Power Efficient Long Range IoT Communication of Wireless PPM System in ISM Band

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Abstract **– This paper addresses the wireless PPM (pulse position modulation) system for the advanced energy-efficient Internet-of-Things (IoT) communication. For the wireless IoT communication applications, a new long-range energy efficient IoT communication technology is critically necessary for the minimum power loss because of the battery problem. Therefore, an advanced energy-efficient wireless PPM system has been proposed to minimize power loss. In this paper, the reduction of inter-symbol interference (ISI) and data collisions within the limited narrow bandwidth, information, and header terms are presented in the form of pulses. The distinction between the middle and start pulse trains is the header and the gap among the end and middle pulse trains are the data/information. The narrow pulses of the system will transmit a reasonable amount of data by which it will achieve the optimum amount of energy savings. As a result, the probability of data collision within the network will be lower due to the reduction of air-on time. Basically, the communication will be performed in such transmission of information signals agreement, and all the zero time duration between the pulses is the core power-saving effect. The calculated total cycle time of the proposed system is 0.1067 ms during 915 MHz ISM band frequency. In this way, the proposed system will be more energy efficient than the previous systems.**

Keywords – IoT, Wireless Communication System, PPM, ISM bands, Power Efficient, Long Range Communications.

I. INTRODUCTION

Internet-of-Things (IoT) revolution is still under progress, and tiny wireless sensor nodes are already everywhere. These are now a part of modern life and come in the shape of network-connected smart devices [1-2]. The growth of IoT-based smart devices monitoring during the past few years is attributable to the creation and advancement of low power wide area networks (LPWANs) [3]. LPWAN technology made it possible to meet the growing demands for smart cities in a variety of applications, including smart buildings, smart parking, traffic control, and cargo tracking, and so on. The capacity to link a specific end device to the internet through a gateway with low-cost, minimal infrastructure equipment and a battery with a very long life is the central tenet of the IoT [4-5]. To build IoT connectivity, a variety of communication standard protocols can be applied. SigFox and LoRaWAN are two of the most well-known LPWAN technologies [6]. Chirp spread-spectrum (CSS) and high power modulation methods are the foundation of these systems [7-9].

The energy efficiency of extensive IoT connections has greatly increased as mobile networks advance towards 5G and next 6G. The approaches and techniques currently used to achieve the energy-efficient IoT communications are outlined in [10]. Narrow-band IoT (NB-IoT) and LTE-MTC systems came next in the evolution process, which started with providing low-cost communications over dedicated resources [11]. It takes less energy to transmit a bit in these systems because the link budget is enhanced. Because the majority of low power pertinent research focuses on three factors: power consumption, coverage area, and network scalability [12]. As a result, modulation scheme parameters and power consumption associated with wireless radio link budget are discussed in this manuscript. The embedded task of advanced wireless communication system is undertaken directly by considering pulse position modulation (PPM). However, the proposed system is involved specially to transmit information signals using three pulses. The difference between the starting and middle pulse interval bears the header information and the distinction between the ending and a middle pulse conveys the information signals. As a result, it will achieve energy efficiency by reducing on air time.

The aim of this paper is to design a low power wireless communication system using PPM modulation technique to efficiently minimize the energy consumption and hence improving the spectral efficiency to enable energy-efficient communication in practical IoT application situations. As consequence, the proposed system is also involved for large scale and long range communications.

II. PROPOSED SYSTEM MODEL

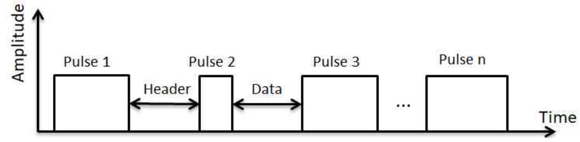

Fig. 1(a). Wireless system using time domain PPM.

