Receiver Sensitivity Improvement for IoT

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***Abstract*—In this paper, we present two basic communication techniques for Internet of Things (IoT), as well as a new software-based solution to increase the receiver sensitivity and to improve the communication link budget. The methodology and the experimental results are also presented at the end. The complexity of the experimental setup is reduced, but it demonstrates how a simple method may be efficient for very low SNR. We apply the Time Synchronous Averaging (TSA) as a powerful signal processing technique to improve receiver sensibility. This technique is very useful for the constraints which occur during narrow band RF communications. The most important disadvantage of TSA is due to synchronization. To overcome this problem, an innovative signal processing method for synchronization in phase and in frequency is applied. The result of Averaging applied with innovative synchronization method, is the remarkable enhancement in signal detection in the presence of a very strong noise (Signal to Noise ratio near zero). The proposed solution can also be applied on large band transmissions.**

Keywords-synchronization; sensitivity; signal processing; IoT; LPWAN.

I. INTRODUCTION

The communication between the objects, Machine-to-Machine (M2M) and Internet of Things (IoT), is the revolutionary movement toward controlling almost all the aspects of costs and resources. IoT could also help us overcome the global challenges like environmental pollution, resource depletion and energy crisis [1]. IoT applications vary between several sectors and consist mainly: smart cities, tele-operation, smart metering, industrial assets and critical infrastructure monitoring, logistics, home automation and also agriculture and wild life tracking. Several studies have proven the huge growth in volume and revenue of the IoT and M2M. The number of connected objects is predicted to surpass the number of human subscribers using smart phones, tablets, laptop and PCs by 2020 [2]. The overall IoT market is also expected to reach a revenue of 4.3 trillion dollars by 2043 [3]. Cellular networks and wireless short range communication technologies were traditionally used for IoT application. These two techniques are limited by their short range of communications or the vast power consumption. Low Power Wide Area Networks (LPWAN) as a novel communication paradigm has been examined as a solution for increasing the communication range while increasing the power efficiency. In the IoT applications, the size of the data packet is very small and therefore the data rate is considered to be lower than data rate in Cellular networks. Lowering the data rate could help us achieving the higher communication range. A brief demonstration of the relationship between the different communication standards, their data rates and the communication ranges is shown in Figure 1. Unlike the data packet size, which is not an issue for IoT applications, the power efficiency, data range and the ability to communicate with large number of devices are the most important concerns in this domain. There are various techniques employed by LPWAN technologies to satisfy the desire conditions of IoT.

The desired link budget for LPWAN technologies is about 150±10 dB which is sufficient to cover a range of few kilometers for urban areas and tens of kilometers for rural areas. There is always the compromise between the data rate and the energy consumption. The receiver should be capable of decoding the noisy and weak signals. The sensitivity of such a receiver reaches as low as -130 dBm. Different LPWAN technologies are based on two main modulation techniques, narrowband and spread spectrum techniques.

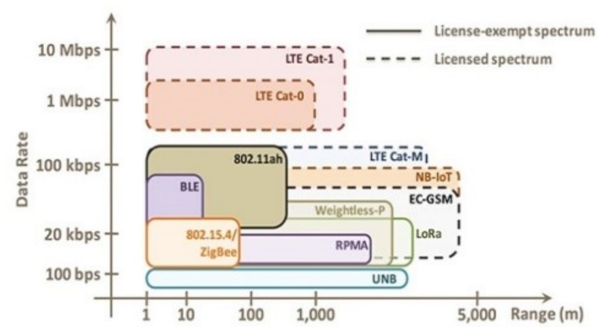

Figure 1. Data rate vs communication range

Assigning a narrow band to each carrier provides a higher link budget. The experienced noise is reduced as well. This will give us a far greater range of communication. However the data rate is also reduced. The main difficulty of narrowband communication is the frequency generation systems. This is mostly related to the oscillator's stability and phase noise. It is hard to achieve the frequency synchronization in the case of very weak signals at the receiver.

On the other hand, the spread spectrum technique spread the information signal over a wider frequency band but keeps the same power. This communication is more robust to interference and jamming. However, this technique is less efficient in terms of spectrum usage. SIGFOX and LoRa are two well-known examples of technologies, which use Narrowband and Spread spectrum techniques, respectively. Here, we introduce a novel technique to increase the receiver sensitivity. In consequence the increase in receiver sensitivity will cause more power efficiency as well as longer ranger of communication. The proposed method is applicable for both LPWAN technologies (Narrowband and spread spectrum). In state-of-the-art TSA approaches, the same information is transmitted K times. The signal must have sufficient energy to be correctly synchronized in receiver before averaging. There is a high risk of data distortion in averaging process in case of losing the synchronization. The most important advantage of our method is its robustness to the noise for achieving the synchronization. In simulations we had a non-zero two-way communication for SNR = -37 dB while in practical measurement, due to some physical limits we achieve a level of SNR = 0.3 dB. These limits and the solution to remove them are explained at the end of the article.

