PROBABILISTIC APPROACH FOR MODIFIED MINIMUM ENERGY CODING WITH PHASE CODED SSMA

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ABSTRACT
Source coding with spread spectrum technique for reducing multiple access interference (MAI) in phase coded SSMA wireless sensor network has been presented in this paper. The source symbol is represented by modified minimum energy coding (MME). 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, 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. 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.

Keywords: *Modified minimum energy coding, phase coded SSMA, power control, low complexity.*

1. 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, 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. A theoretical analysis revealed that the average bit error probability sharply increases as the channel number increases in DS-CDMA system with BPSK modulation [1]. In the past decade, numerous methods for MAI cancellations and reduction have been developed; most of them focus on the design of effective correlation receivers. In Verdu et al., 1986 [13]; Varanasi et al., 1990 [12] a receiver that outperforms the linear correlation receivers is reported. However, these receivers involve a significant increase in complexity. For example, the computational complexity of the proposed receivers in Verdu et al.**,** 1986 [13] grows exponentially with the number of users. In Liu et al., 2002 [8] the total energy consumption $E_{total} = E_{ts} + E_{rs}$ may not be reduced by ME coding; however in some cases it may be increased.

In Fischione et al, 2009 [6] DS-CDMA with MME coding and OOK modulation is analyzed by another method and improved BER performance due to the reduced MAI and achievement of power gain at the expense of code word i.e. bandwidth is reported. However, the bandwidth increases can be justified because the power constraint is much more important than the bandwidth constraint in a wireless sensor network. Due to the modulation technique used the whole system becomes more complex and require more processing T_{on} so require more total energy (E_{total}) at the expense of bandwidth. In this paper a scheme with MME coding and phase coded SSMA is proposed and analyzed.

2. 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.

2.1 ARCHITECTURE OF A SENSOR NODE
A tiny sensor node has typically four components as shown in figure 1 a sensing module, processing (computing) module, a communication module and a power module (Raghunathan et al., 2002 [10]; Akylidiz et al., 2002 [2]; Wang et al., 2002 [14]). 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 (Liu et al., 2002 [8]) 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 (Fischione et. al 2006 [5]). During the operation of a tinny sensor node, most of power is consumed in communication. The average energy consumption of radio communication can be modelled as

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

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, $T_{\text{on-tx/rx}}$ is the transmitter/receiver on-time, and $T_{startup}$ is the start up time of the transceiver (Shih et al., 2001 [11]). Since $P_{tx-rx/ckt}$ and $T_{startup}$ are determined by hardware characteristics equation (1) can be further simplified as

