant parameter that characterizes the narrowband MS receiver's quality. In addition to the highest available sensitivity, it is necessary to specify other receiver parameters to analyze the sensibility reception, improving the maximum possible sensitivity reception. For this, we used LNC techniques to improve the sensitivity significantly. In addition, LNC has recently been proven to improve wireless network performance significantly [16], [17], [18].

In the literature, the passive components such as antennas, matching, and filtering can increase receiver performance in receive mode, such as increasing receiver sensitivity. Some methods for increasing the range were investigated, such as increasing transmission power via a high-gain antenna. Improved receiver sensitivity consequently increases the range. But, results, including throughput vs. sensitivity performance, have never been presented. On the other hand, modulations, BER, and subcarriers separation[19],[20] are also included in this paper for the first time to analyze the performance of the sensitivity reception. While all of these variables are linked, this research focuses solely on the first, particularly the maximal functional sensitivity reception.

In this paper, our main interest is high reception sensitivity without increasing a power transmitter, adding a reception amplifier, or improving the reception filter. As such, it will be ideal in difficult conditions, when the signal is weak or when there are obstacles. It is recommended for patients with medical sensors, and it will provide them with an internet connection anywhere in the hospital. All other sensors also appreciate it for performance in monitor mode.

The rest of this paper is structured as follows. Section II briefly reviews related works. Section III describes MS receiver sensitivity in WBAN, giving it an overview with the mathematical description. Section IV provides the application model for healthcare sensors to analyze the conventional and proposed approaches. Section V gives results and analysis describing our system evaluation and discusses its results. Section VI describes the limitations and future works. Finally, section VII concludes the work.

II. RELATED WORK AND CONTRIBUTIONS

Many investigators have measured and analyzed the receiver sensitivity test in IEEE 802.15 [21]. The authors of [22] offer a new method for speeding up the radiosensitivity sweep test. They used the form invariance of the sensitivity curve in frequencies. The communication in [23] shows an innovative test bench for evaluating the quality of the sensibility of a vehicle's radio reception. To improve the energy efficiency of receiver-dominated nodes in IoT networks, the authors in [24] offer Receiver-Sensitivity Control (RSC). The sensitivity restrictions of the Sensitivity in IEEE 802.15.4 standard 2.4 GHz PHY Receivers for the personal wireless and sensor networks are discussed in [25]. The authors in [26] examined the performance outcomes of various modulation strategies when the system is exposed to conduct receiver sensitivity.

They investigated MD's Sensitivity in a wireless Narrowband Internet of Things (NB-IoT) network. According to [27], the maximum available data sensitivity is the signal's minimal level at the receiver input. Therefore, after demodulation, a carrier creates sensitivity at the receiver's normal frequency, modulated with a standard test signal that provides a data signal with a defined BER of 10^{-2} specified effective message ratio of 80%. A new generation of MSs indicates that these devices will play new roles in a variety of healthcare settings [28], [29] Passive components such as reception antennas, adaptation, and reception filters are examples of improving the device's sensitivity during the reception. On the other hand, there are several analytical methods to improve range. Doubling the range by increasing transmit power brought significantly higher power supply and hardware costs; it can even influence the human body. Using a high-gain antenna significantly increased hardware and installation costs by doubting the range. However, improving receiver sensitivity doubled the range with minimal hardware costs without exposing the receiver to intolerable interference levels. The true power of sensitivity lies in its ability to help designers effectively increase range while maintaining low cost in a wireless product or system. Furthermore, adding gain to a system is one approach to increase its sensitivity.

The proposed method analyses the performance and evaluates the minimum input signal lever (receiver sensitivity), determining the maximum input level with throughput. Their choice leads to an improvement in significant sensitivity without any negative influence on the human body. A receiver must receive signals with a -20 dBm or higher power level. The efficient technical analysis of reception sensitivity in wireless WBAN based on IoT provides significant improvements, especially in throughput, data speed, and coverage.

III. MS RECEIVER SENSITIVITY

A. OVERVIEW

In this context, the MS receiver sensitivity informs us of the weakest signal level that a receiver can identify, detect, analyze, and process. It is measured in dBm with a negative value. The typical values are 11 Mbps: 54 Mbps: -72 dBm. To calculate the efficiency of a wireless system, we will have to use different formulas that allow us to ensure the proper start-up of the installation. By summing the absolute values of the sensitivity of reception (receiver) and the emission power (transmitter), we can calculate the maximum signal power value that may be lost throughout the communication process. A higher number implies that the receiver's performance is less than optimal. The lower signal's power level, the better because it shows how weak an input signal may be before being effectively received by the receiver. As a result, a receiver with a sensitivity of -70 dBm is preferable to one with a sensitivity of -60 dBm, meaning that the -70 dBm receiver is more sensitive and capable of interpreting lower power signals. Generally, RF modules' receiver sensitivity varies from -50 to -100 dBm. Receiver sensitivity requirements vary according to standards

TABLE 1. Receiver sensitivity requirements for modules.

RF modules	Value in dBm
Bluetooth	-70 to -100
Wi-Fi	-40 to -80
Cellular	up to -120
LoRa	up to -130
GNSS	-140 to -165
ZigBee	-85 to -92

and technology [30]. Table 1 gives the receiver sensitivity of different RF modules.

Concerning the nodes located in WBAN, the SS, bandwidth, message size, modulation type [31], and modulation rate affects its receiver sensitivity. Also, other receiver metrics such as noise figure, intermodulation distortion, dynamic range, and even power consumption are commonly overlooked because of patients' sensitivity and range.

When the MS transmitted signal travels through the air and other physical barriers, it is weakened or attenuated. Therefore, the MS receiver must identify 16 times (or 12 dB) signals weaker to double the range. As a result, increasing receiver sensitivity from -93 to -105 dBm effectively doubles the range. Generally, the manufacturers may be hesitant to build wireless systems with better receiver sensitivity since the possibility for much higher hardware prices and unacceptable interference, vulnerability occurs. In the proposed analysis, the MS wireless transceiver improved its receiver sensitivity from -90 dBm to -114 dBm by utilizing proprietary demodulation techniques with different parameters. The research found that the transceiver market has an average sensitivity of -93 dBm. Therefore, developers can use this number as a reference to find transceivers with a better range. A transceiver with a reception sensitivity of -105 dBm has twice the range in an urban-cellular environment than the industry standard. In contrast, a transceiver with a receiver sensitivity of -112 dBm has three times the range. The actual strength of sensitivity comes in its potential to assist designers in improving range in a wireless device.

