

**Online Publication Date: 19 March 2012**  
**Publisher: Asian Economic and Social Society**



### **Energy Efficient Modulation Techniques for Fault Tolerant Two-Tiered Wireless Sensor Networks**

**M.Sheik Dawood** (Department of Electronics and Communication Engineering, Sethu Institute of Technology)

**Sajin Salim** (Department of Electronics and Communication Engineering, Sethu Institute of Technology)

**S.Sadasivam** (Department of Information Technology, Sethu institute of Technology)

**G.Athisha** (Department of Electronics and Communication Engineering, PSNA College of Engineering and Technology, Tamilnadu, India)

**Citation:** M.Sheik Dawood, Sajin Salim, S.Sadasivam ,G.Athisha (2012): “Energy Efficient Modulation Techniques for Fault Tolerant Two-Tiered Wireless Sensor Networks” Journal of Asian Scientific Research Vol.2, No.3, pp.124-131.



#### **Author (s)**

##### **M.Sheik Dawood**

Department of Electronics and Communication Engineering, Sethu Institute of Technology.

Email: [aneesheik@yahoo.com](mailto:aneesheik@yahoo.com)  
[salimsajin@gmail.com](mailto:salimsajin@gmail.com)

##### **Sajin Salim**

Department of Information Technology, Sethu institute of Technology

##### **S. Sadasivam**

Department of Information Technology, Sethu institute of Technology.

Email: [sadasiva1965@gmail.com](mailto:sadasiva1965@gmail.com)

##### **G. Athisha**

Department of Electronics and Communication Engineering, PSNA College of Engineering and Technology, Tamilnadu, India.

Email: [gathisha@yahoo.com](mailto:gathisha@yahoo.com)

## **Energy Efficient Modulation Techniques for Fault Tolerant Two-Tiered Wireless Sensor Networks**

### **Abstract**

A Wireless Sensor Network is composed of hundreds or thousands of nodes that can be equipped with limited energy resources but can still be used over an extensive set of diverse applications such as environment monitoring, healthcare, homeland security, military surveillance, manufacturing, and industry automation. In a safety critical application such as landslide prediction, fault tolerant approaches have to be followed, to ensure the availability of sensor data, at the analysis station, during a critical situation. In this circumstance, we analyze the preeminent modulation scheme, and transmission approach to improve bandwidth and energy efficiency in fault tolerant wireless sensor networks for landslide area monitoring. The total energy consumption includes both the transmission energy and the circuit energy consumption. The modulation schemes are compared based on their energy consumptions at their transceiver node. This paper analyzes the homogenous and heterogeneous modulation schemes to improve the energy efficiency and bandwidth efficiency in a wireless sensor network.

**Keywords:** Sensor network, Physical layer, Energy consumption, Bandwidth efficiency, Modulation, Lifetime

### **Introduction**

Wireless Sensor Networks typically consists of a large number of sensor nodes distributed over a certain region. The radio frequency (RF) transceiver, A/D and D/A converters, baseband processors, and other application interfaces into one device which is called as sensor node. These sensor nodes are characterized by their low power, small size and cheap price. Thus, in many scenarios, the wireless nodes must operate without battery replacement for many years. Consequently, minimizing the energy consumption is a very important design consideration, and energy-efficient transmission

schemes must be used for the data transfer in sensor networks.

In the rainfall induced landslide scenario analysed by Rehna Raj et al. (2008), the sensor nodes are distributed in different locations which are categorized into hierarchical zones. In the hierarchical architecture, the geological data that are measured for the particular application are pore water pressure, ground vibration, soil moisture, tilt or acceleration and strain on the particular sensor column into which these analog sensors are placed and buried under the ground. The sensor nodes periodically sample the environmental data and

transmit the data at constant time intervals to the aggregating node.

Energy consumption in energy-constrained wireless sensor networks has been a hottest topic of discussion. Maryam Soltan et al. (2008) focused on improvement of lifetime of each cluster of sensors in hierarchical WSN using optimization techniques at the physical layer and how the location-aware selection of the modulation schemes for sensors can affect their energy efficiency.