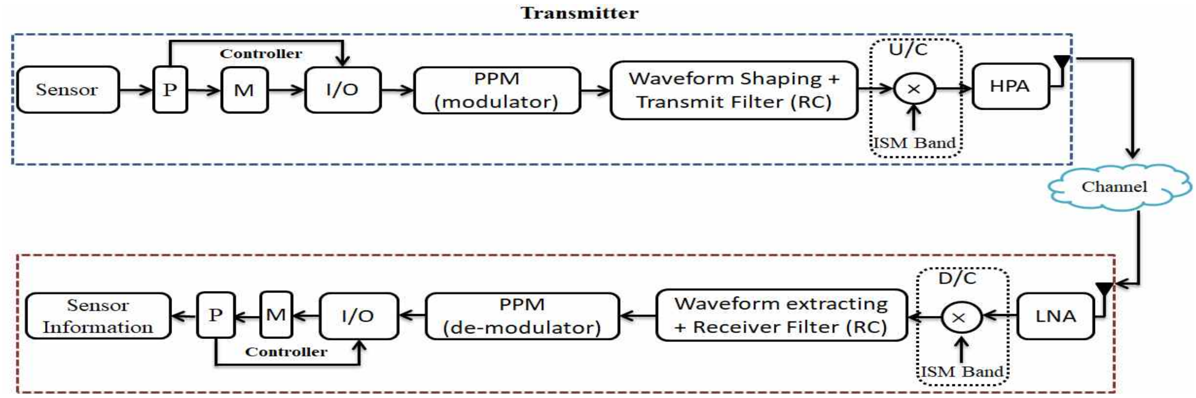

Fig. 1(b). Transmitter and receiver structure of the advanced wireless IoT communication system.

The block diagram of our proposed advanced wireless communication system model is presented in Fig. 1(b). In this system model, binary input data are produced digitally and synthetically. A modulator namely pulse position modulation (PPM) with the transformation of binary input signal inserted into a sequence of complex multilevel symbol changes is suggested. The information symbols are arranged and transmitted through the pulse shaping filter in the form of pulses. The pulses (Pulse 1, Pulse 2, Pulse 3,…, Pulse n) in time domain is depicted in Fig. 1(a). The pulse width of the pulses 1 and 3 are equal but the pulse width of pulse 2 is the half of adjacent two pulses. The designed waveform using ISM band frequency in the up-converter (U/C) and high power amplifier (HPA) is transmitted through the channel with the help of dedicated antenna. Actually, the data stream by converting digital to analog (D/A) forms with filtering transmitted over AWGN channel. At the receiver section, inverse operations are performed. The larger frequency for each pulse indicates the lower pulse width. Inversely, the wider pulse width has lower frequency bandwidth.

III. Data Transmission Scheme

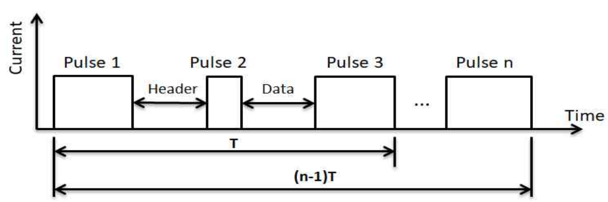

Fig. 2. Wireless system scenario using PPM.

The information transmission could be in the form of continuous or periodic state, depending on the applications. Many applications do not require the continuous transmission and approval of data, such as monitoring body temperature, chemical composition and monitoring of animals. As consequence, power is an important factor to transmit the data and it can be reduced by minimizing the cycle time. The data delivery time includes preparation time (PT) and transmission time (TT).

The power consumption is different in these two modules. However, there are two obstacles for choosing the cycle time i.e. time to prepare the scale and the time required for the correct transmission of the data. If power consumption is not considered, for a given time, the transmission efficiency (TE) will decrease as delivery time will increase. The selected periodic transmission of information in this paper is presented by PPM modulation. The pulses (Pulse 1, Pulse 2, Pulse 3,…, Pulse n) in time domain in depicted in Fig. 2. The pulse width of pulses P_0 and P_2 are equal but the pulse width of pulse P_1 is the half of adjacent two pulses. The distinction of middle and first pulses is the header stream information and the gap between the third and middle pulses is the data stream. In this system, information bits will be transmitted in the form of pulses. Fig.2 describes the implementation of the suggested system module. When reading analog data from a sensor, the transmitter turns on these into digital values $(d_0, d_1, \dots, d_{n-1})$, maps it to the pulse cycle time, T (to correct for timing errors), and sets the timer for competing clock cycle, T. As the cycle time, T is the time difference between the signals, it is not necessary to interact with the transmitter on the receiver. It is enough to use an appropriate timing rate of data transmission. As the radio frequency (RF) modules are in standby mode during data transmission, the message does not affect all the power consumption. During the frequency domain, the information will be transmitted at 915 MHz frequency is shown in Fig. 3. The power spectrum of the information signals in the frequency domain will be shifted efficiently at the respective frequency band.