B. MATHEMATICAL DESCRIPTION

It is worth noting that each modulation type has a unique error function value. This specificity is because each modulation behaves distinctively when subjected to noise. Faster order modulation methods (e.g., 64QAM, etc.) that enable higher data rates are less resistant in the presence of noise. Lower order modulation types (for example, BPSK, QPSK, and others) provide lower data rates but are more resilient. Radio connections and radio communications systems are strongly linked to signal-to-noise ratios (S/N) and the average energy of a bit signal E_b/N_0 values. Furthermore, the bit error rate, or BER, may be expressed in the error probability. The following approximation may convert the symbol error probability into a bit error rate (BER):

$$BER = P_{SEP} = P_{BEP}/\log_2(M) \quad (1)$$

where P_{SEP} is the symbol error probability, P_{BEP} is the bit error probability, and M is the number of modulation symbols ($M=4$ for QPSK and $M=16$ for 16QAM). Consider the

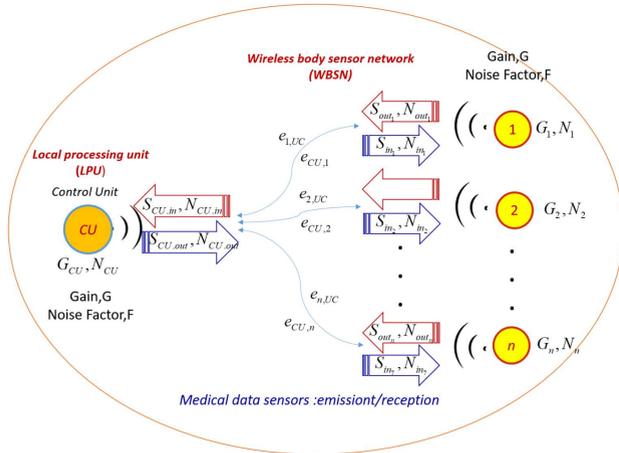


FIGURE 1. Applicable Model Medical Health: sensitivity improvement.

WBSN Fig.1. The network is represented by a graph $G = (V, E)$ consisting of nodes $(n + 1)$ devices V (n MDs and one control unit (CU)) and a set of wireless edges which represent the communication links between the devices. In addition, Fig.1 illustrates each device’s input and output signal for exchanging vital information.

Let us now consider a node of the wireless body sensor network WBSN network with input and output signals S_{in} , S_{out} and gain G . We utilize the noise factor F , which is defined as the following eq.(1), to calculate the SNR for a particular input signal frequency:

$$F = (S_{in}/N_{in}) \times (N_{out}/S_{out}) \quad (2)$$

with $S_{out} = GS_{in}$ we have:

$$N_{out} = (F \times N_{in} \times S_{out})/S_{in} \quad (3)$$

which determines the following equation:

$$N_{out} = F \times N_{in} \times G_{in} \quad (4)$$

If we now observe that from E_b/N_0 we can calculate the signal-to-noise ratio (S/N), as

$$S/N = (E_b/N_0).v_b/B \quad (5)$$

where v_b is the bit rate, and B is the channel bandwidth; it is the bandwidth usable by our receiver. Then finally, the minimum power level (Sensitivity) required at the input of the demodulator to obtain a certain threshold quality may be obtained from the value of S/N if we know the noise level at that point. The receiver sensitivity is taken as the minimum input signal S_{min} required to produce a specified S_{out} with a specified S/N . The receiver sensitivity threshold value corresponds to the minimum power at the receiver input S_{min} (dBm) capable of detecting

The minimum required signal to noise ratio $(S/N)_0$ is:

$$(S/N)_0 = \frac{P_{a,r}}{KT_e B} = \frac{P_{a,r}}{KT_0 FB} \quad (6)$$

implying that:

$$S_{min} = P_{a,r.min} = (S/N)KT_0 FB \quad (7)$$

where

- $P_{a,r}$ = Available power level (signal) at the receiving antenna terminals.
- T_0 = Reference temperature = 290 °K.
- k = Boltzmann constant, in J/K.
- F = system noise factor (F (dB)).

Currently, the techniques and procedures to measure equipment sensitivity have changed substantially. The following formulas can determine the sensitivity of devices in WBSN:

$$S_{min} = (S/N)_0 dB + 10 \log(B(Hz)) + F(dB) - 174(dBm/Hz) \quad (8)$$

$$S_{min} = 10 \log(KTB) + NF + (S/N) \quad (9)$$

where

- -174 dBm is considered the “floor” of the existing signal in the ether.
- NF means stands for “Noise Figure,” which is the electronic noise generated by the input stages of the same receiver by the electronic activity within the semiconductors.
- kTB is the thermal noise power within the bandwidth range, in Watts.

On the other hand, the signal power P_r to noise N ratio $= P_r/N$, it is related to E_0/N_0 by $P_r/N = E_0/N_0.(f_b/W)$, where f_b is the bit rate and W is the bandwidth, But we know from the higher-order modulation techniques such as QAM that f_b/W is the bandwidth efficiency or the spectral efficiency (SE). It is equal to $\log_2(M)$ where M is the modulation order. So, finally one has: $P_r/N = E_b.\log_2/N_0$,

Therefore $P_r = NE_b.\log_2/N_0 = WE_b \log_2(M)$,

We can get the required energy per bit from this relation as all other parameters may be known for a given receiver. As M increases, the required energy per bit increases, as clear from the above relation. An alternative is that we have the minimum input power. We may determine the receiver’s noise power using the receiver’s minimal P_r/N from the specific error performance curve for a certain modulation scheme.

IV. IoT-BASED APPLICATION MODEL FOR HEALTHCARE SENSORS

A. CONVENTIONAL APPROACH

Fig.2 shows an operational model representing a healthcare service using advanced medical sensors and healthcare applications. The model is connected by three wireless networks: WBSN, a wireless transmission network, and a wireless hospital network.

WBSN permits intelligent, low-power medical sensors embedded in, on, or around the human body to monitor bodily functions and environmental elements. It can alter the future of healthcare technology, and it has attracted various academic and industrial researchers in recent years. Mostly, WBSNs are composed of in-body and on-body medical sensor networks. We consider that both an in-body sensor network /an on-body sensor network allow communication between implanted /wearable devices and the control unit.

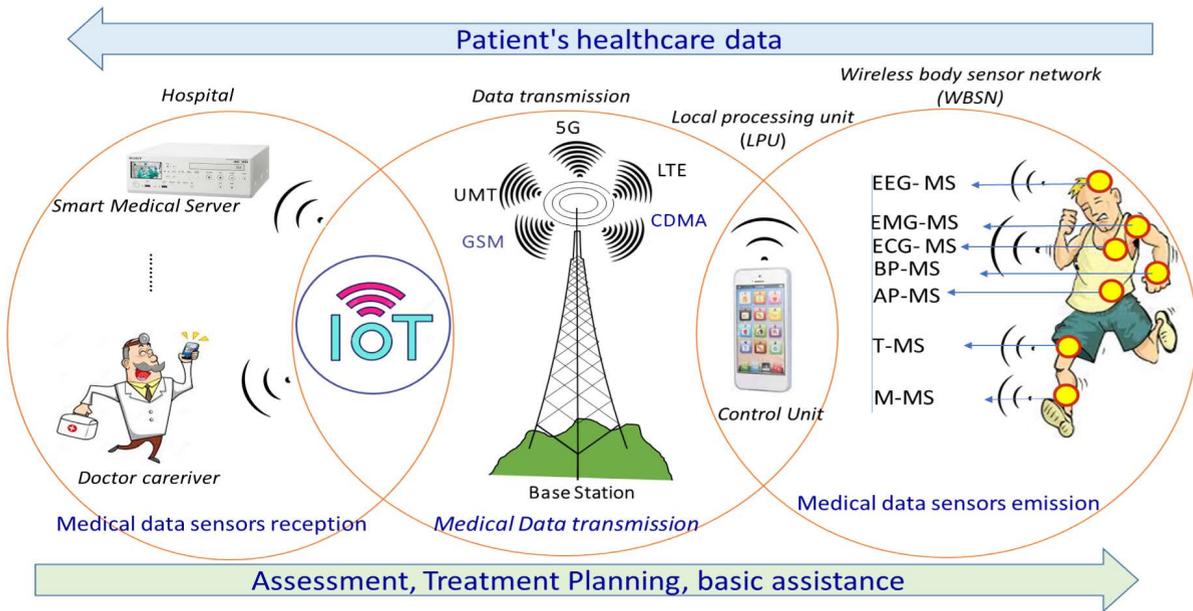


FIGURE 2. A typical wireless body sensor network (WBSN): sensors healthcare applications.

