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Adaptive Modulation for Wireless Sensor Networks

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***Abstract*—There are many variants of modulation techniques used in transceivers of Wireless Sensor Network nodes based on the application for which the nodes are deployed. The option of modulation is based on the channel environment, distance, encoding, etc. By varying the modulation technique in a periodic manner with the analysis of those parameters, an appreciable link quality could be produced. Nowadays as the number of nodes in sensor network is drastically increased that requires good link quality. Considering more parameters in the sensor nodes increases the design complexity of the sensor nodes. This paper provides an easier and effective way of choosing on the modulation technique while maintaining good link quality. This eliminates the complex design while implementing adaptive modulation scheme.**

Keywords—adaptive modulation, probability of error, cluster head, signal to noise ratio

I. Introduction

Adaptive modulation is a technique which modifies the modulation scheme based on the characteristics of the transmission channel and or the throughput requirement of the user. The adaptive modulation is widely used in wireless communication right away from the 3rd generation systems. This technique has a significant benefit of keeping the throughput at an appreciate level. The throughput is measured in terms of probability of error. Hence by keeping the minimum probability of error one could achieve the excellent throughput. Further, the adaptation provides an average higher spectral efficiency. One important thing to be noted is that channel estimation. If the channel information is not known the channel impulse response can be estimated by suitable methods. This should be done carefully and there should not be ambiguous in estimating delay. This can be facilitated by a suitable closed loop control system.To optimize the energy consumption in the WSN there is a usage for adaptive modulation in which the lifetime of [1] the WSN is improved.

Adaptive modulation requires many parameters to be optimized for selecting the modulation techniques. These parameters may be required data rate, transmission power, and fading conditions, bit error rate, signal to noise ratio and encoding schemes [5]. One of the simplest and the powerful technique is choosing the modulation based on the signal to noise ratio and bit error rate. This could cover almost all the other parameters. Moreover including all those parameters for a node in sensor network requires complex design of transceivers in nodes which makes node a bulkier one. Most of the nodes are required to be designed as compact nodes. The sensor network must have the nodes equipped with limited power consumption. A suitable energy efficient modulation is required to extend the battery life of the node.

In this paper we present a systematic method of setting a wireless sensor network scenario and assigning the modulation technique by sensing the signal to noise ratio and bit error rate instantaneously.

The paper is organized as follows. The section II describes the methodology used in this work to achieve the minimum probability of error criteria. Section III presents the probability of error for various modulation techniques that can be used in the wireless sensor network. Simulation methodology is discussed in section IV. Simulation parameters chosen and results are provided in section V. Conclusion and future work are presented in the chapter VI.

II. Implementing Adaptive Modulation

A. Nodes deployment

The deployment of nodes is the first step in this work. It is assumed that initially the nodes are not supporting the mobility. They are fixed nodes, however the placement of nodes is random with Gaussian distribution.

B. Clustering

There are numerous algorithms available in literatures to perform the clustering on the wireless sensor nodes. Basically the clustering is done based on the density of nodes in particular region of the simulation area taken. Also it takes into account the signal to noise ratio at the receiver nodes.[1] In this paper the entire simulation area is divided as a square grid. The square grid is the simple shape; sometimes hexagonal shape is also preferred. Cluster head is selection procedure is another research area where there are many works available. In this paper the cluster head is assigned to a node which is nearest to the center of the cluster grid. This could be the optimum method for any shape of the cluster.

C. SNR estimation

The nodes are allowed to transmit the information to the cluster head. At the cluster head, the received power is estimated by using the Friis Transmission formula.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \quad (1)$$

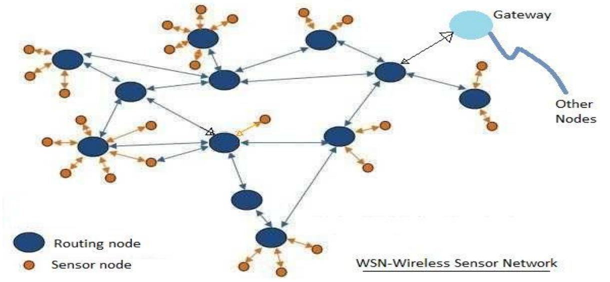


Fig. 1. WSN with Cluster heads

With the knowledge of the received power the received SNR is calculated. It assumes the gain of the transmitter antenna and receiver antenna is unity or 0 dB. This simplifies the calculation. Here there is no adaptation in operating carrier signal's frequency, so a carrier frequency of 2.4GHz is taken for estimating the received power.