IV. Band Spectrum

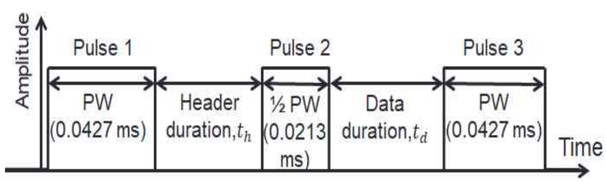

Fig. 3(a). Illustration of wireless system's sender in time domain during 915 MHz ISM band; PW: Pulse Width (ms).

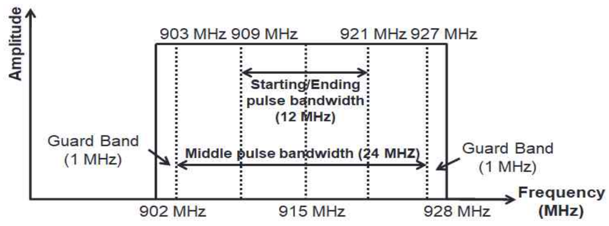

Fig. 3(b). Illustration of wireless system's sender in frequency domain at 915 MHz central frequency.

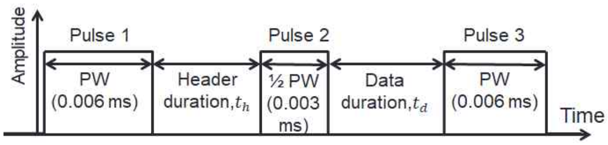

Fig. 4(a). Illustration of wireless system's sender in time domain during 2.45 GHz ISM band; PW: Pulse Width (ms).

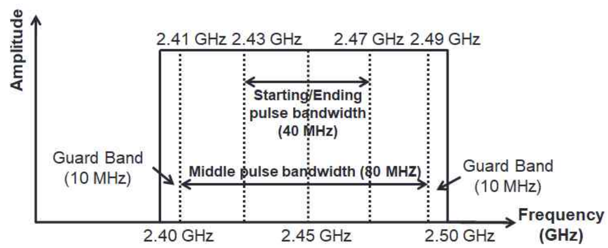

Fig. 4(b). Illustration of wireless system's sender in frequency domain at 2.40 GHz central frequency.

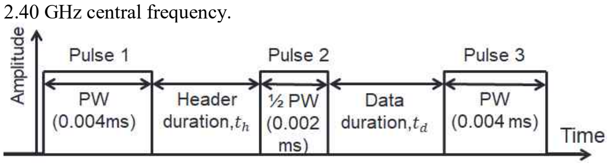

Fig. 5(a). Illustration of wireless system's sender in time domain during 5.80 GHz ISM band; PW: Pulse Width (ms).

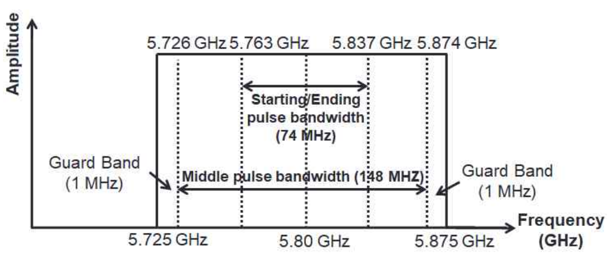

Fig. 5(b). Illustration of wireless system's sender in frequency domain at 5.80 GHz central frequency.