TABLE 2. Summary of acronyms used in Fig.2.

Abbreviation	Definition
EEG-MS	Electroencephalography medical sensor
EMG-MS	Electromyography medical sensor
ECG-MS	Electrocardiogram medical sensor
BP-MS	Blood Pressure medical sensor
AP-MS	artificial pancreas - medical sensor
T-MS	Temperature medical sensor
MMS	Motion medical Sensor
UMTS	Universal Mobile Telecommunications System
LTE	(Long Term Evolution)
CDMA	Code division multiple access)
GSM	Global System for Mobile Communications
5G NR	5G (fifth generation) NR (New Radio)
CU	Control unit

Our WBSN-Care (shown in Fig. 2) is a WBSN architecture comprising wearable and implanted sensors. Each type of sensor in medical devices used in this healthcare application is integrated with bio-sensors such as Electrocardiogram, Electromyography, Electroencephalography, Blood Pressure(BP), etc. To better understand the model system given in Fig.2, Table 2 gives the abbreviations and definitions used for the proposed model.

These sensors collect the physiological parameters and forward them to a Local Processing Unit (LPU) coordinator. They can be applied as a portable devices such as a control unit, a personal digital assistant (PDA), a smartphone, etc. The LPU works, as a router, between the WBSN nodes and the smart medical server. These types of servers are generally called the WBSN-Care server, using the base stations as wireless communication mediums such as 5G (NR),4G (LTE),3G (CDMA/UTMS), 2G (GSM), and mobile networks via wireless IoT network. The medical sensors are in direct contact with the human body, the context in which WBAN operates, and the applications designed to support these networks are

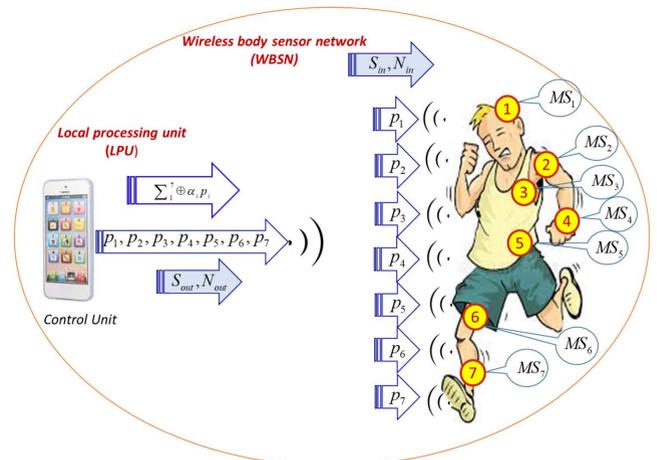


FIGURE 3. With LNC, it is possible to create a new coded packet.

compelled to meet specific requirements. So as not to influence the human body anymore, we focused on analyzing and improving the reception sensitivity of the nodes in WBAN.

B. PROPOSAL APPROACH

Consider downlink transmission paths for each node (MS and CU) see Fig.3.

The signals transmitted by each MS eventually reach the receiver CU (control unit). There, results depend on the received sensitivity of that device, i.e., the minimum power required to handle arriving signals at a given link speed. Thus, receive sensitivity is a given characteristic of a WBAN device and will vary across products and the environment. The WBSN in Fig.3, consists of sept medical sensors ($n = 7$) in wireless IoT devices in coverage areas. The mobile infrastructure of the WBAN is represented by an acyclic directed graph $G = (V, E)$ with $V = v_1, v_2, \dots, v_7$ representing MS_s

TABLE 3. Received packets for recovering the missing packets.

MS	The first received packets	The received packets for recovering the missing packets
MS_1	p_1	$p_2, p_3, p_4, p_5, p_6,$ and p_7
MS_2	p_2	$p_1, p_3, p_4, p_5, p_6,$ and p_7
MS_3	p_3	$p_1, p_2, p_4, p_5, p_6,$ and p_7
MS_4	p_4	$p_1, p_2, p_3, p_5, p_6,$ and p_7
MS_5	p_5	$p_1, p_2, p_3, p_4, p_6,$ and p_7
MS_6	p_6	$p_1, p_2, p_3, p_4, p_5,$ and p_7
MS_7	p_7	$p_1, p_2, p_3, p_4, p_5,$ and p_6

and an edge set E . The directed edge wireless connecting the IoT device $MS_i, i = 1, \dots, 7$ to the CU is denoted by $e_{i,j}$. The CU intends to distribute seven packets labeled $p_1, p_2, p_3, p_4, p_5, p_6,$ and p_7 . $MS_{i=1, \dots, 7}$ are within a wireless transmission range of the CU and hence have a strong chance to receive the packets. For example, the CU broadcasts packet p_1 , but it is just received by MS_1 .

Subsequently, the CU broadcasts packet p_2 , but only MS_2 receives it successfully. So the procedure continues in the same way up to packet p_7 . As a result, each MS receives a unique, distinctive packet. Generally, the retransmissions, basically equivalent to Automatic Repeat reQuest (ARQ), are used to restore lost packets in the classical store-and-forward approach. In our scenario, the UC rebroadcasts packets $p_1, p_2, p_3, p_4, p_5, p_6,$ and p_7 . If all these rebroadcast succeed, $MS_{1,2, \dots, 7}$ will receive the following lost packet:

Therefore, we require a total of 49 rebroadcasts, even if these first transmissions are successful, so that the message is received successfully by all MS . This scenario is presented in Fig.4.

Using an LNC system, instead of rebroadcasting packets $p_1, p_2, p_3, p_4, p_5, p_6,$ and p_7 , CU rebroadcast a new packet:

$$\alpha_1 p_1 \oplus \alpha_2 p_2 \oplus \alpha_3 p_3 \oplus \alpha_4 p_4 \oplus \alpha_5 p_5 \oplus \alpha_6 p_6 \oplus \alpha_7 p_7 = \sum_{i=1}^7 \oplus \alpha_i p_i$$

except for the packet which has already received. Then, the receipt of this packet in MS_1 can decode packet $p_2, p_3, p_4, p_5, p_6,$ and p_7 by executing the XOR operator \oplus between the previously received packet p_1 and the new packet. Thus,

$$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_1 . P_1 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i \quad (10)$$

Similarly, when MS_2 receives a new packet, it may decode $p_1, p_3, p_4, p_5, p_6,$ and p_7 , and apply the XOR operator to packet p_2 , which it has previously received, and so on until all the lost packets are found. The following Table 4 gives the necessary equations for all packet retrievals.

Thus, we can recover 6 packets with only 8 total transmissions. This scenario explains the potential of employing LNC in a single hop topology. The total number of messages has been lowered from 49 to 8. The benefits are substantially bigger for a wider topology with many more hops. As a result, LNC minimizes the number of transmissions while simultaneously lowering energy usage and per-bit energy.

