OPTIMAL MODULATION SCHEME FOR ENERGY EFFICIENT WIRELESS SENSOR NETWORKS

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Abstract

As wireless sensor networks are constituted of nodes with limited life batteries, energy efficiency is a very important metric at all levels of system design. Therefore, performing optimal modulation schemes is a crucial task at the physical layer of this class of networks. This paper investigates the best modulation strategy to minimize the total energy consumption required to send a given number of bits. Energy consumption with digital modulation schemes including M-ary QAM (MQAM), M-ary PSK (MPSK), M-ary FSK (MFSK) and MSK are analytically analyzed and simulated over transmission time, modulation rate and transmission distance. A comparative analysis of energy consumption referring to MSK modulation is presented in this paper. We show that the gain achieved with MSK modulation is very promising to obtain optimal energy network consumption.

1 Introduction

The research in the field of sensors is at present undergoing an important revolution and opens significant perspectives in numerous fields of application. The wireless sensor networks (WSN) is an emerging class of communication networks. It has increasingly attracted many researchers in the field of telecommunications. The increase of the autonomy of these sensors is the main focus of research in this domain. Technology evolution and circuit design progresses are not sufficient to solve the crucial problem of energy in wireless sensor networks. The efforts so far made in the modulation schemes with optimal parameters also helps to narrow this energy gap.

Several pieces of researches evoked the effect of modulation scheme on energy efficiency. For example, [1] analyzed the binary and M-ary modulation techniques. It showed that M-ary modulation is more energy efficient than binary.

In [2] the authors compared performance of MQAM and MFSK modulation schemes in AWGN channel condition. Felipe and Hideki in [3] compared three different modulation techniques i.e. MQAM, MPSK, and MFSK. They presented relation between signal to noise ratio and channel capacity or cutoff rate to find the optimized parameters for minimizing the energy consumption.

The contribution of this paper is the comparative analysis of four types of modulation frequently used in wireless communications namely MQAM, MPSK and MFSK. The performance of MSK modulation is analyzed and compared with the other modulation to improve the energy efficiency and bandwidth efficient in a wireless sensor network.

This paper is organized as follows: Section 2 presents the system model parameters. Section 3 provides a detailed analysis of different modulation techniques. In Section 4 comparison results is discussed followed by the conclusion in Section 5.

2 System Modeling Parameters for a Wireless Sensor Network

2.1 Scenario

We consider a wireless sensor networks consisting of 20 sensor nodes that can collect and transmit information to a central node. These nodes are denoted Si with I = {1, 2, ···, 20}. Suppose that a source node S1 send L bits of data to a destination node S5 in a deadline T seconds.

The communication link between two sensor nodes will be modelled by an additive white Gaussian noise (AWGN) channel.

2.2 Transceiver Model

In this paper, we perform the transmitter and receiver hardware model as introduced in [3].

The transmitter block is composed of a digital to analog converter (DAC), a filter, a frequency synthesizer, a mixer and a power amplifier (PA).

At the receiver side, a filter, a Low noise amplifier (LNA), frequency synthesizer, a mixer, an intermediate frequency amplifier (IFA) and an analog to digital converter (ADC) are implemented.

The energy consumed by both the transmitter and the receiver blocks will be evaluated for calculating the total energy consumption in the network. We assume that powers consumption of filter at the transmitter blocks and receiver blocks are the same.

Case of frequency modulation schemes (MFSK and
MSK), power consumption of both the DAC and the mixer will not be included in the calculation of the total power consumption [3].

2.3 Preliminary Assumptions
It’s assumed that transceiver circuit of a sensor works according to three modes:
• When there is data to transmit the sensor operates in the active mode so all these circuits are active.
• If there is no information to send the circuits switch to standby mode. This contributes to energy saving and power consumption is negligible.
• Knowing that switching from standby mode to active mode, the energy overhead caused by start-up transients is also significant and must be taken into account. This temporary state called transient mode which is used to set up the frequency synthesizer of the local oscillator.

To summarize, the energy consumed during the transient mode is considered constant for a specific hardware but in a sleep state we can assume that it is equal to zero.

In this paper we emphasis our analysis on minimizing the active mode power consumption.

According to the above assumptions, the transmission period \( T \) is given by:

\[
T = T_{\text{start}} + T_{\text{on-time}} + T_{\text{stby}}
\]

where:
- \( T_{\text{start}} \) is the time of the transient mode.
- \( T_{\text{on-time}} \) represents the time spent to transmit \( L \) bits.
- \( T_{\text{stby}} \) is the duration of the standby mode.