The maximum predictable data-rate of the advanced wireless system depends on the pulse durations; the ending and middle pulse duration gaps generally bear the sender information. The accurate pulse width calculation is considered depending on the frequency band, f of each pulses and n- number of binary bits. The pulse width calculation depending on the time components is given by

$$\tau = \frac{1}{f} \times 2^n \qquad (1)$$

Fig.3 represents a detailed timeline of the wireless transmitter system. During the 1 byte of the starting and ending pulses of the system sender, the pulse width based on the time component is 0.0427 milliseconds (ms). On the other hand, the middle pulse width duration is 0.0213 ms. The complete time cycle of the system is the summation of starting pulse width, middle pulse width, and the end pulse width, i.e., T = 0.1067 ms. The duration between the middle and starting pulses contain the header information and the gap between ending and middle pulses are the data information conveyed respectively. To be operated at the frequency band of (902- 928) MHz, the system's sender in frequency domain is depicted in Fig. 3(b). To reduce the interference at the receiver 1 MHz band is used from each side. For the first and last pulses, separately 6 MHz frequency bandwidths are allocated but the middle pulse is considered here as 12 MHz bandwidth. As a result, the time components pulse widths and the frequency bands are vice-versa to each other. The system performance was evaluated at 24 MHz bandwidth and the numerical results demonstrated that the proposed wireless system could consistently achieve very low-level power emissions. One important thing, the middle pulse controls the starting and ending pulses because the middle pulse is independent on the time and frequency domains. Depending on this pulse the header and data bits length will be varied. Thus, the starting/ending pulse must be changed with respect to the middle pulse in the time domain and frequency domain. Moreover, each sensor has each different header length. The previous wireless system's paper [1] using PPM is demonstrated in Fig. 6 whose pulse width of pulses P_0 and P_1 are 2.08 ms and the transmitter ramp-up time is 6.10 ms which are quit higher than this proposed PPM system. In the previous [1] system the air time on the physical layer will be higher than the proposed shorter width pulses system. Finally, the energy efficient data transmission scenarios for the ISM bands of 2.45 GHz and 5.80 GHz are presented in Figs. 4 and 5.

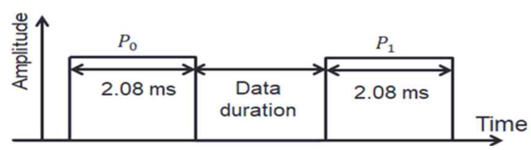

Fig. 6. Illustration of previous wireless system's sender in time domain; (P_0 *and* P_2 : pulses) [1].

V. Power Saving Effect and Range Extension

The energy efficiency of the proposed PPM system is the RF module of a sensor node. Therefore, the energy consumption of the system is given by [1]

$$E = V \times I \times \partial t \qquad (2)$$

where, V is the voltage, I is the current obtained from short duration of time, ∂t . This ∂t is the summation of first to last pulses duration. For a constant values of V= 2 volt, I = 20 mA, and depending on the different time values of ∂t, the corresponding energy consumption values are listed in Table I. Another vital term to evaluate the energy consumption of each sensor node, the energy per bit, E_b is given by [10]

$$E_b = \frac{E}{8 \times PS} \qquad (3)$$

Here, PS is the payload size measured in bits, E is the total consumed energy within the interval. The respective absorbed power by each bit based on the PS is presented in Table II.

Table I. Energy Consumption

Ref.	Time, ∂t (ms)	Energy, E (j)
[1]	10.26	0.4104
[2]	0.25	0.0100
[5]	2.00	0.0800
This	0.1067	0.0042

Table II. Energy Consumption per bit

Payload (bits)	Energy, E (mj)	Energy per bit, E_b (mj)
8	4.2	0.065
10	4.2	0.052
18	4.2	0.029
20	4.2	0.026
32	4.2	0.016

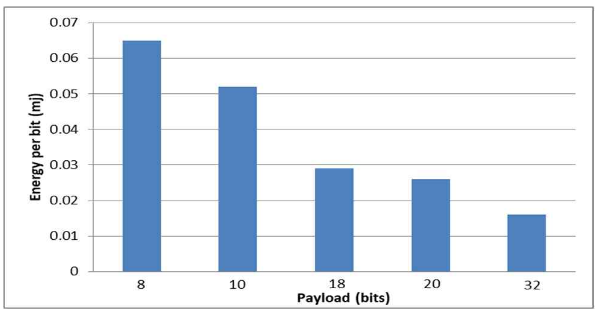

Fig. 7. Per bit energy consumption of the system.