TABLE 4. Setting parameters.

MS	The first received packets	The received packets for recovering the missing packets
Text MS_1	p_1	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_1 . P_1 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$
MS_2	p_2	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_2 . P_2 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$
MS_3	p_3	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_3 . P_3 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$
MS_4	p_4	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_4 . P_4 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$
MS_5	p_5	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_5 . P_5 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$
MS_6	p_6	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_6 . P_6 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$
MS_7	p_7	$p_{i,(i=1,2,3,4,5,6,7)} = \alpha_7 . P_7 \oplus \sum_{i=1}^7 \oplus \alpha_i p_i$

When transmitting a request for medical information from MS_i to CU , either over a wireless link, the key parameter is how many errors will appear in the data that appears at the MS_i reception.

This technique in this application presents several advantages to improve the performance at the reception level of each MS_s . First, it can improve the BER, restricting the influence of the disturbance signal on the BER at the MS receiver. Tables 5 and 6 give the experimental parameters used for analyzing and evaluating the reception sensibility performance of the devices in WBSN.

The proposed WBSN is an evolutionary improvement to the latest WBSN. It greatly improves efficiency, capacity, throughput, and coverage, all of which contribute to a superior user experience, particularly in dense deployment scenarios in an indoor hospital environment. To demonstrate the novelty is the comparison. The best way to highlight the novelty in our study is by comparing it with the conventional approach done by others and pointing out the things that our study does, which was never done before. To achieve this goal, We make supplement comments related to the benefit brought by PA. We then compared the PA, methodology, and

TABLE 5. Setting parameters.

Settings	Status /Mode /Type/Value
RF bandwidth of NB-IoT	200 kHz
Average message size	1000 Bytes
Processing time	20 msec
Modulation type	2CPFSK, 4CPFSK, $\pi/4$ -DQPSK, D8PSK, 16DEQAM
FEC, ACK	On, 3/4
Nodes number	7
The output power of each sensor	20 dBm
RF bandwidth of NB-IoT	200 kHz
Subcarriers spacing	6.5, 12, 25, 50 kHz
Transmission power	-25 dBm, -20 dBm, -15 dBm, -10 dBm, -5 dBm, 0 dBm
Bitrate	10.24, 20.48 kbps

TABLE 6. Modulation types.

Linear	Modulation types	Modulation rate [kbps]
QAM	16DEQAM	138.89
	D8PSK	104.17
	$\pi/4$ -DQPSK	69.44
	DPSK	34.72
Exponential	Modulation types	Modulation rate [kbps]
FSK	4CPFSK	41.67
	2CPFSK	20.83

results with the CA studies. We objectively analyzed, and we found that ours is better than the existing work in the field.

V. RESULTS AND ANALYSIS

The parameters like maximal useful (data) sensitivity, co-channel rejection, neighboring channel selectivity, desensitization, and intermodulation response rejection define the quality of an NB-IoT of MS receivers. Except for the maximum usable sensitivity, all other receiver characteristics are degradation parameters used to assess the impact of undesired (interfering) signals on the receiver’s performance. Although there is a significant relationship between all factors, the results focus on the first, particularly the maximum useable sensitivity.

This section presents the highest useable medical data sensitivity measurement and simulation results for the complete NB-IoT of MS transceiver. All the results are given for $SS = 6.25\text{ kHz}, 12.5\text{ kHz}, 25\text{ kHz}, \text{ and } 50\text{ kHz}$.

A. BER VERSUS SENSIBILITY ANALYSIS

Based on theoretical concepts of digital modulations, to obtain a certain quality threshold (error rate), the demodulator needs at its input a certain level of bit energy over noise spectral density, E_b/N_0 (Fig.4).

The essential parameters needed to calculate data sensitivity in the whole wireless NB-IoT MD transceiver are depicted in Tables 5 and 6. All results are based on a SS of 25 kHz for the proposed approach (PA) and the conventional approach (CA) using exponential modulations. Fig.5 also illustrates the maximum data sensitivity measurement reception of the complete NB-IoT device in WBSN compared between the PA process and CA process as presented in Fig.5.

It represents the BER versus receiver sensitivity at the modulation rate (Kbps) of 10.24 Kbps and 20.48 Kbps,

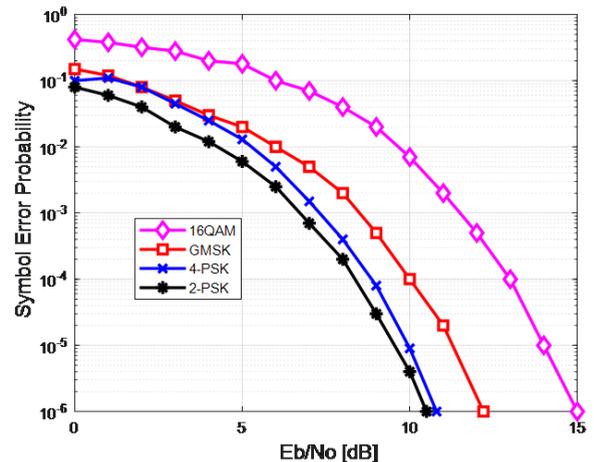


FIGURE 4. Symbol error probability vs. E_b/N_0 for different digital modulations.

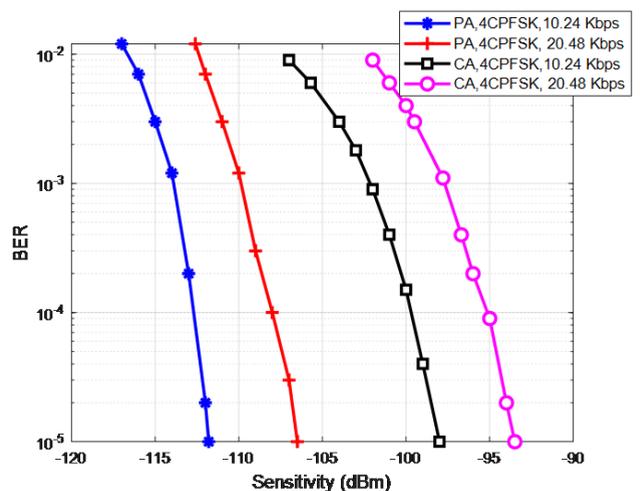


FIGURE 5. The reception sensitivity at reception with $SS = 12.5\text{ kHz}$ for the existing approach and the proposed approach.

respectively, for CA and PA. It should be observed that, when operating at the modulation rate of 10.24 Kbps and 20.48Kbps, respectively, the proposed approach improves reception sensitivity by more than 13%. The power efficiency of these modulations rapidly decreases when larger modulation rates are utilized.

The sensitivity of 4CPFSK drops from (-110dBm, $BER = 10^{-3}$) to (-96.7 dBm, $BER = 10^{-3}$) at the selected modulation rates of 20.48Kbps for 4CPFSK. Instead, our analysis shows a significant advantage of more than 13.3 dBm.

This discrepancy is because the frequency difference is somewhat less at higher packet frequencies. As a result, unlike conventional linear modulations, the reduction in power efficiency as spectrum efficiency rises is not linear. FSK has a restricted bandwidth, a lower symbol rate, and a greater sensitivity than ASK. Consequently, the system gain, power efficiency, and spectrum efficiency are better, but the system gain is lower.