$$E_{tx=} = P_{tx-ckt}\ T_{on-tx} + P_t T_{on-tx} \quad (2)$$

$$E_{rx} = P_{rx-ckt} T_{on-rx} \quad (3)$$

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

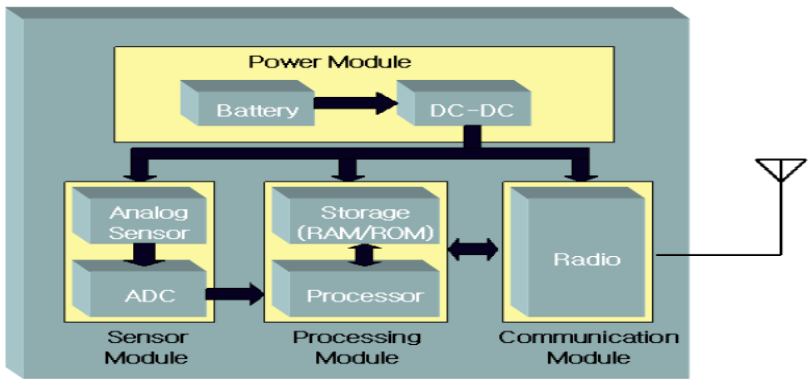

Figure 1: Architecture of a sensor node

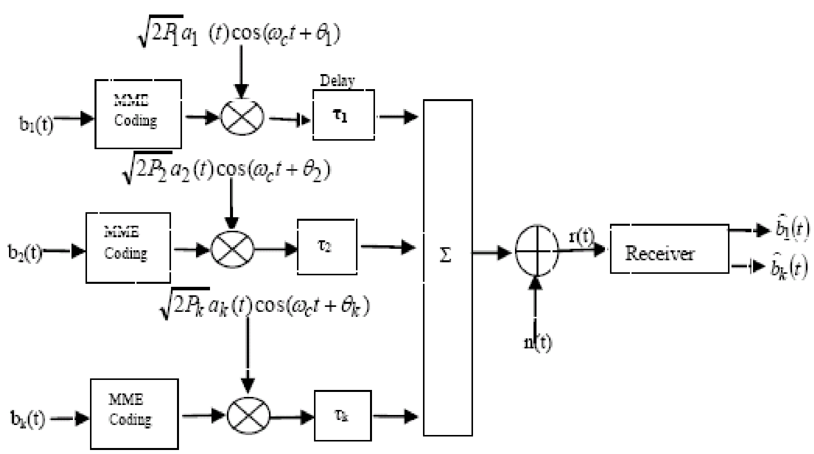

Figure 2: Phase coded SSMA combined with MME coding

2.2 SIGNAL MODEL

We consider an asynchronous phase coded SSMA system with MME coding of K users in local area .The local area can be a cluster as proposed in (Heinzelman et al., 2000 [4]) and the system model and analysis follow reference (Liu et al., 2002 [8]; Pursley, 1977 [9]).

As show in figure 2 the transmitted signal for K users is given

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

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, $d_j^{(k)} \epsilon \{0,1\}$,T_b is the bit duration, and $p_\tau(t)$ is a rectangular pulse 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 Figure 2 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 Figure 2 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, $\o_k = \theta_k - \omega_c\tau_k$ 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 $N_0T_b/4$.

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

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

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

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

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

$$\hat{R}_{k,i}(\tau) = \int_\tau^{0} c_k(t-\tau)c_i(t)dt \tag{12}$$

The ME coding and MME coding reduce the interference term in (9) thus improve the performance shown in section 4.

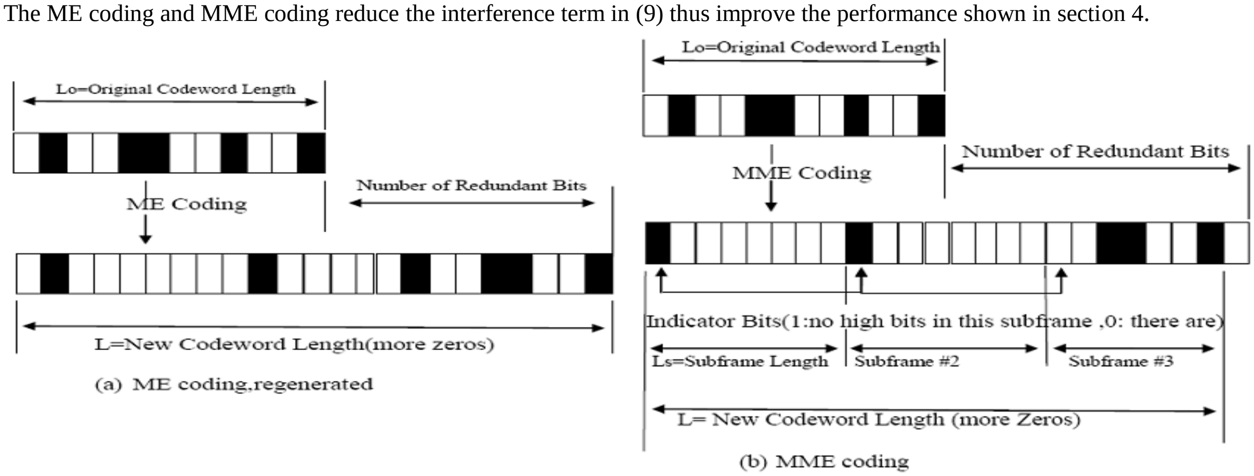

Figure 3: Comparison of ME coding and MME coding

3. MODIFIED MINIMUM ENERGY CODING (MME)

The principle of MME coding is depicted in figure 3. Unlike the ME coding, MME codeword is composed of several sub frames. The first bit of each sub frame indicates if there is one or more high bits in that sub frame, i.e.

