ENERGY GAIN ENHANCEMENT BY ECC CODED DATA IN WIRELESS SENSOR NETWORKS

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Abstract: **Main research in focus nowadays in the area of wireless sensor networks (WSN) is optimizing solution of energy gain. Techniques for optimizing power usage in WSNs have been developed in this paper. The goal is achieved by exploiting a decrease in cross-over distance between error correcting coded (ECC) information signals and its un-coded version. A decrease in total energy gain is observed from the practical data acquisitioning. From analysis presented in this paper, the overall 22% energy gain in ECC coded data was observed with the theoretical analysis and results obtained using MATLAB. The modulation schemes under test were MPSK, MFSK and MQAM. Furthermore, the presented idea has opened ways for researchers to exploit other means to bring a decrease in cross-over distance so that further gain of energy in WSNs can be possible.**

Keywords-WSN, Cross-Over Distance, Error-Correcting Code, Reed Solomon Code, MPSK, MQAM, MFSK

I. INTRODUCTION

Wireless sensor networking is an emerging field of wireless communication. With the advent of technology these sensor networks have a wide range of applications in military and civil areas. Sensor nodes are miniature size, low cost and low power devices mainly deployed for the surveillance and data monitoring of different environmental or chemical/biological processes in extreme conditions. Minimum energy consumption is a critical issue in these low powered sensor nodes. Communication between nodes is either coded or un-coded based upon the severity of error prone conditions and distance between them. The coded term in this paper refer to error correcting coding (ECC) which is directly applied to information signal. RS (Reed-Solomon) encoded scheme is used as error correcting code. In short range, it is always preferable to use un-coded transmitted signal to avoid energy overhead. By using Error correcting codes, energy can be conserved for long range/distant communication as compared to uncoded signal transmission. The research has been carried out to formulate ways for sensor energy consumption to minimize crossover distance (D_{xover}), discussed in [1] and [2] and also for different ECC's and modulation schemes in order to conserve energy. D_{xover} is the optimal distance at which the total energy consumption by *Tx* sensor for ECC coded signal becomes equal to the un-coded signal receiving at *Rx*, keeping sensitivity level of the receiver constant. The purpose of minimizing D_{xover} is that the energy consumption due to ECC encoding scheme decline off its higher D_{xover} counter-part which makes ECC to be the ideal choice to be used under process. Moreover, [6] and [9] shows the conditions of achieving efficient ECC which is an essential review in possibility of new idea discussed in this paper.

Different minimum distance sensitivity aspects are discussed in [2,6] showing dependency of minimum possible distance between two sensors upon certain defined conditions which means D_{xover} cannot be fixed without taking these aspects into account. Practical results in this paper shows an overall 22% decrease in energy consumption by minimizing cross-over distance for ECC coded scheme.

II. EXPERIMENTAL ANALYSIS

An experiment was conducted in order to find ways to compute minimum possible D_{xover} such that a decrease in total energy consumption due to exploiting ECC encoding scheme can be possible. During the experiment, A transmitting data source *Tx* was assumed to transmit a recorded EEG (Electro-Encephalo-Graph) encoded data. The system that exploits *Tx* sensor exploits Tyndall 25mm motes (Atmel mega128 process). Similarly, center carrier frequency f_c is allowed to vary in order to observe the best optimized solution.

Moreover, wireless NI data acquisition card along-with *Rx* sensor was used at receiving end to acquire received signal. Data acquisition card works in two folds. First, it receives the encoded information signal and secondly, its function is to acquire the total energy consumption information of the whole system.

We have compiled results on practical data using MATLAB to calculate the minimum cross over distance. A sample example of the mentioned solution is shown in Figure 1 and Figure 2. Figure 2 shows a decrease in D_{xover} showing an overall energy gain as compared to the case shown in Figure 1.