D. Selection of modulation

The modulation is selected based on the SNR value. For a particular range of signal to noise ratio one sort of modulation is selected. This further requires the calculation of the BER for the range of SNR value. [4] The next section provides the details of the BER as a function of SNR to be used for making the BER limitation criteria. The calculation of BER is done for one round trip. Based on the value of the BER the modulation is chosen for the next round trip. For each round trip the BER is estimated.

III. DIGITAL PASS BAND MODULATION

The theoretical formulation of bit error rate for the modulation schemes used in adaptive modulation is presented in this section. It assumes the AWGN channel as the channel environment. The noise is additive in nature with the channel samples follow the Gaussian distribution given by

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}}\, e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{2}$$

With zero mean and variance of noise is N0/2 the probability density function is given as

$$p(x) = \frac{1}{\sqrt{\pi N_0}} e^{-\frac{x^2}{N_0}} \tag{3}$$

The most simple digital pass band modulation used in wireless communication is binary phase shift keying (BPSK). Implementing BPSK is even more simple. Let s1 and s0 are the transmitted symbols for binary 1 and 0 respectively. The received symbols y = s1+n and y = s0 + n when bit 1 is transmitted and bit 0 is transmitted respectively.

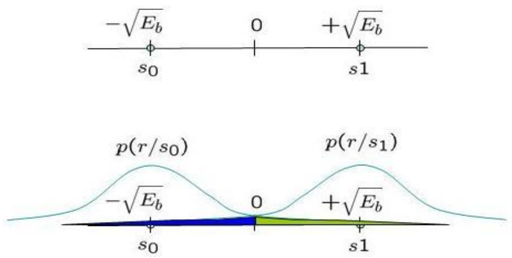


Fig. 2. BPSK decision region

The conditional probability distribution function (PDF) of y for the two cases are:

$$p(y|s_0) = \frac{1}{\sqrt{\pi N_0}} e^{\frac{-(y+\sqrt{E_b})^2}{N_0}} \tag{4}$$

$$p(y|s_1) = \frac{1}{\sqrt{\pi N_0}} e^{\frac{-(y-\sqrt{E_b})^2}{N_0}} \tag{5}$$

The threshold is set at 0 and if y >0 the output is decoded as S1 which is binary 1 and if y < 0 the decoded output is binary zero.

Probability of error given s1 was transmitted is

$$p(e|s1) = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{6}$$

Where erfc is the complementary error function

The probability of error is the sum of the two types of error conditions. The other error condition is that the symbol s0 was transmitted. For both the cases the error probability is same as (6) because they have same probability of occurrence. It results the probability of bit error rate is

$$\mathrm{P_b} = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{\mathrm{E_b}}{\mathrm{N_0}}}\right) \tag{7}$$

The next modulation preferred is QPSK in which two sinusoids quadrature to each other are taken as basis functions to do the modulation. Each symbol is mapped to represent 2 bits.

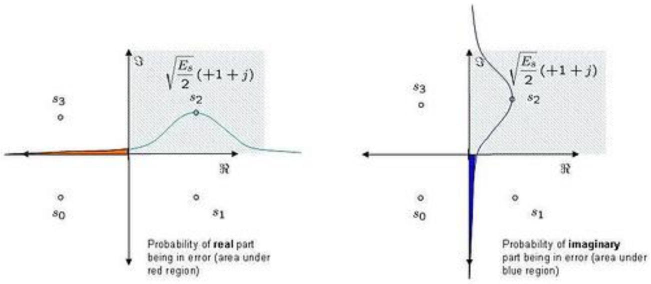


Fig. 3. QPSK decision region

The probability of symbol error is given as

$$\mathrm{P_{QPSK}} \approx \mathrm{erfc}\left(\sqrt{\frac{\mathrm{E_s}}{\mathrm{N_0}}}\right) \tag{8}$$

Quadrature Amplitude Modulation (QAM) is another familiar digital modulation technique used in wireless communication. This modulation technique is a combination of both Amplitude and phase modulation techniques. QAM is better than QPSK in terms of data carrying capacity.

QAM takes benefit from the concept that two signal frequencies; one shifted by 90 degree with respect to the other can be transmitted on the same carrier. For QAM, each carrier is ASK/PSK modulated. Hence data symbols have different amplitudes and phases.

Probability of error of M-ary QAM modulation is given as

$$\mathrm{P_{(e,M-QAM\,)}} = 2\left(1-\frac{1}{\sqrt{\mathrm{M}}}\right)\mathrm{erfc}\left(\mathrm{k}\sqrt{\frac{\mathrm{E_s}}{\mathrm{N_0}}}\right) - \left(1-\frac{2}{\sqrt{\mathrm{M}}} - \right.$$
1Merfc2kEsN0 (9)

Sometimes M-ary PSK modulations can also be used in wireless communication for its constant amplitude property.