Powers consumption associated to the described modes are denoted as:
- \( P_{\text{start}} \): Power consumed for mode changing.
- \( P_{\text{on-time}} \): Power consumed for transition
- \( P_{\text{stby}} \): Power consumed during standby mode (assumed to be null for simplification)

Correspondingly, we can derive the equation of the energy consumed data as follows:

\[
E_{\text{total}} = P_{\text{on-time}} T_{\text{on-time}} + P_{\text{start}} T_{\text{start}} + (P_{\text{rx-circuit}} + P_{\text{rx-circuit}}) T_{\text{on-time}} + 2 P_{\text{syn}} T_{\text{start}}
\]

where:
- \( P_{\text{tx}} \) represents the power of data transmission.
- \( P_{\text{rx-circuit}} \) and \( P_{\text{rx-circuit}} \) are respectively circuit powers for transmitter and receiver without considering the amplifier.

We denote:
• \( P_x \) is the power consumption of device \( x \).

Expressing each term:

\[
P_{\text{tx-circuit}} = P_{\text{tx-ADC}} + P_{\text{filter}} + P_{\text{mixer}} + P_{\text{syn}}
\]

\[
P_{\text{rx-circuit}} = P_{\text{rx-ADC}} + P_{\text{filter}} + P_{\text{mixer}} + P_{\text{syn}} + P_{\text{LNA}} + P_{\text{IFA}}
\]

The power of the amplifier is expressed as:

\[
P_{\text{PA}} = \left( \frac{\zeta}{\eta} - 1 \right) P_{\text{tx}}
\]

where:
- \( \eta \) represents the drain efficiency of the amplifier.
- \( \zeta \) is the peak to average ratio that depends on the modulation technique and is expressed as a function of constellation size \( M \) as [4]:

\[
\zeta = 3 \left( \sqrt{\frac{M-1}{M+1}} \right)
\]

\( \zeta = 1 \) for frequency modulations i.e. MFSK, MSK.

The total energy expression for both the MQAM and MPSK modulation techniques are derived as:

\[
E_{\text{total-MQAM/MPSK}} = \left( 1 + \left( \frac{\zeta}{\eta} - 1 \right) \right) P_{\text{tx}} T_{\text{on-time}} + (P_{\text{tx-circuit}} + P_{\text{rx-circuit}}) T_{\text{on-time}} + 2 P_{\text{syn}} T_{\text{start}}
\]

Similarly for MFSK and MSK:

\[
E_{\text{total-MFSK/MSK}} = \left( 1 + \left( \frac{\zeta}{\eta} - 1 \right) \right) P_{\text{tx}} T_{\text{on-time}} + (P_{\text{ADC}} + 2 P_{\text{filter}} + 2 P_{\text{mixer}} + 2 P_{\text{syn}} + P_{\text{LNA}} + P_{\text{IFA}}) T_{\text{on-time}} + 2 P_{\text{syn}} T_{\text{start}}
\]

3 Analysis of Different Modulation Techniques

3.1 Modeling of Energy for Node-to-Node Communication
In this section a communication link connecting two wireless sensor nodes is considered. Simulations shown below are performed with MATLAB.

3.2 M-ary Quadrature Amplitude Modulation
For M-ary QAM, we define \( M = 2^b \) where \( b \) is the number of bit per symbol. A sensor node must transmit \( L \) bits within a period \( T_{\text{on-time}} \).

On the one hand we define the number of transmitted symbols by:

\[
L_s = L/b
\]

On the other hand, \( L_s = T_{\text{on-time}}/T_s \) where \( T_s \) is symbol duration.

Therefore,

\[
b = LT_s/T_{\text{on-time}}
\]

Let us assume that, square pulses are used for all modulation techniques.

The channel bandwidth \( B \) equals \( 1/T_s \). Thus, the number of bits per symbol can be expressed by:

\[
b = \frac{L}{BT_{\text{on-time}}}
\]

With the data rate \( R_b \) and the channel bandwidth \( B \), we may express the bandwidth efficiency, as:

\[
\rho = \frac{R_b}{B} = \frac{b/T}{B}
\]

Using (8) and (10) we deduce that: \( \rho \approx b \).