$$b_{K,ind}(l) = \begin{cases} 1, & \text{If no high bits in the subframe} \\ 0, & \text{If at least one high bits in the subframe} \end{cases}$$

Where l is bit index of k[th] user's codeword bit. The rest of the codeword is same as ME coding. The receiver first decodes the indicator bit. If it's a "1" then, the receiver doesn't decode the rest (Ls – 1) bits in the sub frame. In this case, the power required to decode a sub frame is reduced by a factor of 1/Ls. Only when the indicator bit is a "0", the receiver decodes the whole sub frame.

MME coding can increase number of high bits in a codeword up to Ns (= L/Ls) bits to that of ME codeword due to the indicator bit. But the Ton-rx is decreased to 1/Ls times of that of ME coding. From equation (3), E_{rx} is decreased accordingly. Thus if we design Ns < Ls, then the total energy $E_{total} = E_{tx} + E_{rx}$ is also reduced. Moreover, since most of operating time of sensor node is used for receiving data rather than transmitting, the MME coding can save power very efficiently. In addition, the insertion of indicator bits helps the receiver to recover the timing synchronization at the receiver.

4. SYSTEM PERFORMANCE EVALUATION

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

4.1 SIGNALS-TO-NOISE RATIO (SNR)

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

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

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

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 (Pursley, 1977 [9]). Thus the variance of the noise component of Z_1 can be expressed as:

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

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

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

We assume that power control is used and the probability of transmitting high bits for each transmitter is the same as in (Liu et al., 2002 [8]) 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)

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

4.2 PROBABILITY OF ERROR

The error probability of MME codeword is analyzed 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:

$$\begin{aligned} P_S(\varepsilon) &= 1 - \Pr(no\ error) \\ &= 1 - \prod_{j=0}^{N_S-1} \overline{P_j}(\varepsilon) \\ &= 1 - \left(1 - P_{sf}(\varepsilon)\right)^{N_s} \end{aligned} \tag{18}$$

Where, $\overline{P}_j(\varepsilon)=1-P_j(\varepsilon)$ is the probability of correct decoding of j[th] sub frame. We can assume the probability of sub frame error is same for all sub frames, i.e. $P_j(\varepsilon) = P_{sf}(\varepsilon); \forall$ j, which can be derived as follows

$$P_{sf}(\varepsilon)=\Pr(b_{ind}^{1})\Pr(Z_1<\delta\,|\,b_{ind}^{(1)})\Pr(decoding\ error)$$
$$+\Pr(b_{ind}^{(0)})[\Pr(Z_1<\delta\,|\,b_{ind}^{(0)})\Pr(decoding\ error)+\Pr(Z_1>\delta\,|\,b_{ind}^{(0)})]$$
$$=\Pr(b_{ind}^{(1)})pe(1)(1-(1-pe(0))^{L_s-1}) \quad (19)$$
$$+\Pr(b_{ind}^{(0)})[(1-pe(0))(1-(1-pe(1))^{\alpha(L_s-1)})(1-pe(0))^{(1-\alpha)(L_s-1)}+pe(0)] \quad (20)$$

Where, $b_{ind}^{(1)}$ means the indicator bit is i (i ε {0,1}), bit error probability pe(i) = Pr(ε|i is sent) and δ is the threshold for bit decision. The probabilities of the indicator bit are

$$\Pr(b_{ind}^{(1)})=(1-\alpha)^{L_s-1} \quad (21)$$
$$\Pr(b_{ind}^{(0)})=1-(1-\alpha)^{L_s-1} \quad (22)$$

