Performance Comparison of QAM and ASK with Minimum Energy Coding in Phase Coded SSMA for Wireless Sensor Network

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Abstract: Source coding with spread spectrum technique for reducing multiple access interference (MAI) in phase coded SSMA for ASK and QAM in wireless sensor network has been presented in this paper. The source symbol is represented by modified minimum energy coding (MME) for both ASK and QAM. When each channel uses MME coding combined with phase coded SSMA the probability of error of multiple channels sending signals at the same time is lowered in QAM as compared to ASK, this implies that the MAI is reduced. It has been analysed that with the new low MAI with MME coding, signal to noise ratio significantly increases while error probability decreases in both ASK and QAM and no another differences is founded. Finally, a sensor network system is designed and simulated to verify the theoretical results and demonstrate the low MAI and low energy features of wireless sensor network

Key words: amplitude modulation, amplitude shift keying, low complexity, modified minimum energy coding, phase coded SSMA, power control, quadrature.

I. INTRODUCTION

There is an increasing need for short range low power multiple access wireless communication .Today, the wireless devices are tiny and can be placed in the human body and micro machines, places where traditional RF and IR devices cannot be used.This will open up new possibilities for wireless local area networks. Low power wireless networking is still a challenging problem, however, Bluetooth is an ambitious technology, but its power consumption of around 30 mW is too high to power the device with a small cell battery. A regular size battery limits its form factor. Furthermore Bluetooth still has a major difficulty in MAI,causing a serious delay of delivery.MAI reduction has been studied extensively in the academia in conjunction with phase coded SSMA for ASK. Theoretical analysis revealed that the average bit error probability sharply increases as the channel number increases in DS-CDMA system with BPSK modulation [9].In the past decade, numerous methods for MAI cancellations and reduction have been developed [2], [5]-[6], [9], [13], [16]most of which focus on the design of effective correlation receivers [16].

II. SYSTEM MODEL

The sensor node architecture and phase coded SSMA for communication are considered in this section. Energy consumption model and signal model are also discussed for system analysis in [16].

A. Architecture of a Sensor Node

A tiny sensor node has typically four components as in [16] a sensing module, processing (computing) module, a communication module and a power module.It may have application specific components such as a location finding module, solar power generator. The sensing module is composed of two subunits: analog sensor and analog-to-digital converter (ADC). It detects analog signal, and feeds digitally converted data to processing module. The processing module controls all the other components in a node and contains microprocessor or microcontroller and storage subunit(s). The communication module connects the node to network and performs physical, MAC layer operations. In [9] we assume this module has transceiver only. Thus, MME coding takes place at the processing module, and communication module deals with phase coded SSMA. The last and may be the most important one is a power module. It contains battery and DC-DC converter and supplies power to the rest of the node [4].

During the operation of a tiny sensor node, most of power is consumed in communication. The average energy consumption of radio communication can be modelled as

$$\begin{aligned} E_{radio} &= \tilde{E}_{tx} + \tilde{E}_{rx} \\ &= [P_{tx-ckt}(T_{on-tx} + T_{startup}) + P_t T_{on-tx}] \\ &\quad + P_{rx-ckt}(T_{on-rx} + T_{stsrtup}) \end{aligned} \tag{1}$$

Where, $\tilde{E}_{tx/rx}$ is average energy consumption of a sensor node while transmitting/receiving, $P_{tx/rx-ckt}$ is the power consumption of the electronic circuits while transmitting/receiving, P_t is the output transmitter power, $T_{on-tx/rx}$ is the transmitter/receiver on-time, and $T_{startup}$ is the start-up time of the transceiver [18]. Since $P_{tx-rx/ckt}$ and $T_{startup}$ are determined by hardware characteristics equation (1) can be further simplified as

$$E_{tx=} = P_{tx-ckt} T_{on-tx} + P_t T_{on-tx} \tag{2}$$

$$E_{rx} = P_{rx-ckt} T_{on-rx} \tag{3}$$

Where, $E_{tx/rx}$ denotes the average energy consumption which is manageable by MME coding and phase coded SSMA scheme.