Maryam Soltan et al. (2008) also analysed on how certain physical layer attributes can affect both the lifetime and the end-to-end delay in a hierarchical WSN. A heterogeneous modulation scheme has been presented and reported its impact on the spatial distribution of energy dissipation and the resulting network lifetime. Moreover, authors discussed how this heterogeneous modulation scheme affects the end-to-end delay due to inherent trade-offs in power efficiency and bandwidth efficiency of the different modulation schemes.

An analysis on hop distance estimation is used to find the minimum number of hops required to relay a packet from one node to another node in a random network by statistical method (Padmavathy and Chitra, 2010). The energy consumption and latency are calculated from the minimum number of hops. Felipe and Hideki (2010) explained three different modulation types frequently employed in wireless communication and derived an energy minimization scheme for point-to-point wireless communications. A cost effective heterogeneous sensor network with lifetime constraint has been discussed (Mhatre, V. P. et al., 2005).

Energy-efficient strategies for deployment of wireless sensor networks (WSN) for the purpose of monitoring some phenomenon of interest in a coverage region were analysed by various researchers. In which, describes a two-level WSN structure where the sensors in the lower level monitor their surrounding environment and the micro-servers in the top level provide connectivity between the sensors and a base station (Iranli et al., 2005).

Soltan and Pedram (2007) analysed a hierarchical wireless sensor network with mobile overlays, along with a mobility-aware multi-hop routing scheme, in order to optimize the network lifetime, delay, and local storage size.

This paper extends the work of earlier research to improve the energy efficiency of clustered wireless sensor networks by analysing performance study of homogeneous and heterogeneous modulation. This work consider three different modulation types frequently employed in wireless communications; BPSK QAM and MSK, and derive an energy minimization scheme for node -to-node wireless communications in sensor network. Among these three modulation types, MSK has been a preferable choice for wireless sensor network due to its constant peak-to-average power ratio of transmit signal and low complexity that allows the use of noncoherent detection at the receiver. Numerically analysis of the minimum energy, considering both transmit signal and circuit, spent per information bit are carried out in this work. Our main objective is to derive a suitable modulation format and the optimum parameters that achieve minimum energy consumption for a given distance between nodes.

### **Circuit Model**

In this paper, only the energy spent by the transmitter is considered, as the energy limitations of the receiver in this case are not a major concern. The circuit has three modes of operation: *on*, *transient*, and *sleep*. The *on* state is used for the transmission of information. The *sleep* state is used for saving energy and the *transient state* is a temporary one between the *sleep* and *on* states, which is used to set up the frequency synthesizer of the local oscillator. The *sleep* state has a very small power consumption compared to the other states, with the state-of-the-art hardware technology. Thus, its power is considered to be zero. The power and time spent in the *transient* state are constants for a given hardware. Consequently, our objective in this paper is precisely the minimization of the energy spent in the *on* state.

### **Two Tiered WSN Architecture**

A two-tiered WSN consists of *event aggregator relay (EAR)* nodes and sensor nodes. Sensors form a cluster around each *EAR* node as shown in Figure 1. The *EAR* node directly collects data from sensors in its assigned cluster and forwards the data towards the base station. Within a cluster, sensors communicate with the *EAR* node through different pairs of FDMA/TDMA channels, so there is no co-channel interference between sensors in one cluster. The network lifetime depends on the lifetime of each cluster. In this study, we try to balance the distribution of energy consumption within each cluster. Assume that *EAR* nodes have access to much larger energy source than the sensor nodes, so we focus on the energy consumption of the sensors due to data transmission to *EAR* nodes. By definition, a cluster is at the end of its lifetime when the percentage of live sensors in the cluster falls below a specified threshold such that the cluster can no longer satisfy the required quality of sensing for its coverage area. To increase a cluster's lifetime, the energy consumption in each sensor should be reduced. Energy dissipation due to data transmission is a large percentage of the overall energy consumption within the sensors.