II. TIME SYNCHRONOUS AVERAGING

The sensitivity of a digital receiver is the minimum input signal power P_{MIN} in dBm required for a particular quality of the received information in terms of Bit Error Rate (BER) [4].

$$P_{min} = -174 + 10 \log (B) + NF + SNR \tag{1}$$

NF is the noise figure, B is the receiver equivalent noise bandwidth, and SNR is the detector input signal-to-noise ratio (SNR) needed to achieve a fixed BER.

The smaller contribution of the receiver, which means the lower power to encode the receiving signal is mostly translated to the better sensitivity.

By using advanced signal processing methods, we are capable of increasing the receiver sensitivity. Since the processing method is a software technique there is no need to change any in-use hardware. Coherent averaging is a software processing method to apply on the coherent component (a periodic signal). The received signal is damaged by a non-coherent component (stationary additive noise) [5]. An uncorrelated stationary white Gaussian noise is supposed to affect the data during the transmission. Averaging the repeated data at the receiver node will reduce the noise power K times. [6][7]. Let s(t) is a periodic signal with period T and power P_S, and n(t), an additive white Gaussian noise (AWGN) with variance σ_n^2 . The signal to-noise ratio SNR is:

$$SNR = \frac{P_S}{\sigma_n^2} \tag{2}$$

By averaging the K signals synchronously, the SNR of the averaged signal becomes [5]:

$$SNR_{TSA} = \frac{P_S}{(\frac{\sigma_n^2}{K})} = K.SNR \tag{3}$$

TSA is widely used in communications [8], medicine [9], mechanics [10], electronics and all scientific fields which treat periodic weak signals corrupted by noise [11].

III. METHODOLOGY

The most critical problem of averaging method is related to the synchronization. This is also the main issue for using the narrowband receivers.

Synchronization for averaging concerns synchronization in phase and in frequency. These correspond to the data repetition period and data stream starting point. It is very difficult to recognize and distinguish the data period and data start point when the noise power becomes very strong in comparison to the signal power (low SNR). In reality we cannot apply averaging anymore since there is no information about start and end of each period. Here we use an innovative software signal processing method to achieve the synchronization. This method is based on the periodic behavior of the signal. The main stages for applying this technique are shown in Figure 2.

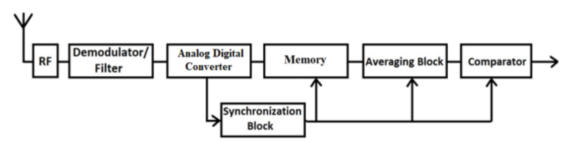

Figure 2. Principle of the Time Synchronous Averaging

The novel signal processing technique has been realized by MATLAB. For the experimental measurement, a signal generator is used to generate a series of data which are periodic.

The incoming data will be registered in a memory block. The synchronization block and the memory block work in parallel. The synchronization block drives also the averaging and comparator blocks. The output is a multi-level signal. The comparator converts it to the binary data signal. The modulation type and the SNR at the comparator (threshold circuit) input define the BER at the receiver output.

The BER for the minimum shift key (MSK) modulation, which is very common for low data rate communication systems, in the presence of AWGN is [6]:

$$BER = Q\left(\sqrt{2\frac{E_B}{N_0}}\right) \tag{4}$$

E_B is the energy per bit and N_0 is the noise power spectral density. The last equation is valid only if we consider a perfect synchronization for the coherent demodulator / matched filter. The noise power P_n is:

$$P_n = N_0 B_n \tag{5}$$

B_n is the equivalent noise bandwidth of the Demodulator / Filter circuit in Figure 2. Using (2), (3) and (5) (D is the data rate in bit/s.):

$$\frac{E_B}{N_0} = \frac{P_S}{P_n}\frac{B_n}{D} = SNR_{TSA}\frac{B_n}{D} = K.SNR\frac{B_n}{D} \quad (6)$$

As we can see the TSA method improves the SNR at the comparator input K times and the corresponding BER is:

$$BER_{SA} = Q\left(\sqrt{2K\frac{E_B}{N_0}}\right) \quad (7)$$

K is the number of retransmission of the data frame. This repetition will increase K times the energy per bit since each bit is repeated K times. It is good to notice that the transmitted power remains the same. This is one of the important advantages of this method since the communication standards limit the transmitted RF power. In other words, with no need to increase the signal power, the signal energy can be improved significantly. This technique spread the signal in the time but keeps the same bandwidth for the system as well as the same RF power. The time diversity, which is due to the providing the receiver with several replicas of the transmitted signal is useful to overcome the fading problem and will improve the overall performance of the radio link.