978-0-7695-4927-9/12 $26.00 © 2012 IEEE
DOI 10.1109/FIT.2012.11

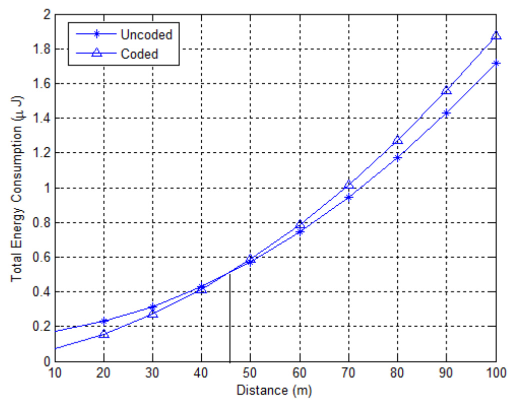

Figure 1. Regression Performed at Practical Acquired Data Before Applying Optimization

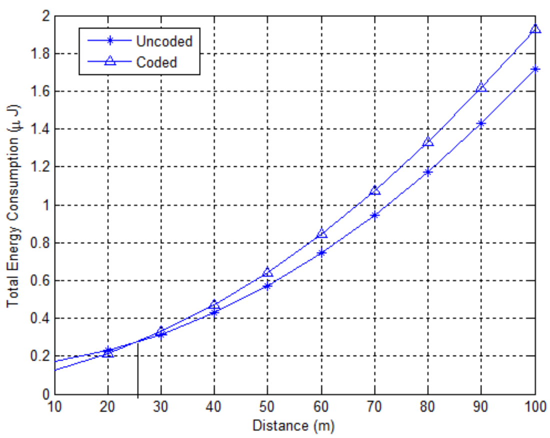

Figure 2. Regression Performed at Practical Acquired Data After Applying Optimization.

Before discussing the sensor node energy model, some important aspects of the modulation schemes need consideration. There is a short literature review of the said discussion.

MFSK stands for M-Ary frequency-shift keying which use represents data as a function of M-Ary frequecies. In this scheme each symbol consists of one element from an alphabet of orthogonal waveforms. M, the size of the alphabet, is usually a power of two so that each symbol represents $\log_2 M$ bits.

MPSK stands for M-Ary Phase Shift Keying. In this modulation scheme data is encoded by changing phase of the reference signal (The carrier signal) with constant amplitude. PSK uses a finite number of phases; each assigned a unique pattern of binary bits. Each phase encodes an equal number of bits and each pattern of bits forms the symbol that is represented by the particular phase. The demodulator, which is designed specifically for the symbol-set used by the modulator, determines the phase of the received signal and maps it back to the symbol set, thus recovering the original data. In MPSK constellation set can be represented as a circle of equidistant constellation points. The number of points and the angular difference between them depend on the value of M.

The last used modulation scheme is MQAM (M-Ary Quadrature Amplitude Modulation). In MQAM modulation schemes, the information is encoded in both the amplitude and the phase of the transmitted signal. Therefore, the constellation set of MQAM can have any shape depending on the allocation of the constellation points.

III. SENSOR NODE ENERGY MODEL

The node energy per bit for uncoded ($E_{node\ uncoded}$) and error-encoded transmission system exploiting Reed-Solomon (RS) code (E_{node_coded}) suggested in [1] simply suggested coded system for distance greater than D_{xover}. Energy node equations for un-coded and error-encoded systems are shown in (1) and (2) respectively.

$$E_{node\_uncoded} = \frac{(1+\alpha)P_{sig}T_{on}+P_{ckt}T_{on}\frac{N}{K}+LE_{com}\frac{N}{K}}{L} \quad (1)$$

$$E_{node\_coded} = \frac{(1+\alpha)P_{sig}T_{on}+P_{ckt}T_{on}}{L} \quad (2)$$

Where α relates inversely to the drain efficiency η as $\eta = 1/(1+\alpha)$, discussed in [5]. Drain efficiency is the ratio of output power to DC input power. Moreover, P_{sig} is the power consumed due to transmitting signal whereas P_{ckt} is the power consumed due to circuit element. In WSN the signal transmission is ON occasionally when power transmission is required or that the transmission is required after regular amount of time called sampled time. In all the mentioned cases ON-time of the sensing device cannot be neglected if energy conservation is concerned. T_{on} is considered for this purpose which is the Steady-State ON-Time. Other parameters as mentioned in (1) and (2) are shown below:

E_{com} = Energy Consumed during numerical computation.