For large value of SNR the symbol error rate for equally likely, coherent detectedM-ary PSK is given [6]

$$P_E(M) \approx 2Q\left(\sqrt{\frac{2E_s}{N_0}} \sin\frac{\pi}{M}\right) \quad (10)$$

Here Es is the energy per symbol. The probability of symbol error for M-ary PSK is given in Fig. 4 for various values of M.

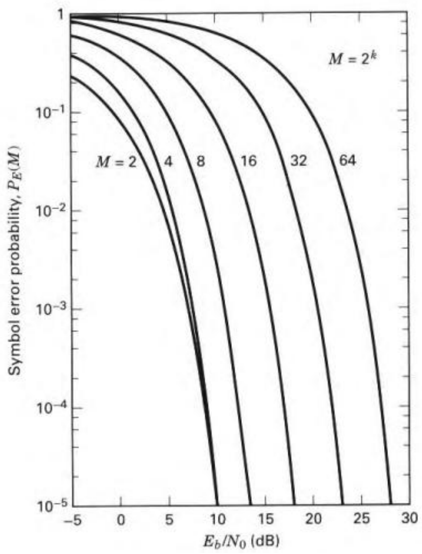


Fig. 4. SER of M-ary PSK

IV. Simulation Methodology

The simulation assumes a wireless sensor network scenario with clusters having square shape. The cluster head is selected based on the distance with the center of the square cluster.

The simulation takes the number of clusters or grid size and the number of wireless nodes as the input parameters. It first affixes the cluster head. Then it calculates the distance between the cluster head and nearby nodes within the cluster. Based on the distance the received power from the nodes are calculated at the cluster head by using the Friis formula.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi D}\right)^2 \quad (11)$$

Where

P_R = received power at cluster head, in Watt
P_T = transmitted power by sensor node, in Watt
G_T = Gain of transmit antenna,
G_R = Gain of receive antenna,
λ = wavelength, in meter
D = Distance between the Cluster Head and node, in meter

In the previous section the probability of error is obtained in terms of error function. In the simulation the probability of error is taken in terms of Q-function. Both results in the same value.

Probability of bit error for BPSK

$$P_{e,BPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad (12)$$

Probability of bit error for QPSK is given by

$$P_{e,QPSK} = 2\,Q\left(\sqrt{\frac{E_b}{N_0}}\right) \quad (13)$$

Probability of bit error of QAM of square constellation with M x M constellation points (generalized)

$$P_{e,QAM} = \frac{4(\sqrt{M}-1)}{\sqrt{M}\log_2 M} Q\left(\sqrt{\frac{3\left(\frac{E_b}{N_0}\right)\log_2 M}{(M-1)}}\right) \quad (14)$$

The Probability of bit error for 16 QAM is simplified as

$$P_{e,16-QAM} = 0.75\,Q\left(\sqrt{0.8\,\left(\frac{E_b}{N_0}\right)}\right) (15)$$

The Probability of bit error for 64 QAM is simplified as

$$P_{e,64-QAM} = \left(\frac{7}{12}\right) Q\left(\sqrt{\frac{2E_b}{7N_0}}\right) (16)$$

The equations 11, 12, 14 and 15 are used in the simulation to calculate the probability of bit error for the adaptively chosen modulation. In those equations the term Eb/N0 denotes the ratio of energy per bit to noise power spectral density, which is taken as the signal to noise ratio at the cluster head. In the next section the simulation results are presented.

V. Simulation Results

The WSN scenario is simulated using MATLAB with the following specifications. The simulation area is 100m x 100m and it can be divided into any arbitrary number of square grids. For the sample simulation the area is divided as 5x5 square grids. It has 25 squares arranged as a grid which covers the entire simulation area. (Fig. 5) The transmit power of node is taken as 50 milliwatt and the environment noise is chosen to be -160 dB. Those parameters are taken from the sensor node's data sheet.

The simulation area is assumed to be a terrain as a farm field. There are 500 nodes to be deployed (as a sample scenario). The nodes are deployed in a random fashion. Also the nodes are taken to be fixed nodes without supporting the mobility. They are numbered as node-1 through node-500.