The energy efficiency can be explained by the effect of bandwidth (BW) on power consumption, communication range and network capacity. By considering the Gaussian noise channels, the maximum channel data rate is expressed as [10]

$$R_b = B \times \log_2\left(1 + \frac{S}{NB}\right) \quad (4)$$

when B is the signal of bandwidth in Hz, S is the signal strength and N is the spectral density of noise. Broadcast higher band signals can achieve high data rates, reducing transmission time (time spent using the channel). By reducing the signals on-air-time, the active transmission time of the RF module is shortened, and hence reducing the power consumption. However, the signal-to-noise ratio (SNR) decreases with the increasing bandwidth, as signal strength increases with bandwidth. During the wide rage, the signal strength achieved lower due to the path loss factor; consequently, a smaller bandwidth can reduce the noise potentially, and increase the SNR. Therefore, a narrow band (NB) signal is suitable for propagating long distances using acceptable SNR.
In addition, the previous communication system's power consumption is very high because it occupies all the time always to send information data. However, the proposed PPM based communication system's power consumption happens in only the duration of pulse time. So, this can save the power consumption radically which is the power saving effect. As the energy efficiency which is the ratio of data volume, provided by the network and the energy consumption obtained during the time period necessary for the transmission of data. The data rate of the proposed PPM system link is defined by [4]

$$R_b = \frac{n \times f_c}{T} \quad (5)$$

here, T is the time of transmitting n- bits data in the range of [0 to 2^{n-1}], f_c is the clock rate in MHz. The available data rate is less than the rate of comparable threshold LPWAN (low power WAN) technology. The time function in equation (5) is inversely proportional to the data rate. As a result, this is in contrast to the current exchange rate system, where the amount of data is constant and does not depend on the duration of the reward. Therefore, the proposed PPM system is not suitable for applications with high data rates and low latency requirements.
Another strategy for advancing data rate is to reduce the average wait time between anchor lines by using the prior process from source to destination. The expected mean time to send n-bits data is given by

$$T_m = \sum_{i=0}^{2^{n-1}} i \, P(d(i)) \quad (6)$$

T_m is the average time, $P(d(i))$ is the probability of the sensing data value of $d(i)$. Minimizing the value of $T_m$will lead to reduce the average time of sending number of bits. Ultimately, it will maximize the data rate. The proposed PPM modulation system is being considered as low data rate of IoT sensor networking. The n- bits message encodes to one of the 2^{n-1} symbols by representing definite number of pulses and M- number of time slots. These pulses are then transmitted over narrow frequency band of 24 MHz.
Low Power Wide Area Network (LPWAN) technology such as LoRa could successfully achieve wide range and longer battery life by limiting the duty-cycle and by reducing the number of data bits. The proposed system is based on the shortest pulse width for low energy consumption on the air and the each transmitter will have unique pulse trains. The energy efficiency by reducing the number of symbols and hence the air time per message, wider rage by sending the anchor symbols over narrow band could be achieved. This reduced air-on-time and advanced spectral efficiency permits the system network to scale largely as Energy is proportional to time-on-air, Time-on-air inversely proportional to bandwidth (B), Range proportional to $\frac{1}{B}$, finally, Scale is proportional to B.

Table III. Data Speed Comparison

Ref	Number of bits, n	Clock rate , f_c (KHz)	Time, T (s)	Data rate, R_b (bits/s)
[1]	16	32	2^{15}	150
[2]	16	15	2^{15}	70
[5]	16	25	2^{15}	120
This	16	25	2^{15}	120

VI. CONCLUSIONS

This paper is about the design of energy efficient wireless system in order to meet the spectrum efficiency for the next generation wireless IoT personal/sensor communications. The proposed system has minimum complexity and is designed by using pulses. The duration between the middle and starting pulses bear the header information signals whereas the interval among the end and middle pulses occupy the data signals information. The whole duty cycle is about 0.1 milliseconds approximately during the time component of the sender side at 915 MHz central frequency. The proposed system designs to operate at the other ISM bands of 2.45 GHz and 5.80 GHz frequencies. Therefore, the proposed wireless PPM system could be more energy efficient than many previously published wireless system works.

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