B. Signal Model

*W*e consider an asynchronous phase coded SSMA system with MME coding of K users in local area as shown in fig. (1). The local area can be a cluster as proposed in [3] and the system model and analysis follow reference [9], [10], [16].

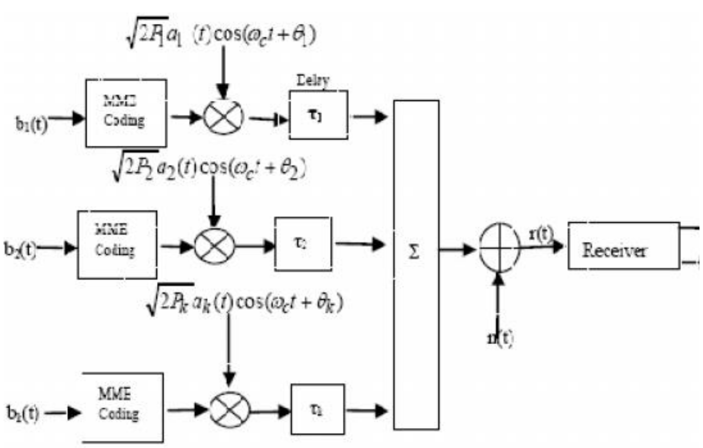

Fig. 1. *Phase* coded SSMA *combined with MME coding*

As show in fig. (1)the transmitted signal for K users is given

$$S_k(t) = \sqrt{2P_k}\, d_k(t) a_k(t) \cos(\omega_c t + \theta_k) \tag{4}$$

Where

$$d_k(t) = \sum_{j=-\infty}^{\infty} d_j^{(k)} p_{T_b}(t - jT_b)$$

Where, $d_j^{(k)}$ is the data bit, $d_j^{(k)} \in \{0,1\}$,T_b is the bit duration, and $p_\tau(t)$ is a rectangularpulse which are $p_\tau(t) = 1$ for $0 \le t < \tau$ and $p_\tau(t) = 0$ otherwise .

In the above expressions θ_k represents the phase of the k-th carrier, ω_c, represents the common centre frequency, and P_k represents the common signal power. The results that follow can easily be modified for unequal centre frequencies and power levels.

If the SSMA system is completely synchronized, then the time delays τ_k shown in the model of Fig. (1)can be ignored (i.e., $\tau_k = 0$ for k = 1, *2, ..* , K).This would require a common timing reference for the *K* transmitters and it would necessitate compensation for delays in the various transmission paths. This is generally not feasible and hence the transmitters are not time-synchronous. For asynchronous systems the received signal r(t)in Fig. (1)is given by

$$r(t) = \sum_{k=1}^{k} \sqrt{2P_k}\, a_k(t-\tau_k)\cos(\omega_c t + \phi_k) + n(t) \tag{5}$$

Where, $\phi_k = \theta_k - \omega_c \tau_k$ and *n(t)* is the channel noise process which we assume to be a white Gaussian process with two sided spectral density $N_0/2$.Since we are concerned with relative phase shifts modulo 2π and relative time delays modulo T,there is no loss in generality in assuming $\theta_i = 0$ and $\tau_i = 0$ and considering only $0 < \tau_k < T$ and $0 < \theta_k < 2\pi$ for k # i.

If the received signal r(t)is the input to a correlation receiver matched to $s_i(t)$ **,** the output of user 1is

$$Z_1 = \int_0^T r(t) a_1(t) \cos \omega_c t\, dt \tag{6}$$

$$Z_1 = D_1 + I_1 + \eta_1 \tag{7}$$

D_1= desired signal for user 1

I_1= Interferences from other users

η_1=AWGN with variance $N_0 T_b/4$.