L = Total number of transmitting bits

N = Total number of encoded bits including original bits and additional K bits.

In Figure 1 and 2 we have compiled the practical data and a comparison is demonstrated about the gain in energy due to decrease in D_{xover}; specifically ECC, and Un-coded node. Our purpose is to shift D_{xover} such that it moves to backward direction so that ECC becomes the leading and efficient technique throughout the course of distance. Keeping BER constant at D_{xover}, the node energy of coded and uncoded systems becomes equal as shown in (3).

$$E_{node\_uncoded} = E_{node\_coded} \quad (3)$$

Using (1), (2) and (3) we get:

$$D_{xover} = \left(\frac{P_{ckt}T_{on}\left(\frac{N}{K}-1\right)+LE_{comp}\frac{N}{K}}{\left(\frac{4\pi}{\lambda}\right)^2 \frac{(1+\alpha)SNR_{uncoded}}{2G_rG_t} bBN_oNFT_{on}\left(1-\frac{1}{CG}\right)} \right)^{1/n} \quad (4)$$

Where

$$P_{sig} = \left(\frac{4\pi}{\lambda}\right)^2 d^n \frac{P_r}{G_r G_t} \qquad (5)$$

Here d is the distance between transmitter and receiver, λ is the wavelength of the transmitted signal, P_r is the received signal power, G_r and G_t are the receiver and transmitter antenna gains respectively, n is the path loss factor, b is the resolution bits per modulation symbol, B is the channel bandwidth, N_0 is the received signal noise spectral density, NF is the receiver noise figure and CG is the coding gain [1]. The transmitter ON duration time, T_{on} used in (4) is different for different modulation techniques.

In Figure 3, a relation is derived between D_{xover} and energy consumption for coded and Un-coded transmission between two sensor nodes separated distance apart about few meters. If the D_{xover} can be brought further close then the energy consumption can be reduced further if coded transmitted signal is used for communication.

Table 1. ON-Duration of a node for different modulation techniques

Modulation Technique	T_{on}
MPSK	L/bB
MQAM	L/2bB
MFSK	2^bL/bB

Keeping f_c constant. In MFSK, the D_{xover} significantly decreases with resolution bits per symbol (b) whereas there is a slight decrease in the case of MPSK and MQAM. The effect is shown in Figure 3.

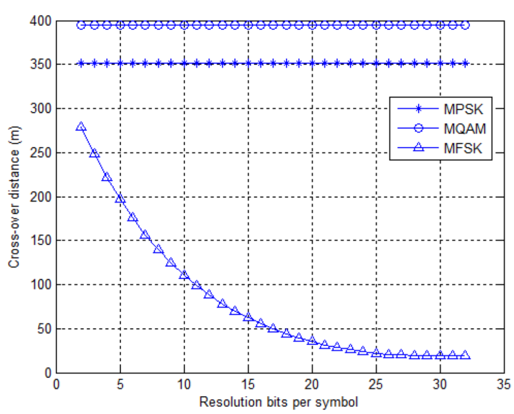

Figure 3. Crossover distance vs. resolution bits per symbol for MPSK, MQAM and MFSK modulation schemes.