**Energy Efficiency**

Using a log-distance path loss model, the required energy per transmitted bit in the *i*th sensor node may be written as:

$$e_{Tx}(i) = k_{Tx} \cdot E_b \cdot (4\pi d_{e(i),i} / \lambda_w)^{\beta_{e(i),i}} \text{-----}(1)$$

where  $k_{Tx}$  is a constant coefficient, which depends on the antenna gain and the output amplifier efficiency of the sensor as well as the receiver Noise Figure of the *EAR* node.  $E_b$  is the needed energy per bit at the receiver in order to satisfy a desired maximum bit error rate (BER) requirement.  $d_{e(i),i}$  and  $\beta_{e(i),i}$  denote the distance and the path loss exponent between sensor *i* and its assigned *EAR* node  $e(i)$ , respectively.  $\beta_{e(i),i}$  depends on the environment and is typically between 2 and 5, whereas  $\lambda_w$  denotes the signal wavelength.

**BER VS Eb/No**

(Proakis, 2007; Xiong, 2000) explained the various digital modulation schemes its performance over different channel conditions. For any modulation scheme, the bit error rate

can be characterized as a function of  $E_b/N_0$ , which is ratio of the energy per bit to the noise power spectral density. For a given  $E_b/N_0$ , there can be a large difference between the required BER of different modulation schemes and vice versa. (Rappaport, 1996) .The comparison for BPSK and MSK for AWGN channel is shown in figure2. Here the value of BER is assigned to be 0.001% and the corresponding  $E_b$  value is found from the graph.

The choice of digital modulation scheme will significantly affect the characteristics, performance and resulting physical realisation of a communication system. An energy efficient modulation scheme for wireless sensor networks is chosen by the aid of BER Vs  $E_b/N_0$  plot using MATLAB.

There is no universal 'best' choice of scheme, but depending on the physical characteristics of the channel, required levels of performance and target hardware trade-offs, some will prove a better fit than others. Consideration must be given to the required data rate, acceptable level of latency, available bandwidth, anticipated link budget and target hardware cost, size and current consumption. The physical characteristics of the channel are it hardwired without the associated problems of fading, or a mobile communications system with fast changing multipath, will typically significantly affect the choice of optimum system. The objective of this paper is to review the key characteristics and salient features of the main digital modulation schemes used, including consideration of the receiver and transmitter requirements.

The comparison for MSK and QAM for AWGN is shown in figure 3.

**Homogenous Modulation**

In homogenous modulation scheme a unique power efficient modulation technique is used for all the sensor nodes. In this scenario BPSK modulation has been used in all sensors. BPSK has the advantage of being very simple to generate, simple to demodulate and has constant envelope. Significant disadvantages, however, are the poor spectral efficiency and BER performance. Despite of simplicity, the use of same modulation scheme over the entire

network will adversely affect the energy efficiency of the network and subsequently the network lifetime will be reduced.

**Heterogeneous Modulation**

In heterogeneous location-aware Modulation BPSK modulation is used for the centrally located sensors that are within 50 meters from their assigned *EAR* node. The rest of the sensors that are located more than 50 meters from the *EAR* node use the MSK modulation. This is an example implementation of our proposed location-aware modulation selection methodology.

There is also a trade-off between modulation power efficiency versus the receiver complexity and bandwidth efficiency. Therefore, using the most power efficient modulation for all sensors in the network may not be desirable. Hence we prefer heterogeneous modulation for better performance of the wireless sensor network.

The bandwidth efficiency can further increased by using GMSK modulation. GMSK can be viewed as either frequency or phase modulation. The phase of the carrier is advanced or retarded up to 90 degree over the course of a bit period depending on the data pattern, although the rate of change of phase is limited with a Gaussian response. The net result of this is that depending on the Bandwidth Time product (BT), effectively the severity of the shaping, the achieved phase change over the bit may fall short of 90 degree. This will obviously have an impact on the BER, although the advantage of this scheme is the improved bandwidth efficiency.