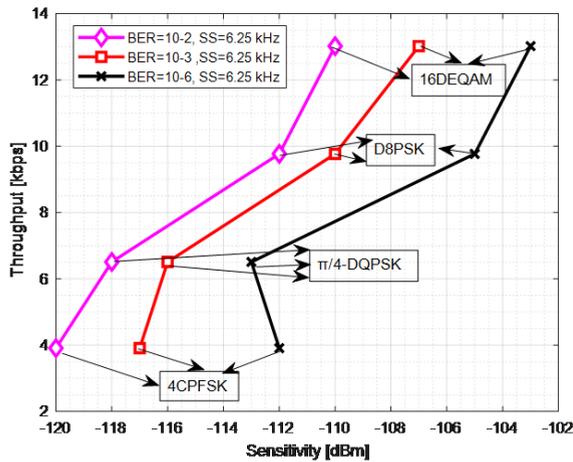


FIGURE 6. Conventional approach: Measurement results of throughput vs. maximum useable sensitivity for different linear and non-linear modulation techniques at $SS = 6.25$ kHz.

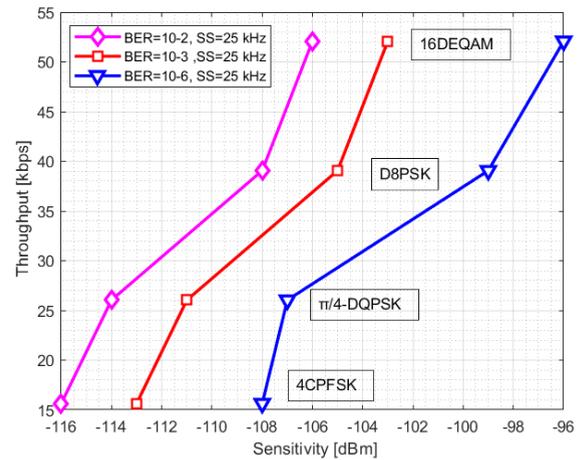


FIGURE 8. Conventional approach: Measurement results of throughput vs. maximum useable sensitivity for different linear and non-linear modulation techniques at $SS=25$ kHz.

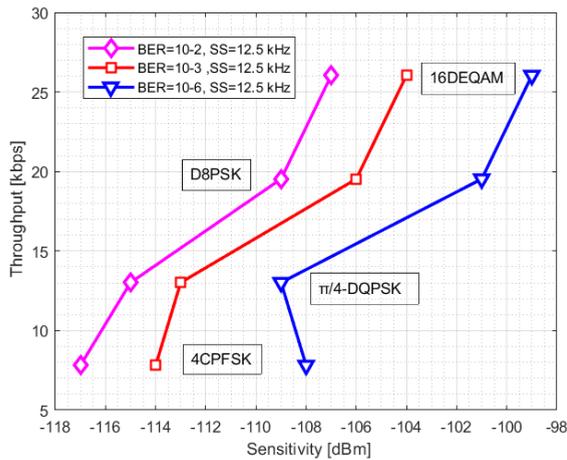


FIGURE 7. This figure shows the measurement results of throughput vs. maximum useable sensitivity for different linear and non-linear modulation techniques at $SS = 12.5$ kHz: Conventional approach.

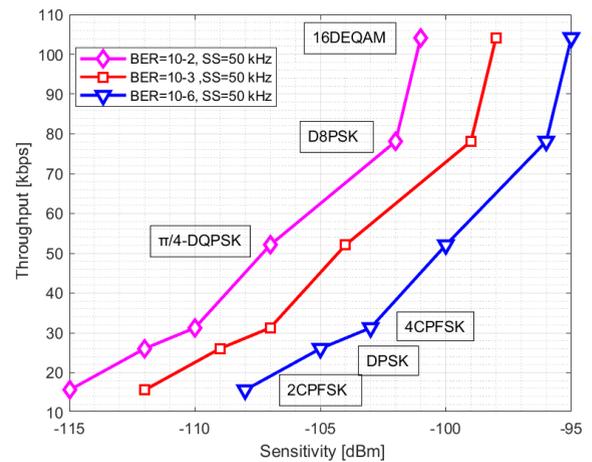


FIGURE 9. Conventional approach: Measurement results of throughput vs. maximum useable sensitivity for different linear and non-linear modulation techniques at $SS=50$ kHz.

B. THROUGHPUT AND SENSIBILITY ANALYSIS WITH COMPARISON

The following figures (Fig.6, Fig.7, Fig.8, and Fig.9) show some throughput versus sensibility with different $BER = 10^{-2}$, $BER = 10^{-3}$, $BER = 10^{-6}$, $FEC=3/4$, and fixed subcarrier spacing $SS=6.25$ kHz, 12.25 kHz, 25 kHz, and 50 kHz. Again, the exponential and linear modulation types are used for valid and generalized results.

When higher modulation rates are applied, the power efficiency of the devices decreases rapidly. The performance characteristics of the sensibility and throughput based on $BER = 10^{-3}$ are collectively given in Tables 7 and 8.

From Tables 6 and 7, we can deduce that for $BER = 10^{-3}$ (Figs: Fig.6, Fig.7, Fig.8, and Fig.9), the sensitivity decreases to 10% at the specified modulation rate 2CPFSK, DPSK, 4CPFSK, $\pi/4$ -DQPSK, D8PSK, and 16DEQAM. On the other hand, we note that the throughput increase of 9.11 kbps, 18.23 kbps, 36.43 kbps, 72.92 kbps for $SS = 6.25$ kHz, 12.5 kHz, 25 kHz, 50 kHz, respectively, when

TABLE 7. Relationship between modulation types and sensitivity [dBm] with $BER = 10^{-3}$.

modulation Types	Fig.7 SS=6.25 kHz	Fig.8 SS=12.5 kHz	Fig.9 SS=25 kHz	Fig.10 SS=50 kHz
2CPFSK				-112
DPSK				-109
4CPFSK	-117	-114	-113	-107
$\pi/4$ DQPSK	-116	-113	-111	-104
D8PSK	-110	-106	-105	-99
16DEQAM	-107	-104	-103	-98

the modulation rate increase of 41.67 kbps, 69.44 kbps, 104.17 kbps, and 138.89 Kbps, respectively. Thus, lower SS represents higher receiver sensitivity and, therefore, higher receiver performance. Higher modulation rates allow faster data transmission, but they also diminish receiver sensitivity, resulting in a narrower coverage range. Conversely, lower Modulation rates always increase communication reliability over a radio channel. Furthermore, the $\pi/4$ -DQPSK model outperforms the 4-CPFSK, DPSK, and 2CPFSK modes of operation in terms of spectrum efficiency. Higher-order

TABLE 8. Relationship between modulation types and throughput with $BER = 10^{-3}$.

modulation Types	Fig.7 SS=6.25 kHz	Fig.8 SS=12.5 kHz	Fig.9 SS=25 kHz	Fig.10 SS=50 kHz
2CPFSK				15.62
DPSK				26.04
4CPFSK	3.91	7.81	15.63	31.25
$\pi/4$ DQPSK	6.51	13.02	26.04	52.08
D8PSK	9.77	19.53	39.06	78.12
16DEQAM	13.02	26.04	52.06	104.17