The error probability evaluated in the case of AWGN
channel is expressed in terms of average value of the transmitted energy \([4]\) as:

\[
P_e \approx 2 \left(1 - \frac{1}{\sqrt{M}}\right) \text{erfc}\left(\sqrt{2\text{SNR}/(M-1)}\right) \tag{11}\]

SNR is the signal-to-noise ratio equal to \(E_b/N_0\). The function \(\text{erfc}(.)\) denotes the complementary error function, given by

\[
\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} \, dt
\]

The error probability could be also expressed as:

\[
P_e \approx \frac{4}{3} \frac{1}{\sqrt{M}} N_f (M-1) \ln \left(\frac{4(1 - \frac{1}{\sqrt{M}})}{bP_e}\right) \tag{12}\]

The signal to noise ratio is approximated by:

\[
\text{SNR} = \frac{P_e}{(2BN_f\sigma^2)} \tag{13}\]

where:

- \(P_e\) is the received power.
- \(N_f\) is the receiver noise figure.
- \(\sigma^2\) is the AWGN power spectral density

Hence, the received signal power can be written as:

\[
P_{rx} = \frac{4}{3} B\sigma^2 N_f (M-1) \ln \left(\frac{4(1 - \frac{1}{\sqrt{M}})}{bP_e}\right) \tag{14}\]

The power of the signal in the output of the transmitter is calculated by the equation of \(K^{th}\) path loss model \([5]\).

We can state that:

\[
P_{tx} = P_{rx} G_d \tag{15}\]

Or, \(G_d = G_1 d^k M_1\) represents the power gain factor, \(G_1\) is the gain factor at 1 m, \(M_1\) is the link margin and \(d\) (meters) is the distance that separate two communicating nodes. The exponent order \(k\) is between 2 and 4, in this paper \(k = 3\) is selected.

The transmission energy is given by:

\[
E_{tx-MQAM} = P_{tx} T_{on-time} = \frac{4}{3} N_f \sigma^2 (M-1) \ln \left(\frac{4 - 4/\sqrt{M}}{bP_e}\right) T_{on-time} G_d B \tag{16}\]

Using (6) and (15), the expression of total energy consumption is:

\[
E_{total-MQAM} = \frac{4}{3} N_f \sigma^2 (M-1) \times \ln \left(\frac{4 - 4/\sqrt{M}}{bP_e}\right) G_d B T_{on-time} + P_{circuit} T_{on-time} \tag{17}\]

The energy consumption per information bit is calculated as follows:

\[
E_{inf-bit} = \frac{E_{total}}{L} \tag{18}\]

Derived relationships between energy consumption and transmit-on time \((T_{on-time})\) are simulated and shown in Figure 1. The vertical axis presents the energy in terms of decibels relative to a 10-3-joule: \(10\log_{10} (E_{inf-bit} 10^3) \text{ dB mjoule}\), and the horizontal axis is the normalized transmission time \((T_{on-time}/T)\).

The setting parameters considered in simulation are reported in Table 1 \([2]\).

**Table 1. Simulation parameters.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{start})</td>
<td>(5 \times 10^{-6}) s</td>
</tr>
<tr>
<td>(T)</td>
<td>0.1 s</td>
</tr>
<tr>
<td>(L)</td>
<td>10(^3) bit</td>
</tr>
<tr>
<td>(\sigma^2)</td>
<td>(3.981 \times 10^{-21})</td>
</tr>
<tr>
<td>(k)</td>
<td>3</td>
</tr>
<tr>
<td>(\eta)</td>
<td>0.35 for MQAM/MPSK, 0.75 for MFSK/MSK</td>
</tr>
<tr>
<td>(B)</td>
<td>10(^4) Hz</td>
</tr>
<tr>
<td>(P_e)</td>
<td>10(^{-3})</td>
</tr>
<tr>
<td>(G_1)</td>
<td>10(^3)</td>
</tr>
<tr>
<td>(M_1)</td>
<td>10(^4)</td>
</tr>
<tr>
<td>(P_{ADC})</td>
<td>6.70 mw</td>
</tr>
<tr>
<td>(P_{DAC})</td>
<td>15.40 mw</td>
</tr>
<tr>
<td>(P_{out})</td>
<td>50 mw</td>
</tr>
<tr>
<td>(P_{bias})</td>
<td>20 mw</td>
</tr>
<tr>
<td>(P_{I_{FA}})</td>
<td>3 mw</td>
</tr>
<tr>
<td>(P_{P_{mixer}})</td>
<td>30.3 mw</td>
</tr>
<tr>
<td>(N_f)</td>
<td>10 dB</td>
</tr>
</tbody>
</table>

The variation of optimum transmit-on-time for different values of transmission distance is shown in Figure 1.