IV. THE MEASUREMENT SETUP

Signals are generated and processed via MATLAB and Simulink. For the transmission, we use MSK modulation technique. The received signal is demodulated first and then TSA method is applied.

To transmit and receive data, an ADF70XX evaluation board with ADF7021 transceiver was used. At the transmitter, the data generated by MATLAB is transferred to Keysight 33622A digital signal generator. The output of signal generator is connected to ADF70XX board. The transceivers are adjusted in a way to establish a MSK modulation. At the receiver, we use another ADF70XX and ADF7021 board. A manual attenuator is also applied at the first stage of receiver to attenuate the signal strength and to control the SNR. The output signal is driven from the analog port at the ADF7021 and can be seen with an oscilloscope. Registered data from oscilloscope at the receiver node is analyzed with MATLAB. The schematic of the measurement setup for transmitter and receiver are shown in Figures 3 and 4.

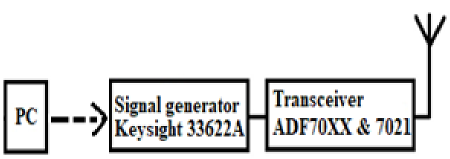

Figure 3. Schematic of the transmitter

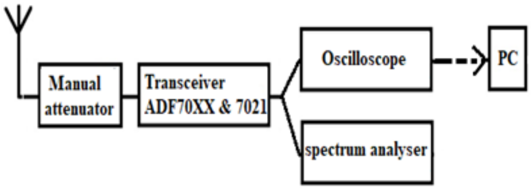

Figure 4. Schematic of the Receiver

The decision over the value of each bit has to be made after signal processing in MATLAB. To ignore any other effects during the measurements, any potential RF coupling has to be removed.

Here, we present an experiment in which we use a series of 15 bits [010100001111101], which is the length of the data frame or one period of data. It will be repeated 80 times at the rate of 2 k.Samples/s. The over sampling rate at the receiver node on oscilloscope is 5, which makes 75 samples in each period of data repetition. The information binary data rate $\mathbf{D_b}$ at the receiver node, after processing is calculated by dividing the samples data rate $\mathbf{D_s}$ by Total number of repetitions and equal to:

$$D_b = \frac{D_S}{Number\ of\ repetitions} = \frac{2000}{5*80} = 5_{bit/s} \quad (8)$$

The received signal power was about -119.7 dBm while noise power at the receiver was -120 dBm, so, the SNR = 0.3 dB. The registered signal from oscilloscope at the receiver is shown in Figure 5 as a function of sample index (Time interval between two samples is equal to 0.5 ms). Please note that, this is the noisy signal before applying the signal processing methods.

To synchronize the data and apply TSA we need the data start point as well as each repetition period. The calculating method is based on the periodic behavior of the information signal.

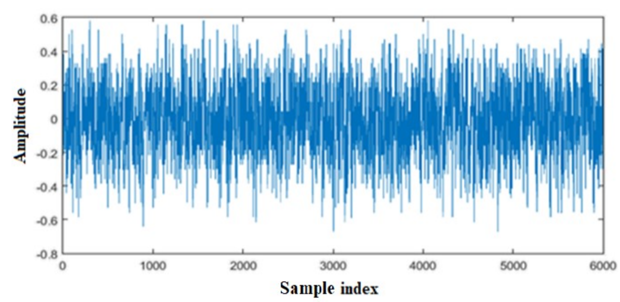

Figure 5. Received signal

The calculated values from received signal are presented bellow (corresponding peak index in Figures 6 and 7).

In this experiment, there were 1400 non data zero samples before data stream. In Figure 6, the peak point value is 1401 which is exactly the position of the first chip of data in the memory. The length of the data frame for one period multiply by the over sampling rate at the oscilloscope is 75, which is the period of data repetition. This is exactly the peak value calculated and demonstrated in Figure 7. These two values are essential for synchronization in phase and in frequency.