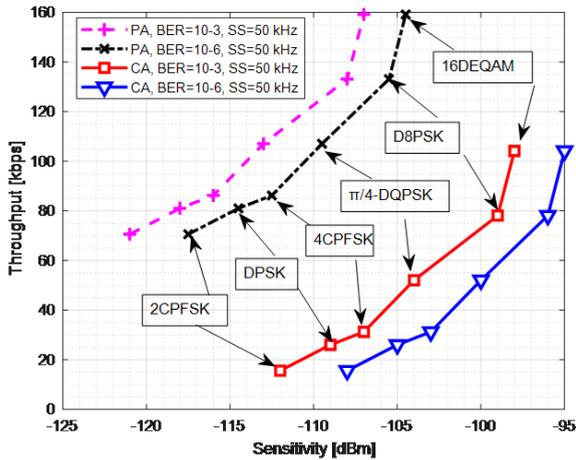


FIGURE 10. Comparison between the conventional and proposed approach for different linear and non-linear modulation techniques at 50 kHz subcarrier separation.

constellations such as D8PSK and 16DEQAM may improve spectrum efficiency, while the MS receiver keeps practically the usable sensitivity. Fig.10 provides a visual comparison between the PA and CA. It provides the throughput vs. the maximum useable sensitivity for different linear and non-linear modulation techniques using 50 kHz as subcarrier separation, based on $BER = 10^{-3}$ and $BER = 10^{-6}$. According to SS, it shows the throughput evolution under the mobile modulation mode QAM and FSK. We consider that all curves are given for 50 kHz subcarrier spacing.

From Fig.10, we can conclude that the throughput of PA increased by 55% compared to the CA. However, at the same time, the sensitivity decreased by 14,3%. This improvement is because of the proposed method of considering linear network error correction (LNEC) coding when errors occur on the edges of a WBSN communication. Nevertheless, the modulation types are known and selected.

Fig.11. show the throughput evolution according to SS under the mobile both modulation mode QAM and FSK. We consider that all curves are given for 50 kHz subcarrier spacing.

QAM and FSK modulations have approximately 45% and 44% higher throughput using PA than CA with different SS. So the receiver's sensitivity for the same modulation is better when the SS increases. The received signal must satisfy a minimum received power threshold to get the required bit rate. Decreased performance may occur if the received signal power is below the threshold, causing the maximum bit rate.

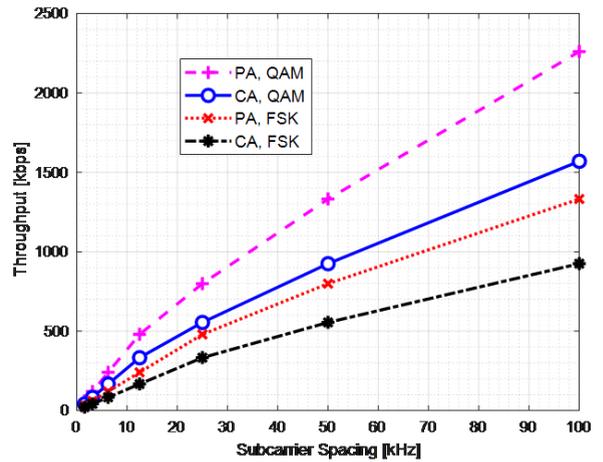


FIGURE 11. Comparison between the conventional and proposed approach for different linear and non-linear modulation techniques at 50 kHz subcarrier separation.

Therefore, an RF and SS design affect receiver sensitivity as with any other receiver design. Our approach provides various modulation parameter choices for each SS, allowing different rules to apply in different areas. FSK is appropriate for challenging circumstances, longer radio hops, non-line of sight, and radio channel noise/interferences. It has a smaller bandwidth, a lower symbol rate, and greater sensitivity. Consequently, system gain increases, power efficiency increases, but spectral efficiency is decreased. QAM is suitable for typical circumstances and provides greater data throughput. Compared to FSK (non-linear modulations), QAM has a larger bandwidth. Consequently, spectral efficiency increases, power efficiency decreases, and system gain are usually reduced. The sensitivity parameters determine how effectively it will catch faint signals. It is an important specification since it directly affects the system's range.

VI. LIMITATIONS AND FUTURE WORKS

Using LNC, the depth and innovation of technology are limited. It can be considered a traditional method used in many areas. Still, Optimizing the reception sensitivity of WBAN sensors by combining LNC with modulation techniques in an advanced NB-IoT is a particular challenger. Naturally, different limits on transmitted signal parameters result in different Modulation rates. Interference between MS or WBSN may reduce receiver sensitivity, lowering the quality of received signals. As a result, the receiver's sensitivity is often employed as a criterion for protecting the interfered with system. Squaringly eliminating these interferences to stabilize the sensitivity in difficult situations more at the reception level in WBAN still need intelligent reception filters that can adapt to all the difficult propagation conditions encountered As shown in this paper, the strict limits of the referenced standard and the state of the technology hindered increasing the communication efficiency with which the narrowband systems have been using the occupied frequency bandwidth. The key limiting factor has been identified as the adjacent channel power attenuation limit.

Lessening the requirement has opened up the closed door to implement linear digital modulation techniques. $D8PSK$ and $16 - DEQAM$ modulation schemes provide an additional improvement in spectrum efficiency for applications requiring greater data throughputs. However, compared to $\pi/4 - DQPSK$, no improvement in total communication efficiency can be anticipated, and power efficiency features must be sacrificed. When larger symbol rates are used, the power efficiency of exponential modulation methods is substantially reduced (and their main advantage). It is possible that increasing the exponential modulation spectrum efficiency beyond what is presently utilized by narrowband systems is deemed wasteful. Exponential modulation methods 2CPFSK and 4CPFSK at relatively low symbol rates, such as 10.24 kbps (Fig.5), may be suggested when long-distance coverage and overall power efficiency are the main application concerns. In this situation, non-linear modulation methods may enhance system gain by using greater frequency deviation and exceptional receiver sensitivities. Practically majority of the studies have used linear modulation formats like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). Continuous phase modulation (CPM), on the other hand, offers significant benefits over linear modulation in wireless communication systems, which will be our main concern in future work.

VII. CONCLUSION

The PA becomes a novel and more reliable sensor technology for medical applications. It delivers creative solutions, quick development cycles, and exceptional quality control to fulfill the most strict criteria in hospitals. Monitoring important vitals is easier with the suggested efficient technical analysis for reception sensitivity in NB-IoT, particularly in WBAN using LNC. When we use the PA, the MS transceiver may achieve broader system gain at greater spectrum efficiency while operating in either a linear or exponential modulation mode, despite the reduced available transmitter power. It can achieve receiver sensitivity of up to -120 dBm when using $SS = 50kHz$. For $SS = 6.25 kHz$, $12.5 kHz$, and $25kHz$, the receiver sensitivity can reach ideal values adaptable to each critical application. With the PA, one can even receive the signal under unfavorable conditions by adjusting the sensitivity level most recommended in human safety.