**Figure 1.** Total energy consumption per bit information \(E_{inf-bit}\) - MQAM for MQAM (AWGN).
the variable $T_{on-time}$ for long distance as compared to short distance and that the total energy consumption is not a monotonically decreasing function. For fixed $B$ and $L$, we can deduce an optimum $T_{on-time}$ for AWGN channel using this simulation. Indeed for $d = 10$ m and at the optimal case when $T_{on-time} < T - T_{start}(T_{on-time} \approx 0.27)$ the total energy consumption per information bit is about 7 dB lower than the case where $T_{on-time} \approx T$. At $d = 30$ m we notice also about 4 dB energy saving under optimized case.

![Figure 2. Total energy consumption per bit information Einfbit-MQAM and transmission Energy Etx-MQAM, MQAM (AWGN).](image)

It is obvious that the more the transmission distance increases the more the transmission energy is important. However, energy consumption by circuits is independent of $d$. Therefore for a certain threshold value of $d$, no energy savings could be possible by optimizing $T_{on-time}$. Both of total energy and transmission energy are plotted in Figure 2. It is seen, that for small distances, there is a remarkable difference between the total energy consumed and transmission energy. This difference is less important for longer distance.

The constellation size can be related to the speed of modulation given in symbols per second (bauds) which depends on bit rate $D$ and modulation rate $b$:

$$R = \frac{D}{b} = \frac{L}{bT_{on-time}}$$

(19)

Hence,

$$T_{on-time} = \frac{L}{bR}$$

(20)

Equivalently, total energy consumption can be formulated in terms of speed modulation as follows:

$$E_{total-MQAM} = \frac{4}{3} \left( \left( \frac{\sigma}{\eta} - 1 \right) \right) N_r \sigma^2 (M - 1)$$

$$\times \ln \left( \frac{4 - 4\sqrt{M}}{\log(M)P_e} \right) G_B \frac{L}{bR} + P_{circuit} \frac{L}{bR} + 2P_{on} T_{start}$$

(21)

Figure 3 depicts the variation of energy consumption which decays with the modulation speed. We also remark that when the modulation speed increases, the constellation size decreases resulting in energy decreasing.

![Figure 3. Energy per information bit versus speed of modulation, MQAM (AWGN) for $d = 10$ m.](image)

Energy consumption per information bit $E_{inf-MQAM}$ and transmission energy $E_{tx-MQAM}$ are drawn over modulation rate $b$ for $d = 10$ m in Figure 4.

![Figure 4. Energy per information bit versus Modulation rate for MQAM (AWGN).](image)

We can deduce that the optimal number of bit per symbol $b_{opt}$ is about 8 if we consider the total energy and $b_{opt} = 2$ when only transmission energy is taken into account.

### 3.3 M-ary Phase-Shift Keying (MPSK)

The bit per symbol $b$ for MPSK modulation scheme depends on the time spent to transmit $L$ bits $T_{on-time}$ as defined for MQAM modulation.

Let us assume that MPSK uses the same hardware configuration as the one used for MQAM.

The bit error probability for AWGN channel is expressed as follows [4]:

$$P_e = \text{erfc} \left( \sqrt{SNR} \sin(\pi/2M) \right)$$

(22)

Using Equations (6), (9), (13), (15) and (22), the total energy consumption is derived as:

$$E_{total-MPSK} = 2 \left( \left( \frac{\xi}{\eta} - 1 \right) \right) N_r \sigma^2 \left( \frac{2}{b \rho_P} \right) \left( \sin \frac{\pi}{M} \right) \right)$$

$$\times G_B T_{on-time} + P_{circuit} \frac{T_{on-time}}{bR} + 2P_{on} T_{start}$$

(23)
The total energy consumption \( E_{\text{infbit-MPSK}} \) as a function of \( T_{\text{on-time}} \) for transmission distances \( d = 10, 30 \) and \( 100 \) m are shown in Figure 5. The numerical values considered for these curves are the same as those used for MQAM modulation.