IV. OPTIMIZING D_{XOVER} AS A FUNCTION OF f_c

In the case of increasing f_c keeping b constant, there is a significant D_{xover} decline if all the three modulation schemes, namely MPSK, MQAM and MFSK are used. Figure 4 demonstrates the mentioned effect. Similarly, it is shown that the modulation schemes play a very important role in obtaining an optimized D_{xover} value. Practical demonstration results from MATLAB shows that MPSK is the worst modulation scheme as compared to MQAM and similarly MQAM is the worst modulation scheme as compared to MFSK from the optimization point of view. Keeping f_c and b constant, the MFSK shows lower D_{xover} value and hence an optimized energy gain as compared to MQAM and MPSK modulation schemes.

A series of experiments are conducted to demonstrate all possible effects. Figure 4 and Figure 5 shows that a change in D_{xover} trend is unaffected for the modulation schemes of MPSK and MQAM if b is increased from 2 to a limited value of 16. Concentrating upon MFSK modulation scheme, Figure 4 shows that there is a significant change in D_{xover} as compared to b=16 in Figure 5. This effect shows that the change in D_{xover} is insignificant for higher values of b.

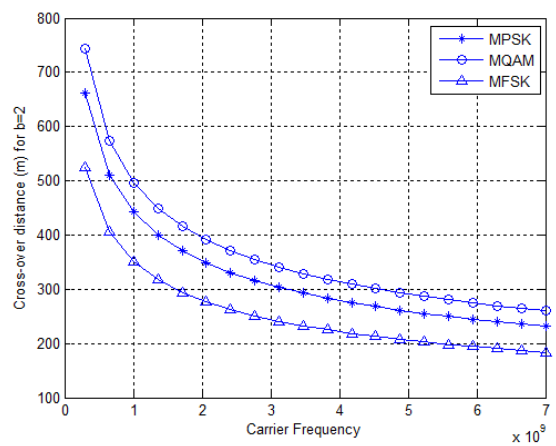

Figure 4. Cross-Over distance estimation for two resolution bits per symbol.

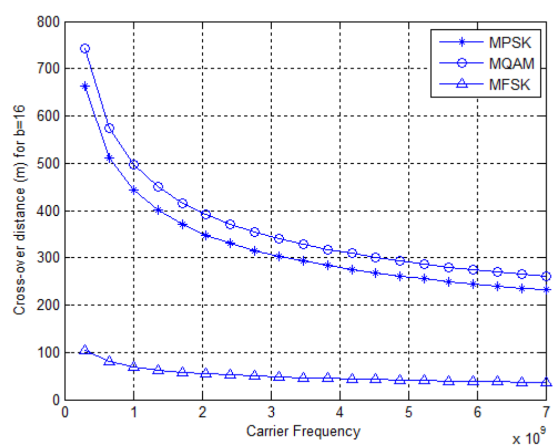

Figure 5. Cross-Over distance estimation for sixteen resolution bits per symbol.

Figure 6 shows a 3-dimensional relationship between carrier frequency (f_c), Resolution bits per symbol (b) and cross over distance (D_{xover}). Figure 6 shows all the concluded remarks about Figure 4 and Figure 5 in the single demonstration.

In figure 7, 3-dimensional relationship of f_c, b, and D_{xover} has been mapped to 2D XZ-plan which shows that an increase in b shows a significant change in D_{xover} if MFSK is used as modulation scheme whereas MQAM and MPSK shows no change throughout keeping f_c constant.

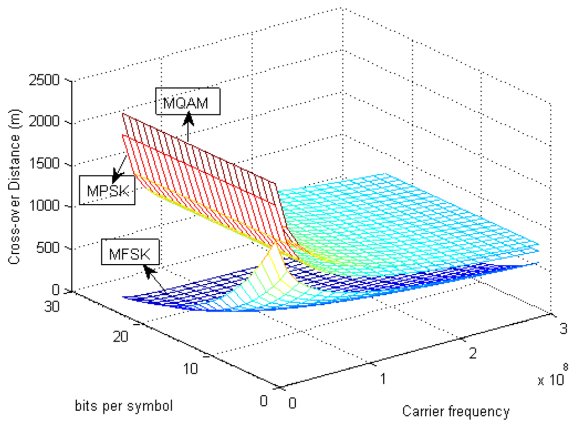

Figure 6. D_{xover} characteristics for MPSK, MQAM and MFSK modulation techniques.