$$D_1 = \sqrt{\frac{P_1}{2}} T\, d_0^{(1)} \tag{8}$$

$$I_1 = \sum_{k=2}^{k} \sqrt{\frac{P_k}{2}} \left[d_{k,-1} R_{k,i}(\tau_k) + d_{k,0} \hat{R}_{k,i}(\tau_k) \right] \cos \phi_k \tag{9}$$

$$\eta = \int_0^{T_b} n(t) a_1(t) \cos \omega_c t\, dt \tag{10}$$

Where, $R_{k,i}$ and $\hat{R}_{k,i}(\tau)$ are the continuous-time partial cross correlation functions defined by

$$R_{k,i}(\tau) = \int_0^{\tau} c_k(t-\tau)c_i(t)\,dt \quad (11)$$

$$\hat{R}_{k,i}(\tau) = \int_{\tau}^{T} c_k(t-\tau)c_i(t)\,dt \quad (12)$$

The ME coding and MME coding reduce the interference term in (9) thus improve the performance shown in section 4.0

III. SYSTEM PERFORMANCE EVALUATION

The system performance in the sense of probability of bit error and power consumption is analysed in this section. In order to do the required analysis, SNR of the MME Phase Coded SSMA system is derived first.

A. Signals-To-Noise Ratio (SNR)

Signal-To-Noise ratio is defined as the ratio of signal power to the variance of noise Z_1.

$$\text{SNR}=\frac{P_{D!}}{\sqrt{\operatorname{var} Z_1}} \quad (13)$$

$$P_{D_1}=\frac{1}{T}\int_0^T\left(\sqrt{\frac{P_1}{2}}T_b d_0^{(1)}\right)^2 dt=\frac{\alpha_1 P_1}{2}T^2 \quad (14)$$

Where, α_1 is the rate of high bits for $d_1(t)$ during the MME symbol period $T = LT_b$. The noise power consists of MAI term and Gaussian noise term as defined in (5). The interference term I_1 are random and are treated as additional noise as in [10]. Thus the variance of the noise component of Z_1 can be expressed as:

$$\operatorname{var}(Z_1) = \sum_{k=2}^{K}\frac{P_k}{4T}\int_0^T\left(R_{k,1}^2(\tau)+\hat{R}_{k,1}^2(\tau)d\tau+\frac{\alpha_1^2 N_0 T}{4}\right)$$

$$= \sum_{k=2}^{K}\sum_{l=0}^{N-1}\frac{\alpha_1\alpha_k P_k}{4T}\int_{lT_c}^{(l+1)T_c}\left(R_{k,1}^2(\tau)+\hat{R}_{k,1}^2(\tau)\right)d\tau+\frac{\alpha_1^2 N_0 T}{4} \quad (15)$$

$$= \frac{T^2}{12N^3}\sum_{k=2}^{K}\alpha_1\alpha_k P_k r_{k,1}+\frac{\alpha_1^2 N_0 T}{4} \quad (16)$$

We assume that power control is used and the probability of transmitting high bits for each transmitter is the same as in [9] i.e. $P_1 = P_2 = : : : = P_K = P_t$ and $\alpha_1 = \alpha_2 = \ldots\ldots = \alpha_K = \alpha$. Under these conditions, the SNR can be expressed by the equation (13) is:

$$\text{SNR}=\left[\alpha\left(\frac{K-1}{3N}+\frac{N_0}{2E_b}\right)\right]^{-\frac{1}{2}} \quad (17)$$

B. Probability of Error

The error probability of MME codeword is analysed in this subsection. Since the decoding process is performed on a sub frame basis, the decoding of the indicator bit is very important. The symbol error rate can be expressed as:

$$P_S(\varepsilon) = 1-\Pr(no\ error)$$
$$= 1-\prod_{j=0}^{N_S-1}\overline{P}_j(\varepsilon)$$
$$= 1-\left(1-P_{sf}(\varepsilon)\right)^{N_s} \quad (18)$$

Where, $\overline{P}_j(\varepsilon) = 1-P_j(\varepsilon)$ is the probability of correct decoding of j^{th} sub frame.