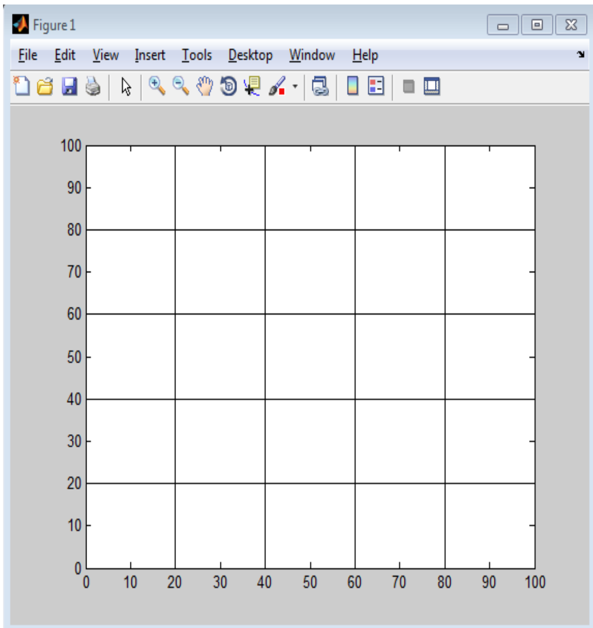


Fig. 5. Simulation area (100m x 100m)

The cluster head is chosen as a node which is located most close to the center of the cluster. The cluster heads are numbered corresponding to the column wise cluster cell counting. It is highlighted as filled circles. (Fig. 7)

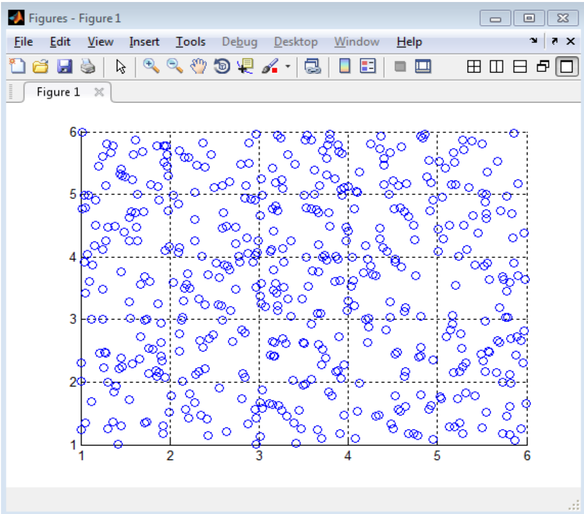


Fig. 6. Random deployment of 500 Nodes

The distance between the cluster heads and the nodes connected with them are calculated. The criteria for a node to be connected to a cluster head is that the node must lie within circle of radius equal t half of the diagonal of the square cluster.

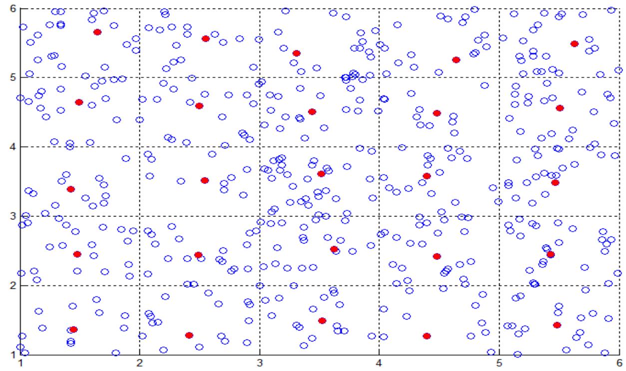
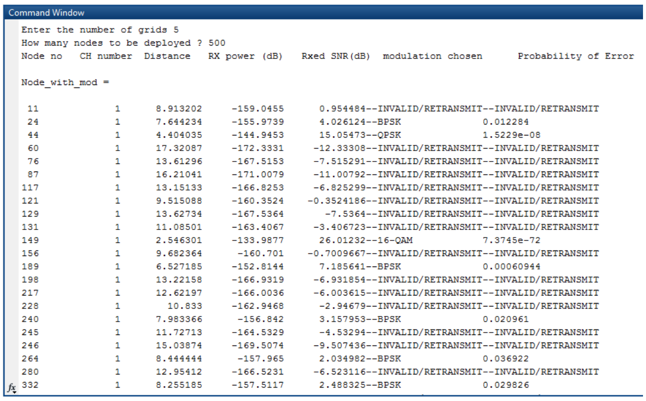


Fig. 7. Cluster Head

After calculating the distance between the nodes and the cluster head to which the nodes are connected, the received power, received signal to noise ratio at cluster head are evaluated.

Based on the range of SNR values, the modulation are adaptively chosen and this is indicated to the node by the cluster head. For the next round trip the node will chose the modulation specified by the cluster head to that particular node.