**3.4 Multiple Frequency-Shift Keying (MFSK)**

Remember that, for MFSK we must eliminate the two components noted earlier, the DAC and the mixer of the hardware configuration since FSK can be implemented by a simple direct modulation such as \( \Sigma - \Delta \) modulator. In this section analysis is done for non-coherent MFSK [3].

Let us assume that signals are orthogonal and the adjacent signals are separated by \( 1/2T_s \).

The bandwidth channel is defined as: \( B = M/2T_s \).

Therefore, \( B = R_s M/2 \log_2 M \).

Using the previous equation and (10) we can derive bandwidth efficiency expression as:

\[
\rho = \frac{2 \log_2 M}{M} = \frac{2b}{2^b}
\]

(24)

The bit per symbol of MFSK modulation can be related to the transmit on-time as following:

\[
\frac{2b}{2^b} L = \frac{2}{BT_{\text{on-time}}}
\]

(25)

The probability of error for no-coherent MFSK detection is expressed as [4]:

\[
P_e \leq \frac{(M-1)}{2} \text{erfc} \left( \sqrt{\text{SNR}} \right)
\]

(26)

Hence,

\[
P_e \leq 2^{b-2} e^{-\text{SNR}/2}
\]

(27)

We can deduce that:

\[
\gamma = 2 \ln \left( \frac{2^{b-2}}{P_e} \right)
\]

(28)

On the other hand we find that [4]:

\[
\gamma = b E_{\text{urb}}/2\sigma^2 N_f
\]

(29)

where \( E_{\text{urb}} \) represents the energy per information bit at the receiver:

\[
E_{\text{urb}} = (P_r T_{\text{on-time}})/L
\]

(30)

Using (27), (28), (29) and (30) we deduce the received signal power as follows:

\[
P_r = 4N_f \sigma^2 \ln \left( \frac{2^{b-2}/P_e}{M} \right) B
\]

(31)

Knowing that \( P_{tx} = P_r G_d \) and \( E_{tx} = P_{tx} T_{\text{on-time}} \)

We obtain:

\[
E_{\text{tx-MFSK}} = 4N_f \sigma^2 \ln \left( \frac{2^{b-2}/P_e}{G_d} \right) L/b
\]

(32)

Then the total energy is:

\[
E_{\text{total-MFSK}} = 4 \left( 1 + \frac{\varepsilon}{\eta} - 1 \right) N_f \sigma^2 \ln \left( \frac{2^{b-2}/P_e}{G_d} \right) L/b + P_{\text{circuit}} T_{\text{on-time}} + 2 P_{\text{start}} T_{\text{start}}
\]

(33)

And the total energy consumption per information bit \( E_{\text{infbit-MFSK}} \) is deduced from (33) and (18).
bandwidth B and the packet size L and we change the value of drain efficiency to 0.75 and that of transmission period T to 1.10 s.

In fact, MFSK modulation needs a longer transmission time to send L bits due to its lower bandwidth efficient comparing to MQAM and MPSK modulations. Figure 7 shows that the total energy is an increasing function of Ton-time for short distance (10 m - 30 m) and under optimized case, we observe about 7 dB energy savings compared to the case where (Ton-time = T).

Figure 7. Total energy over Ton-time for short distance (10 m - 30 m). Optimized case shows about 7 dB energy savings compared to the case where (Ton-time = T).

Curves plotted in Figure 8 represent the total energy and transmission energy as a function of b. It is clear that the transmission energy decreases when b increases. Therefore, better energy efficiency is obtained when constellation size is larger. The optimal data rate b in this case is 6. Nevertheless, based on the total energy measurements, the optimal value of b is 1.5 for d = 1 m and d = 30 m and 2 for d = 100 m. Approximately 82% energy savings is achieved by using optimal bopt = 1.5 compared with the non-optimized case where (Ton-time = T (b = 6)). This result agrees with [3].

3.5 Minimum-Shift Keying (MSK)

MSK can be viewed as a special form of continuous phase-frequency shift keying, (CPFSK) where the deviation index is precisely equal to ½. A modulation index of 0.5 corresponds to the minimum frequency spacing that allows two FSK signals to be coherently orthogonal.

Where we consider the same configuration as that used for MFSK modulation. The frequency difference is equal to 1/2Tc.