IV. BER PERFORMANCE

A. Amplitude Shift Keying

As discussed earlier that the bit error rate (BER) can be deliberately reduced by using minimum energy (ME) and modified minimum energy coding (MME) using on off keying (OOK).By analyzing the graph shown in fig.(2) we can say that the minimum energy (ME) and modified minimum energy coding (MME) using on off keying (OOK) have better bit error rate (BER) performance than the conventional DS-CDMA system that uses BPSK. The conventional DS-CDMA system using BPSK means rate of high bits (α) =1 which is shown in fig. (2). Another discussion which has been done is better performance of modified minimum energy coding (MME) over minimum energy (ME) coding and the results are shown in fig. (2) that bit error rate (BER) in modified minimum energy coding (MME) coding is lesser than minimum energy (ME) coding for all α . Also as discussed earlier that as the rate of high bits (α) decreases the bit error rate (BER) both in modified minimum energy coding (MME) coding and minimum energy (ME) coding decreases [16].

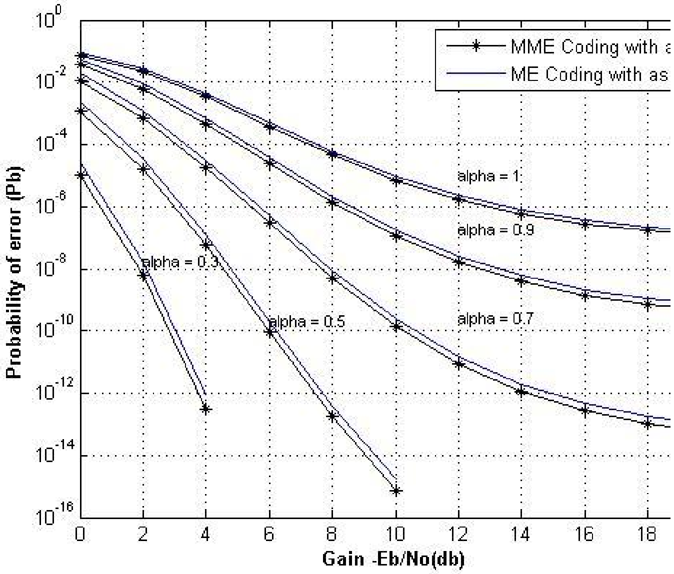

Fig.2 Results of bit error rate of MME coding and ME coding with ASK

B. Quadrature Amplitude Modulation

By analyzing In [18] the graph of QAM as the gain increases for different value of alpha the probability of error increases that means as alpha is increased the probability of error also increases ,otherwise if we decrease the value of alpha or number of high bite probability of error decreases but for the value of alpha =0.3 the probability of error in QAM is less than as compared to probability of error in ASK as shown in fig. (2)

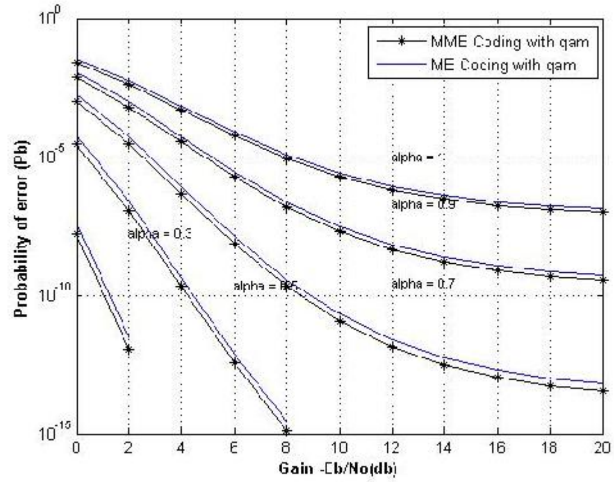

Fig.3Results of bit error rate of MME coding and ME coding with QAM

V. POWER CONSUMPTION

MME coding reduces energy consumption for receiving data. The energy gain of MME to ME coding is shown in fig. (4) and it can be represented as:

$$\rho = \frac{E_{rx}^{ME}}{E_{rx}^{MME}} = \frac{T_{on-rx}^{ME}}{T_{on-rx}^{MME}} = \frac{L}{N_s\left[L_s(1-(1-\alpha)^{L_s-1}) + (1-\alpha)^{L_s-1}\right]} = \left(1 + \frac{1-L_s}{L_s}(1-\alpha)^{L_s-1}\right)^{-1} \quad (19)$$