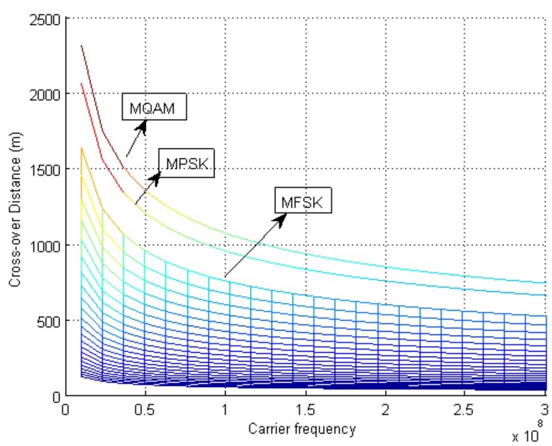

Figure 7. Characteristics in regard to MPSK, MQAM and MFSK showing XZ-Plane of 3D graph in Figure 6.

V. OPTIMIZING D_{XOVER} AS A FUNCTION OF t

Error correcting capability t of a channel code is the capability of the encoded scheme to correct the received erroneous information. For RS encoding scheme, incorporating error correcting capability t in MFSK, MPSK and MQAM for constant b, the cross over distance D_{xover} is comparably less in MFSK than remaining techniques used.

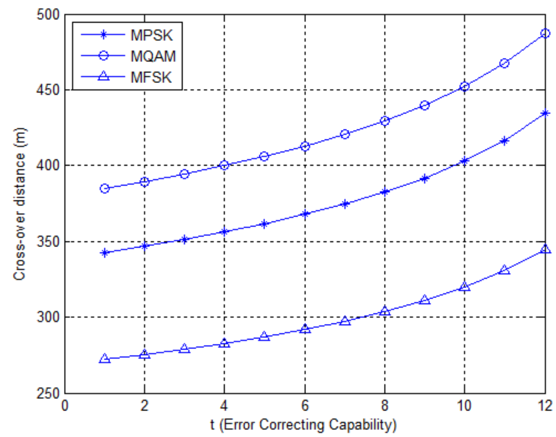

Figure 8. Cross-Over distance estimation for two resolution bits per symbol.

Figure 8 demonstrates the dependability of D_{xover} w.r.t error correcting capability t for all the mentioned modulation schemes namely MPSK, MQAM and MFSK. It is shown that D_{xover} increases with an increase of t. From Figure 8 and Figure 9 it can be confirmed that the overall trend of D_{xover} decreases with an increase in b, two mentioned cases for b=2 and b=16 are shown in Figure 8 and Figure 9 respectively.

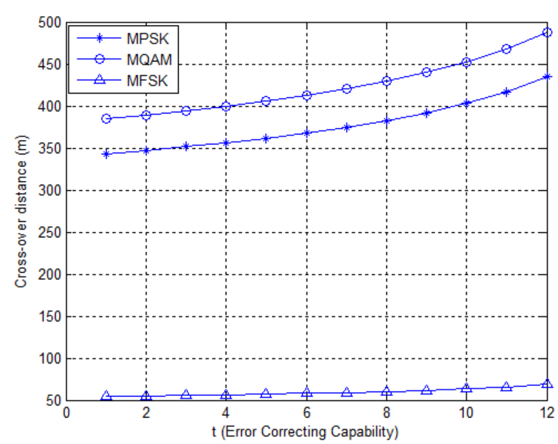

Figure 9. Cross-Over distance estimation for sixteen resolution bits per symbol.

Figure 9 shows that trend of D_{xover} w.r.t t is almost constant at higher value of b which has the limited value of 16.