**Simulation setup**

In this study, we randomly place 1600 sensors using a two-dimensional uniform distribution. The sensors are divided into four clusters with *EAR* nodes placed in the centre of each cluster. The path loss exponent,  $\beta = 3$ , frequency  $f = 3\text{MHz}$ ,  $K_{TX} = 1$ ,  
 Velocity =  $3 \times 10^8$  m/s, Signal wavelength  $\lambda_w = c/f$

For our simulation purposes, different modulation schemes are considered in the area, namely, BPSK, QAM, MSK and GMSK. To achieve 0.001% BER, the required *Eb/No* for

these modulations can be obtained. The value of *Eb/No* for different modulation scheme is determined from the BERvs *Eb/No* graph for a predetermined value of BER. Here BER is taken as  $10^{-5}$ . Using a log-distance path loss model, the required energy per transmitted bit in the *i*th sensor node can be calculated from equation (1).

**Lifetime**

Bhardwaj and Chandrakasan (2002) defined the network lifetime as the time span from the sensor deployment to the first loss of coverage. Yunxia Chen and Qing Zhao (2005) defined Network lifetime as the time span from the deployment to the instant when the network is considered non-functional, for example the instant when the first sensor dies, a percentage of sensors die, the network partitions, or the loss of coverage occurs.

**Extended Lifetime**

The results show that our proposed location-aware heterogeneous modulation scheme using MSK improves the network lifetime by 23.5% compared to a homogeneous modulation scheme using DQPSK. Further, GMSK has improved spectral efficiency than MSK. These results clearly demonstrate how selecting heterogeneous modulations in the network can balance the energy dissipation in different sensors within a cluster, and thereby, increase the cluster lifetime, and subsequently, the WSN lifetime.

Table 2 shows the improved energy gain (%) of MSK with respect to DQPSK, DBPSK and BPSK. The results show that MSK is more energy efficient than other combination of modulation schemes.

In this study, 1600 sensors placed using a two-dimensional uniform distribution in a 200x200 m<sup>2</sup> field .The sensors are divided into four clusters with *EAR* nodes placed in the centre of each cluster. The packet size is set to 128 bytes, while the average sensing rate is 0.6 kb/s. The initial battery energy level of each sensor is 2 kJ. There are a total of 500 TDMA/FDMA channels (in 10 frequencies and 50 time slots) for each *EAR* node so as to avoid any co-channel interference. For each channel, the bit

rate is set to 40 kb/s. The path loss exponent is set to 3.

### **Conclusion and Future works**

This paper presents how the homogenous and heterogeneous modulation scheme can improve the energy efficiency and bandwidth efficiency of a clustered wireless sensor network. Distance based homogenous and heterogeneous modulation scheme may be implemented in combination with other energy efficient techniques in different layers in order to improve the network lifetime. The future work is to determine the strategies to further improvement in sensor node lifetime and to increase the overall performance of transmission schemes for fault tolerant energy efficient clustered wireless sensor network.