A bound on the probability of error for MSK is written as [4]:\[
P_e = \frac{1}{2} \text{erfc} \left( \sqrt{\text{SNR}} \right)
\] (34)

Therefore, we can deduce:
\[
P_e \approx e^{-\text{SNR}}
\] (35)

Next the energy per information bit at the receiver is:
\[
E_{\text{inf bit}} = N_o N_f \text{SNR} \approx 2\sigma^2 N_o N_f \ln \left( \frac{1}{P_e} \right)
\] (36)

By following the same process used for previous modulations:
\[
P_t = \frac{E_{\text{inf bit}}}{P_{\text{t}} G_d} = \frac{E_{\text{T}} G_d}{T \text{on-time}}
\] (37)

And,
\[
E_{\text{inf bit-MSK}} = 2N_o N_f \sigma^2 \ln \left( \frac{\sigma}{\eta} \right) N_o N_f \ln \left( \frac{1}{P_e} \right) G_d
\] (38)

Energy consumption per information bit is written as:
\[
E_{\text{inf bit-MSK}} = 2 \left( \frac{1}{\eta} \right) \sigma^2 \ln \left( \frac{1}{P_e} \right) G_d + \frac{P_{\text{circuit}} T_{\text{on-time}}}{L} + \frac{2P_{\text{syn}} T_{\text{start}}}{L}
\] (39)

The plot of $E_{\text{inf bit-MSK}}$ over Ton-time in the case of MSK technique is presented in Figure 9. Not surprisingly, energy consumption is also an increasing function of transmission time and optimal Ton-time = 0.1T. Furthermore, in the optimal case, for d = 10, 30 and 100 m we respectively obtain about 10, 9.5 and 5.5 dB of energy savings compared to the non-optimized system (Ton-time = T).

3.6 Modeling of Energy Aware Routing

Our objective is to evaluate in terms of energy the performance of realistic wireless sensor network in an indoor scenario.

Figure 10. An example of random distributed sensors network of 100 m².
We consider a small scale network based on 20 nodes capable of collecting and transmitting information to a central node.

These sensors are deployed in non-deterministic mode (randomly) over an area of about 100 square meters and can have different sensitivities. Routing data from the source sensor node to the destination one can use intermediate nodes to relay information (Figure 10).

The energy consumed along the route is calculated as follows [6]:

\[ E_i(t) = \sum_{i=1}^{n} \left( P_{tx}(i) + P_{rx}(i+1) \right) T_{on-time} \]  

where, \( E_i(t) \) is the energy of node \( S_i \) at time \( t \), \( P_{tx}(i) \) is the transmission power of node \( S_i \), \( P_{rx}(i) \) is the receiving power of node \( S_i \) and \( n \) is the number of node. The formula (40) is used for energy calculation aware routing in the following.

4 Comparison Results

4.1 Point to Point Communication

![Figure 11. Comparison of different modulation techniques for node to node communication, d = 10 m.](image)

The total energy per information bit versus transmit-on time curves are shown in Figure 11. The simulations are presented in the case of four modulation techniques. We deduce that MSK permits for the best energy consumption comparing to the other modulation techniques.

4.2 Inter-Nodes Communication Through Relay

Among the 20 sensor nodes, we will evaluate energy consumption of communication between the node \( S_1 \) and the node \( S_5 \) (Figure 10).

We can derive the expression of total energy consumption for each modulation technique for inter-nodes communication through relays from above equations. From (17), (18), (23), (33), (39) and (40).

Then, total energy consumed along the route is redrawn using optimal parameters deduced previously for the four modulation schemes.

Figure 12. Comparison of different modulations for inter-nodes communication at optimum constellation and transmit-on time.

![Figure 12. Comparison of different modulations for inter-nodes communication at optimum constellation and transmit-on time.](image)

Energy per bit (dBmjoule)

The comparative analysis concludes that MSK modulation becomes more advantageous than its counterparts in an energy point of view.

The results also disclose that, MSK may be a good choice for wireless sensor network, because this modulation schemes has a high bandwidth efficient and it has the advantage of being simple to generate, simple to demodulate and has a constant envelope. The obtained results can be used as a design guideline for coded modulation techniques in WSN.

5 Conclusion

The comparative analysis concludes that MSK modulation becomes more advantageous than its counterparts in an energy point of view.

The results also disclose that, MSK may be a good choice for wireless sensor network, because this modulation schemes has a high bandwidth efficient and it has the advantage of being simple to generate, simple to demodulate and has a constant envelope. The obtained results can be used as a design guideline for coded modulation techniques in WSN.

References