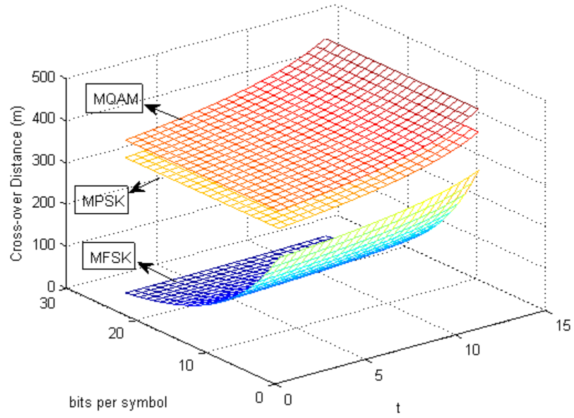

Figure 10. 3D view of D_{xover} dependability upon b and t

Figure 10 shows a 3D view of D_{xover} dependability upon b and t and hence show how the trend values vary with the mentioned variables. Figure 11 demonstrates XZ-plane of the 3D view in Figure 10 to show dependability of D_{xover} upon b and hence it is construed that the D_{xover} trend w.r.t b does not change for MPSK and MQAM modulation schemes.

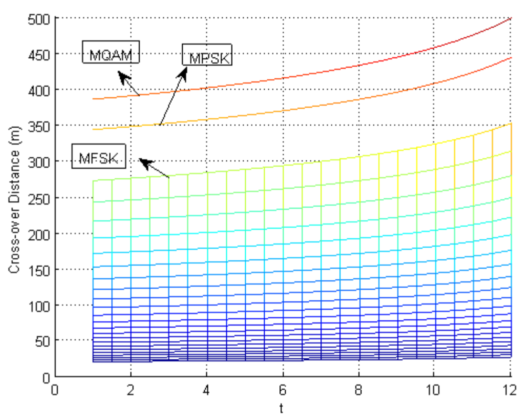

Figure 11. Characteristics in regard to MPSK, MQAM and MFSK showing XZ-Plane of 3D graph in Figure 10.

VI. CONCLUSIONS AND FUTURE WORK

Various simulation results are presented in this paper to calculate the optimal D_{xover} value for a number of modulation techniques with respect to different number of resolution bits per symbol b, a range of carrier frequencies fc and the error correcting capability t. MPSK, MQAM and MFSK are the modulation schemes used under test. Based on the required calculations and simulations presented, it is concluded that the change in the value of resolution bits per symbol b brings about a significant change in characteristics of D_{xover} if MFSK is used as modulation scheme and no significant change was noticed in the behavior of D_{xover} incase of MQAM and MPSK modulation schemes keeping f_c and t constant. Similarly, other related changes in D_{xover} were observed in previous two sections. Using all the modulation techniques mentioned, a threshold was suggested to keep b no more than 24 as increasing b beyond 24 do not decline D_{xover} further but instead it is responsible for extra energy consumption.

Of all the mentioned modulation schemes in use, MPSK technique is worst of all with the same values of b and f, whereas the best modulation technique is MFSK and it is said to be the excellent modulation technique with the larger possible values of b independent of f, provided that the maximum possible value of b in our case is 24. It is further concluded that the D_{xover} in MPSK and MQAM modulation techniques changes constantly with respect to the carrier frequencies keeping b constant, whereas using the MFSK modulation technique, the change in D_{xover} with respect to carrier frequencies decreases if b is increased. From the above mentioned observations and conclusions, it is suggested to adopt MFSK modulation technique for a higher possible value of b, 24 in our case. The points mentioned below shows vacant space in the field presented in this paper that need utilization in future:

I. Practical data presented in this paper shows the similar gain in energy consumption but unlike theoretical simulation the exact 22% gain wasn't observed, which means there must be some additional work to be done in order to track out the possible causes of degradation.

II. Other factors need consideration to bring a decrease in cross-over distance so that further optimization can be possible in future.

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