### **References**

- Maryam Soltan, Inkwon Hwang and Massoud Pedram, (2008)** "Modulation-Aware Energy Balancing in Hierarchical Wireless Sensor Networks" in proceedings of 3<sup>rd</sup> International Symposium on Wireless Pervasive Computing.
- Maryam Soltan, Inkwon Hwang, and Massoud Pedram (2008)** "Heterogeneous Modulation for Trading-off Energy Balancing with Bandwidth Efficiency in Hierarchical Sensor Networks" Proceedings of the 2008 International Symposium on a World of Wireless, Mobile and Multimedia Networks.
- Padmavathy and Chitra, M. (2010)** "Performance Evaluation of Energy Efficient Modulation Scheme and Hop Distance Estimation for WSN" International Journal of Communication Networks and Information Security (IJCNIS), Vol. 2, No. 1, pp.44-49.
- Rehna Raj, Maneesha Ramesh, V. and Sangeeth Kumar, (2008)** "Fault Tolerant Clustering Approaches in Wireless Sensor Network for Landslide Area Monitoring" in Proceedings of the International Conference on Wireless Networks (ICWN'08), Vol. 1, pp. 107-113
- Yunxia Chen and Qing Zhao (2005)** "On the Lifetime of Wireless Sensor Networks" IEEE Communications letters, vol. 9, No. 11
- Felipe M. Costa and Hideki Ochiai (2010)** "A Comparison of Modulations for Energy Optimization in Wireless Sensor Network Links" in proceedings of IEEE Globecom conference.
- Mhatre, V. P. Rosenberg, C. Kofman, D. Mazumdar, R. and Shroff, N. (2005)** "A minimum cost heterogeneous sensor network with lifetime constraint," IEEE Transactions on Mobile Computing, Vol. 4, No.1, pp. 4-15.
- Iranli, A. Maleki, M. and Pedram, M. (2005)** "Energy-efficient strategies for deployment of a two-level wireless sensor network" in proceeding of SLPED, pp. 233-238.
- Soltan, M. Maleki, M. and Pedram, M. (2007)** "Lifetime-aware hierarchical wireless sensor network architecture with mobile overlays" in proceeding of IEEE Radio and Wireless Symposium, pp. 325-328.
- Proakis, J.G. (2007)** "Digital Communications", McGraw-Hill Inc., Fifth Edition.
- Xiong, F. (2000)** "Digital Modulation Techniques", Artech House.
- Bhardwaj, M and Chandrakasan, A.P (2002)** "Bounding the Lifetime of Sensor Networks Via Optimal Role Assignments," in Proceedings of the 21st IEEE INFOCOM.
- Rappaport, T. S. (1996)** Wireless Communications, Principles and Practice, Prentice Hall.

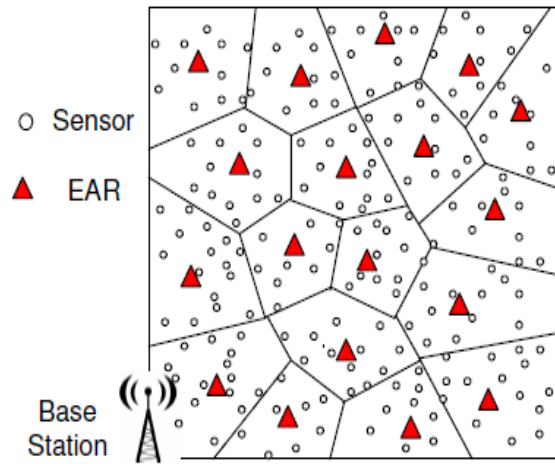


Figure-1 Two Tiered WSN Architecture.