REFERENCES

- [1] I. Pandey, H. S. Dutta, and J. S. Banerjee, "WBAN: A smart approach to next generation e-healthcare system," in *Proc. 3rd Int. Conf. Comput. Methodol. Commun. (ICCMC)*, Mar. 2019, pp. 344–349, doi: [10.1109/ICCMC.2019.8819713](https://doi.org/10.1109/ICCMC.2019.8819713).
- [2] H.-J. Yoo, "Wireless body area network and its healthcare applications," in *Proc. Asia-Pacific Microw. Conf. Proc. (APMC)*, Nov. 2013, pp. 89–91, doi: [10.1109/APMC.2013.6695200](https://doi.org/10.1109/APMC.2013.6695200).
- [3] C. A. Tavera, J. H. Ortiz, O. I. Khalaf, D. F. Saavedra, and T. H. H. Aldhyani, "Wearable wireless body area networks for medical applications," *Comput. Math. Methods Med.*, vol. 2021, pp. 1–9, Apr. 2021, doi: [10.1155/2021/5574376](https://doi.org/10.1155/2021/5574376).
- [4] G. Mehmood, M. Z. Khan, S. Abbas, M. Faisal, and H. U. Rahman, "An energy-efficient and cooperative fault-tolerant communication approach for wireless body area network," *IEEE Access*, vol. 8, pp. 69134–69147, 2020, doi: [10.1109/ACCESS.2020.2986268](https://doi.org/10.1109/ACCESS.2020.2986268).
- [5] G. Mehmood, M. Z. Khan, M. Fayaz, M. Faisal, H. U. Rahman, and J. Gwak, "An energy-efficient mobile agent-based data aggregation scheme for wireless body area networks," *Comput., Mater. Continua*, vol. 70, no. 3, pp. 5929–5948, 2022.
- [6] M. A. Raluca, S. George, A. V. S. Carlos, P. Sever, and M. Rajagopal, "Internet of wearable low-power wide-area network devices for health self-monitoring," in *LPWAN Technologies for IoT and M2M Applications*. New York, NY, USA: Academic, 2020, pp. 307–325, doi: [10.1016/B978-0-12-818880-4.00015-6](https://doi.org/10.1016/B978-0-12-818880-4.00015-6).
- [7] S. Khan, W. Iqbal, A. Waheed, G. Mehmood, S. Khan, M. Zareei, and R. R. Biswal, "An efficient and secure revocation-enabled attribute-based access control for eHealth in smart society," *Sensors*, vol. 22, no. 1, p. 336, Jan. 2022, doi: [10.3390/s22010336](https://doi.org/10.3390/s22010336).
- [8] E. M. Ar-Reyouchi, K. Ghomid, D. Ar-Reyouchi, S. Rattal, R. Yahiaoui, and O. Elmazria, "Protocol wireless medical sensor networks in IoT for the efficiency of healthcare," *IEEE Internet Things J.*, early access, Nov. 13, 2021, doi: [10.1109/JIOT.2021.3125886](https://doi.org/10.1109/JIOT.2021.3125886).
- [9] T. Ernst, R. Guillemaud, P. Mailley, J. P. Polizzi, A. Koenig, S. Boisseau, E. Pauliac-Vaujour, C. Plantier, G. Delapierre, E. Saoutieff, R. Gerbelot-Barillon, E. C. Strinati, S. Hentz, E. Colinet, O. Thomas, P. Boisseau, and P. Jallon, "Sensors and related devices for IoT, medicine and S mart-living," in *Proc. IEEE Symp. VLSI Technol.*, Jun. 2018, pp. 35–36, doi: [10.1109/VLSIT.2018.8510692](https://doi.org/10.1109/VLSIT.2018.8510692).
- [10] J. J. Kim, K. M. Yang, J. M. Kim, Y. J. Kim, and S. Y. Lee, "Methodology for RF receiver sensitivity analysis using electromagnetic field map," *Electron. Lett.*, vol. 50, no. 23, pp. 1753–1755, 2014.
- [11] A. C. Scogna, H. Shim, J. Yu, C.-Y. Oh, S. Cheon, and N. Oh, "RFI and receiver sensitivity analysis in mobile electronic devices," in *Proc. DesignCon*, vol. 7, 2017, pp. 1–6.
- [12] W. T. Toor, A. A. Bhatti, and M. Nasir, "Comparison of different modulation schemes for signal decoding in analog network coding," in *Proc. 15th Int. Conf. Adv. Commun. Technol. (ICTACT)*, 2013, pp. 692–696.
- [13] E. M. A. Reyouchi, Y. Chatei, K. Ghomid, and A. Lichioui, "The powerful combined effect of forward error correction and automatic repeat request to improve the reliability in the wireless communications," in *Proc. Int. Conf. Comput. Sci. Comput. Intell. (CSCI)*, Dec. 2015, pp. 691–696, doi: [10.1109/CSCI.2015.39](https://doi.org/10.1109/CSCI.2015.39).
- [14] V. Joseph and S. Mulugu, "Network convergence: Ethernet applications and next generation packet transport architectures," in *Computers and Technology Networking and Cloud Computing*, 1st ed. Amsterdam, The Netherlands: Elsevier, 2014.
- [15] E. M. Migabo, K. D. Djouani, and A. M. Kurien, "The narrowband Internet of Things (NB-IoT) resources management performance state of art, challenges, and opportunities," *IEEE Access*, vol. 8, pp. 97658–97675, 2020, doi: [10.1109/ACCESS.2020.2995938](https://doi.org/10.1109/ACCESS.2020.2995938).
- [16] S.-Y. R. Li, R. W. Yeung, and N. Cai, "Linear network coding," *IEEE Trans. Inf. Theory*, vol. 49, no. 2, pp. 371–381, Feb. 2003, doi: [10.1109/TIT.2002.807285](https://doi.org/10.1109/TIT.2002.807285).
- [17] L. Lu, M. Xiao, M. Skoglund, L. Rasmussen, G. Wu, and S. Li, "Efficient network coding for wireless broadcasting," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Apr. 2010, pp. 1–6, doi: [10.1109/WCNC.2010.5506109](https://doi.org/10.1109/WCNC.2010.5506109).
- [18] E. M. Ar-Reyouchi, Y. Lamrani, I. Benchaib, S. Rattal, and K. Ghomid, "NCBP: Network coding based protocol for recovering lost packets in the Internet of Things," in *Advanced Communication Systems and Information Security*, vol. 1264, Cham, Switzerland: Springer, 2019.
- [19] E. M. Ar-Reyouchi, K. Ghomid, D. Ar-Reyouchi, S. Rattal, R. Yahiaoui, and O. Elmazria, "An accelerated end-to-end probing protocol for narrow-band IoT medical devices," *IEEE Access*, vol. 9, pp. 34131–34141, 2021, doi: [10.1109/ACCESS.2021.3061257](https://doi.org/10.1109/ACCESS.2021.3061257).
- [20] E. M. Ar-Reyouchi, I. Maslouhi, and K. Ghomid, "A new fast polling algorithm in wireless mesh network for narrowband Internet of Things," *Telecommun. Syst.*, vol. 74, no. 3, pp. 405–410, Jul. 2020, doi: [10.1007/s11235-020-00671-z](https://doi.org/10.1007/s11235-020-00671-z).
- [21] *Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)*, Standard IEEE 802.15.4, Sep. 2006.
- [22] Z. Liu, F. Li, Y. Qi, and J. Chen, "An effective receiver sensitivity measurement," in *Proc. IEEE Symp. Electromagn. Compat. Signal Integrity*, Mar. 2015, pp. 310–313, doi: [10.1109/EMCSI.2015.7107705](https://doi.org/10.1109/EMCSI.2015.7107705).
- [23] A. Maouloud, M. Klingler, and P. Besnier, "A test bench for measuring the sensitivity threshold of FM receivers in the presence of interference through direct injection of the radio signal," in *Proc. Int. Symp. Electromagn. Compat. (EMC Eur.)*, Sep. 2020, pp. 1–6, doi: [10.1109/EMCEUROPE48519.2020.9245696](https://doi.org/10.1109/EMCEUROPE48519.2020.9245696).