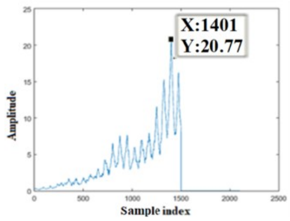

Figure 6. Data start point

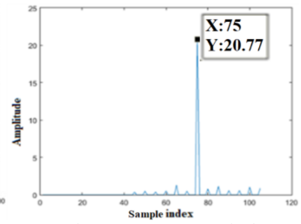

Figure 7. Data period

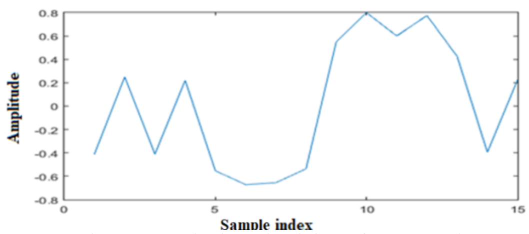

Figure 8. Final received data after processing

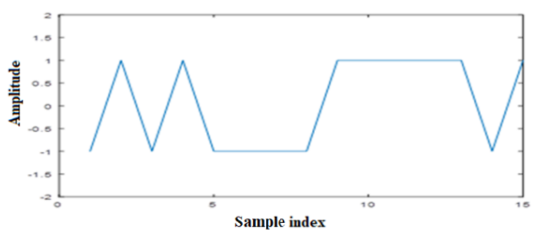

Figure 9. Data at the comparator block

Finally, the result of averaging after applying TSA and before making decision is shown in Figure 8. The overall gain due to synchronized averaging techniques is significant. Using the comparator gives the digital signal (presented in Figure 9). The result after comparator block is [010100001111101] which is the transmitted data with no error.

V. CONCLUSION

Averaging helps to establish a link in the presence of a very strong noise. The cost of averaging is the size of repeated data (more bits than information bits are needed). The limitations of averaging are due to synchronization in phase and in the frequency. In other words, the exact instant at which the data starts as well as the period of each repetition are needed. One solution is to manipulate the data before sending. These manipulation parameters are used later at the receiver to reveal this information. The gain of whole process (averaging plus synchronization in phase and in the frequency) becomes infinity, as long as, there are no limitations in terms of data repetitions and memory size. But, in real measurements for SNR close to zero, it becomes more difficult to measure the received signals. It is mostly due to heavy coupling effect while the transmitter and receiver are near to each other (in the presented experiment). One solution to overcome this problem is to put a sufficient distances between receiver and transmitter to avoid the electromagnetic coupling. We also have to avoid using the same power line for both receiver and transmitter. In very low SNR the signals propagated over the powerlines are comparative to free space propagation. Therefor repeating the measurement in an anechoic chamber will reduce this effect as well. The other difficulty is the lack of memory in experimental devices in case of large information block. WE have to break the information into small block or add more memory at receiver node.

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REFERENCES

[1] Usman Raza, Parag Kulkarni, and Mahesh Sooriyabandara, "Low Power Wide Area Networks: An Overview", IEEE Communications surveys & tutorials, VOL. 19, No. 2, Second quarter 2017.

[2] "Cellular networks for massive IoT: Enabling low power wide area applications", Ericsson, Stockholm, Sweden, Tech. Rep. UEN 284 23-3278, [retrieved: May 2018]. [Online]. Available: https://www.ericsson.com/res/docs/whitepapers/wp_iot.pdf

[3] E.Berthelsen and J.Morrish, "Forecastingthe Internet of things revenue opportunity", Machina Res., London, U.K., Tech. Rep., [retrieved: May 2018]. [Online]. Available: https://machinaresearch.com/report/forecasting-the-internet-of-things-revenue-opportunity/

[4] Emil Novakov, Mohammadmahdi Asgharzadeh, and Ghislaine Maury, "Enhancement of the Sensitivity of a Digital Receiver by Time Synchronous Averaging", URSI GASS, Montreal, 2017.

[5] R. Lyons, "Understanding Digital Signal Processing", Third Edition, Pearson Education Inc., 2011, pp. 562-589.

[6] L. W. Couch, "Digital and Analog Communication Systems" Seventh Edition, Pearson Prentice Hall, 2007, pp. 476-508.

[7] M. Sahmoudi, M. Amin, and R. Landry, "Acquisition of Weak GNSS Signals Using a New Block Averaging Tre-Processing", IEEE 2008.

[8] J. Jarret and N. Flowers, "Signal-Averaged Electrocardiography: History, Techniques, and Clinical Applications", Ciln. Cardiol. 14, 984-994, 1991.

[9] L. Zhu, H. Ding, and X.-Y. Zhu, "Extraction of Periodic Signal Without External Reference by Time-Domain Average Scanning", TEEE Trans. on Industrial Electronics, vol. 55, NO2, February 2008, pp.918-927.

[10] D. Hochmann and M. Sadok, "Theory of Synchronous Averaging", 2004 IEEE Aerospace Conference Proceedings, pp.3636-3653.