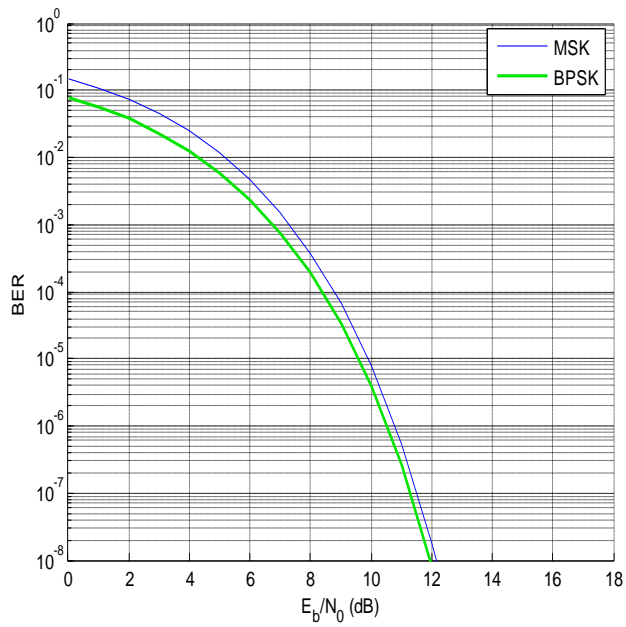


Figure-2 BER VS  $E_b/N_0$  for MSK and BPSK

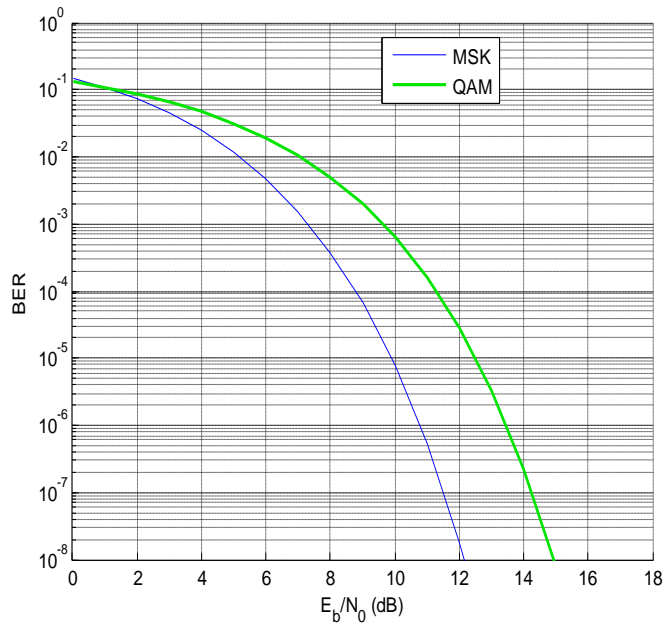


Figure-3 BER VS  $E_b/N_0$  for MSK and QAM

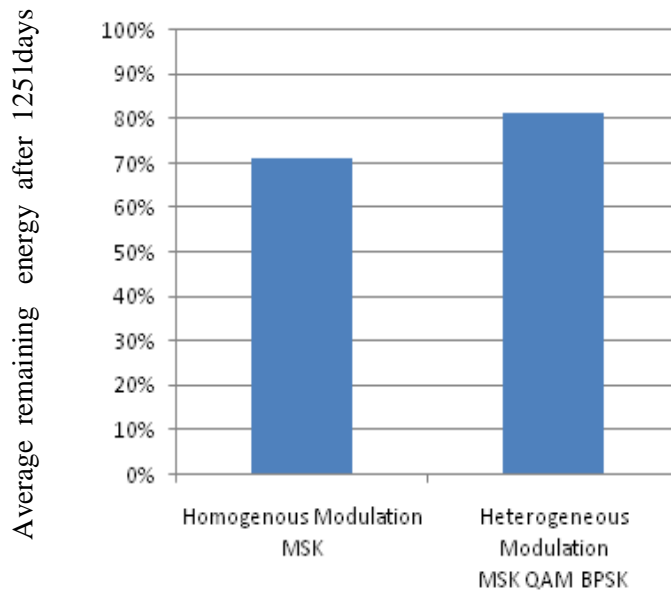


Figure-4 Average remaining energy over initial energy after 1251 days



**Table-1** The value of Eb/No at BER=.001% for different modulation schemes.

	BPSK	QAM	GMSK	MSK
Eb/No (dB)	9.8	13	14.5	9.2

**Table-2** Improved Energy gain of MSK with respect to other modulation schemes.

	DQPSK	DBPSK	BPSK
Improved Energy Gain(%) of MSK Compared with other modulation. Schemes	23.5%	12.5%	6%

**Table-3** Energy and Lifetime Results

	Homogenous modulation (MSK)	Heterogeneous modulation (MSK QAM and BPSK)
Average remaining energy over the initial energy after 1251 days	71% (2% Dead)	82.5% (0% Dead)
Life Time (2% dead sensors)	1251 DAYS	2103 DAYS