- [24] P. Detterer, M. Nabi, H. Jiao, and T. Basten, "Receiver-sensitivity control for energy-efficient IoT networks," *IEEE Commun. Lett.*, vol. 25, no. 4, pp. 1383–1386, Apr. 2021, doi: [10.1109/LCOMM.2020.3041935](https://doi.org/10.1109/LCOMM.2020.3041935).
- [25] S. Lanzisera and K. S. J. Pister, "Theoretical and practical limits to sensitivity in IEEE 802.15.4 receivers," in *Proc. 14th IEEE Int. Conf. Electron., Circuits Syst.*, Dec. 2007, pp. 1344–1347, doi: [10.1109/ICECS.2007.4511247](https://doi.org/10.1109/ICECS.2007.4511247).
- [26] Y. Lamrani, I. Benchaib, S. Rattal, E. M. Ar-Reyouchi, and K. Ghomid, "Performance analysis on modulation techniques for medical devices sensitivity in wireless NB-IoT network," in *Proc. Int. Conf. Smart Data Intell. (ICSMDI)* May 2021, pp. 1–6. [Online]. Available: <https://ssrn.com/abstract=3852562>, doi: [10.2139/ssrn.3852562](https://doi.org/10.2139/ssrn.3852562).
- [27] *Electromagnetic Compatibility and Radio Spectrum Matters (ERM), Part 1: Technical Characteristics and Methods of Measurement*, European Standard ETSI EN 300 113-1 V1.6.2 (2009-11), ETSI, Nov. 2009.
- [28] C. Camara, P. Peris-Lopez, J. M. de Fuentes, and S. Marchal, "Access control for implantable medical devices," *IEEE Trans. Emerg. Topics Comput.*, vol. 9, no. 3, pp. 1126–1138, Jul. 2021, doi: [10.1109/TETC.2020.2982461](https://doi.org/10.1109/TETC.2020.2982461).
- [29] Y. Blein, A. Clere, F. Bertrand, Y. Ledru, R. Groz, and L. D. Bousquet, "Improving trace generation and analysis for medical devices," in *Proc. IEEE Int. Conf. Softw. Qual., Rel. Secur. Companion (QRS-C)*, Jul. 2017, pp. 599–600, doi: [10.1109/QRS-C.2017.135](https://doi.org/10.1109/QRS-C.2017.135).
- [30] Z. Zhiqiang, W. Yunling, and Y. Lei, "Approaches and simulation for receiver sensitivity test of ZigBee module," in *Proc. 13th IEEE Int. Conf. Electron. Meas. Instrum. (ICEMI)*, Oct. 2017, pp. 98–102, doi: [10.1109/ICEMI.2017.8265921](https://doi.org/10.1109/ICEMI.2017.8265921).
- [31] Y. Lamrani, I. Benchaib, K. Ghomid, and E. M. Ar-Reyouchi, "A new coded diversity combining scheme for high microwave throughput," in *Intelligent Data Communication Technologies and Internet of Things (Lecture Notes on Data Engineering and Communications Technologies)*, vol. 101. Coimbatore, India: Springer, 2022, doi: [10.1007/978-981-16-7610-9_50](https://doi.org/10.1007/978-981-16-7610-9_50).



EL MILOUD AR-REYOUCHI (Member, IEEE) received the Engineering degree from the INPT Institute National of Telecommunication, Rabat, Morocco, the M.S. degree in industrial computer and the C.P.D./D.E.A. degree in automatic and industrial computer from the Department Computer Science and Control, ETS Computer Engineering, Madrid, Spain, and the Ph.D. degree in telecommunication and computer engineering from Abdelmalek Essaadi University, Tétouan, Morocco. He is currently the Service Regional Head of the Radio and Television Broadcast Station, Société Nationale de Radiodiffusion et de Télévision (SNRT), Morocco. His research interests include telecommunication, broadcasting TV/FM, engineering automatic systems, mobile wireless networks, the Internet of Things, wireless communications, broadcasting TV/Radio FM, antennas, and propagation. His current research interests include wireless devices for medical communication systems and sensing applications.



KAMAL GHOUMID (Member, IEEE) received the Ph.D. degree from the Institut FEMTO-ST, University Bourgogne Franche-Comté, Besançon, France, and the Télécom SudParis de l'Institut Polytechnique de Paris, Evry, France, in 2008, and the Diploma Habilitation à Diriger des Recherches (HDR) degree from the Sorbonne University (Pierre-et-Marie-Curie University, France). He was a Postdoctoral Researcher with the Jean Lamour Institute, Lorraine University, Nancy, France, and the FEMTO-ST Institute, University Bourgogne Franche-Comté, from 2008 to 2009. He is currently a Professor with the National School of Applied Sciences, Mohammed First University, Oujda, Morocco. At the start of these research activities, he worked on integrated components dedicated to optical telecommunications systems (optical filtering and modulations) and radio-over-fiber applications. His current research interests include digital communications, the Internet of Things, wireless and optical communications, and antennas and propagation research areas.



RÉDA YAHIAOUI received the Engineering degree in electronics from USTHB-Algeria, in 1993, and the Diploma of Advanced Studies (DEA) degree in electronics, sensors and integrated circuits—microwave and fast electronics option and the Ph.D. degree in engineering sciences from the University of Paris-XI, Orsay, in 1998 and 2002, respectively. Since September 2005, he has been a Lecturer with the University of Franche Comté, Electronics Department, UFR-ST of Besançon, for the teaching mission, he was attached for the research mission to the MN2S Department, FEMTO-ST Institute, until April 2019, when he joined the LNIT laboratory. His research interests include both the development of BioMEMS devices for biomedical applications, in particular, vibrating MEMS for the detection of bacteria in healthcare establishments, and in intelligent monitoring systems connected remotely, capable of monitoring health, preventing illnesses, and falls at home or in institutions for the elderly.



OMAR ELMAZRIA (Senior Member, IEEE) is currently a Full Professor (Exceptional Class) with the Université de Lorraine (UL), Institut Jean Lamour (IJL UMR 7198), for research, and Polytech Nancy for teaching. He is also an Emeritus Member of the Institut Universitaire de France (IUF) and was a Guest Professor at several Universities around the world, such as SFU, Canada; IoA, Chinese Academy of Sciences; and UCF, USA. He is the author and coauthor of more than 180 international scientific articles, four international patents issued, and more than 120 communications in international conferences. His current research interests include SAW devices for communication systems and sensing applications. He is a Senior Member of IEEE Society and a member of several technical committee programs, including IEEE International Ultrasonic Symposium and IEEE MTT-TC26 RFID, wireless sensor, and the IoT. In 2017, he receives a URSI-France Medal from the International Union of Radio Science.

...