VI. CONCLUSION

In this paper, phase coded SSMA with modified minimum energy coding has been proposed for ASK and QAM and analysed using MATLAB. Results indicate that MME coding greatly reduce both multiple access interference and transmit

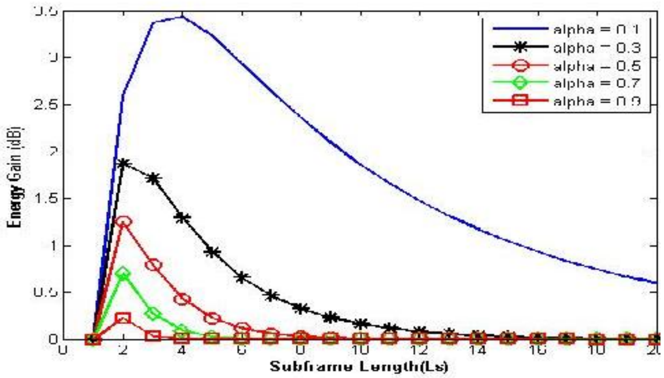

Fig.4 Results of received energy gain of MME coding relative to ME coding

energy of phase coded SSMA system for ASK and QAM modulation, their results are compared as shown in fig. (2) and fig. (3) for the different value of alpha at gain=2db, it has been seen thatthe value probability of bit error of QAM is less as compared to ASK with low MAI , it means as increasing the value of gain the probability of bit error is less for QAM as compared to ASK using MME coding as compared to the previously proposed systemwithout MME coding scheme [5], [10]-[11], [19].

Finally, it is concluded that when MME coding is combined with each modulation schemes i.e. QAM and ASK it achieves more energy saving at both the transmitter and receiver by partitioning the code word into several sub frame using indicator bits. The MME coding also improves BER performance dues to the reduced MAI and achieves power gain at the expense of codeword length i.e. bandwidth. However, the bandwidth increased can be justified because the power constraints are much more important than bandwidth constraints in wireless tinny sensor network. In other words, combining MME and phase coded SSMA is an attractive choice for wireless tiny sensor networks, in the context of total system energy saving and improved BER performance.

Table – Comparison of different modulations and error control codes

S.No.	Modulation	Codes	Performance parameters	Overall system performance	Channels		Simulation
					AWGN	Rayleigh	
1	BPSK QPSK 16QAM 64QAM	Convolutional	SE BLER	Good system performance		✓	MAT LAB
2	BPSK QPSK 16QAM 64QAM	RS	BER	Efficient physical layer design	✓		MAT LAB
3	BPSK QPSK 16QAM 64QAM	RS BCH	BER Power	Better, energy efficiency	✓		MAT LAB
4	BPSK QPSK	RS FEC	Energy Frame loss	Suitable for mobile Sensor	✓		MAT LAB

	16QAM 64QAM	ARQ	rate Frame PSNR	Networks			
5	QPSK 16QAM	HARQ	Code rate SINR gain	Efficient error control mechanism	✓		MAT LAB
6	QPSK 16QAM	BCH RS Convolution	BER	BCH code comparatively better than other codes	✓		MAT LAB
7	MPSK MQAM MFSK	BCH RS Convolutional	BER Energy Lifetime	Suitable for short distance communication	✓		MAT LAB
8	16QAM 8PSK BPSK	Turbo	Avg throughput FER SNR	The maximum Avg throughput achieved	✓		MAT LAB
9	8PSK 16QAM	Extended BCH	BER	Multistage decoding and modulation used	✓		MAT LAB
10	ASK or OOK	ME coding	BER SNR	Reduced transmit power & increased receiver power consumption	✓		MAT LAB
11	ASK or OOK	MME coding	BER SNR	Reduced transmit power & decreased receiver power consumption	✓		MAT LAB
12	QAM ASK	MME coding	BER SNR	DO Decreased BER in QAM Total system energy saving & improved BER performance	✓		MAT LAB

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