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Command Window
Enter the number of grids 5
How many nodes to be deployed ? 500
Node no   CH number  Distance   RX power (dB)   Rxed SNR(dB)  modulation chosen      Probability of Error

Node_with_mod =

 11         1      8.913202   -159.0455     0.954484--INVALID/RETRANSMIT--INVALID/RETRANSMIT
 24         1      7.644234   -155.9739     4.026124--BPSK              0.012284
 44         1      4.404035   -144.9453     15.05473--QPSK              1.5229e-08
 60         1      17.32087   -172.3331    -12.33308--INVALID/RETRANSMIT--INVALID/RETRANSMIT
 76         1      13.61296   -167.5153    -7.515291--INVALID/RETRANSMIT--INVALID/RETRANSMIT
 87         1      16.21041   -171.0079    -11.00792--INVALID/RETRANSMIT--INVALID/RETRANSMIT
117         1      13.15133   -166.8253    -6.825299--INVALID/RETRANSMIT--INVALID/RETRANSMIT
121         1      9.515088   -160.3524   -0.3524186--INVALID/RETRANSMIT--INVALID/RETRANSMIT
129         1      13.62734   -167.5364      -7.5364--INVALID/RETRANSMIT--INVALID/RETRANSMIT
131         1      11.08501   -163.4067    -3.406723--INVALID/RETRANSMIT--INVALID/RETRANSMIT
149         1      2.546301   -133.9877     26.01232--16-QAM            7.3745e-72
156         1      9.682364    -160.701   -0.7009667--INVALID/RETRANSMIT--INVALID/RETRANSMIT
189         1      6.527185   -152.8144     7.185641--BPSK              0.00060944
198         1      13.22158   -166.9319    -6.931854--INVALID/RETRANSMIT--INVALID/RETRANSMIT
217         1      12.62197   -166.0036    -6.003615--INVALID/RETRANSMIT--INVALID/RETRANSMIT
228         1        10.833   -162.9468     -2.94679--INVALID/RETRANSMIT--INVALID/RETRANSMIT
240         1      7.983366    -156.842     3.157953--BPSK              0.020961
245         1      11.72713   -164.5329     -4.53294--INVALID/RETRANSMIT--INVALID/RETRANSMIT
246         1      15.03874   -169.5074    -9.507436--INVALID/RETRANSMIT--INVALID/RETRANSMIT
264         1      8.444444    -157.965     2.034982--BPSK              0.036922
280         1      12.95412   -166.5231    -6.523116--INVALID/RETRANSMIT--INVALID/RETRANSMIT
332         1      8.255185   -157.5117     2.488325--BPSK              0.029826
```

Fig. 8. Node details

TABLE I. SNR VS MODULATION FOR ADAPTIVE MODULATION

S.No.	Minimum SNR or E_b/N_0 in dB	Maximum SNR or E_b/N_0 in dB	Modulation to be chosen
1	2	15	BPSK
2	16	25	QPSK
3	26	30	16-QAM
4	31	35	64-QAM

For the received SNR less than 2 dB from any node, the cluster head informs the node to retransmit with increased power.Also for the received SNR greater than 35 dB from any node the cluster head informs the node to retransmit with reduced power so as to protect the receiver circuitry. The probability of error is also calculated while using the modulation technique chosen and instructed by cluster head.

Sample results are shown below:

TABLE II. SIMULATION RESULTS

Node No	Cluster head No	Distance between CH and node (m)	RX power in dB	RX SNR in dB	Modulation chosen	Probability of error
11	1	8.91	-159.04	0.95	Invalid retransmit	--
24	1	7.64	-155.97	4.02	BPSK	0.012
55	3	4.12	-143.63	16.36	QPSK	$4.61x10^{-11}$
31	9	2.44	-133.18	26.81	16-QAM	$6.79x10^{-86}$
66	25	3.89	-142.50	17.49	QPSK	$6.57x10^{-14}$

VI. Conclusion

The simulation is carried out using MATLAB. The simulation result is presented in Table 2. It contains the details of few nodes, which includes the modulation and probability of error which using this modulation. Basically for higher signal to noise ratio values the higher order modulation techniques like M-ary PSK [2] or MQAM modulations are used. Typically they are used to support large data rates.

For lower signal to noise ratios in order to maintain the BER to be in an appreciable value the lower order modulations like BPSK, Differential PSK or QPSK are used. This technique provides very less system complexity because here only one parameter is taken as criteria for obtaining good link quality with lowest possible BER[7].

This work can be extended by including more criteria for choosing the modulation. The other parameters might be quality of service, throughput and density of nodes in a given scenario. Though it could increase the complexity and requires more battery power it provides appreciable link quality.

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