The threshold δ and corresponding bit error probability for orthogonal system is given as

$$\delta=\sqrt{\frac{P_t}{2}T_b} \quad (23)$$
$$p_e=p_e(i)=Q(SNR),\quad i\ \varepsilon\ 0,1 \quad (24)$$

Where, $Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^{\infty}e^{-\frac{u^2}{2}}du$

Then the bit error rate (BER) of proposed system can be expressed as

$$P_b=\frac{P_s(\varepsilon)}{L_0} \quad (25)$$

The BER of ME coding can be shown in similar way, i.e.

$$P_{b,ME}=\frac{P_{s,ME}(\varepsilon)}{L_0}=\frac{1-(1-p_e)^L}{L_0} \quad (26)$$

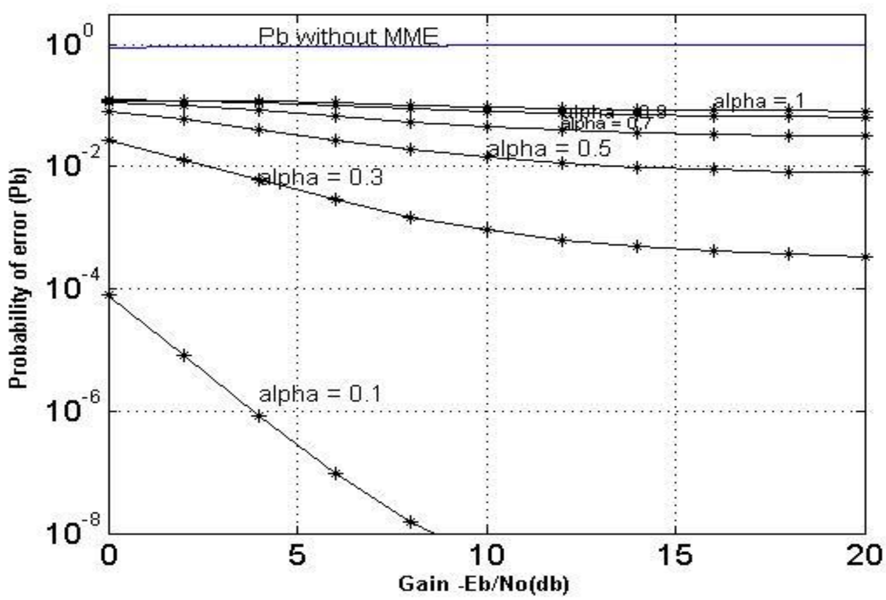

Figure 4: Results of bit error rate of MME coding and without MME coding

4.3 POWER CONSUMPTION

Besides the transmitter power P_t saving as shown in the previous subsection, MME coding reduces energy consumption for receiving data. If we suppose the required power be the same for ME and MME systems, then the ratio of energy saving is the ratio of Rx on-time as in (3). The average Rx on-time for MME coding is as follows.

$$T_{on-rx}^{MME} = N_s\left[T_b + \Pr\left(b_{ind}^{(0)}\right)(L_s - 1)T_b\right] \quad (27)$$

$$= N_s\left[1 + \left(1 - (1-\alpha)^{L_s - 1}\right)(L_s - 1)\right]T_b \quad (28)$$

$$= N_s\left[L_s\left(1 - (1-\alpha)^{L_s - 1}\right) + (1-\alpha)^{L_s - 1}\right]T_b \quad (29)$$

The decoding time for ME coding is independent with the value of α as

$$T_{on-rx}^{ME} = LT_b \quad (30)$$

Thus the energy gain of MME to ME coding is

$$\rho = \frac{E_{rx}^{ME}}{E_{rx}^{MME}} = \frac{T_{on-rx}^{ME}}{T_{on-rx}^{MME}}$$

$$= \frac{L}{N_s\left[L_s(1 - (1-\alpha)^{L_s-1}) + (1-\alpha)^{L_s-1}\right]}$$

$$= \left(1 + \frac{1 - L_s}{L_s}(1-\alpha)^{L_s-1}\right)^{-1} \quad (31)$$

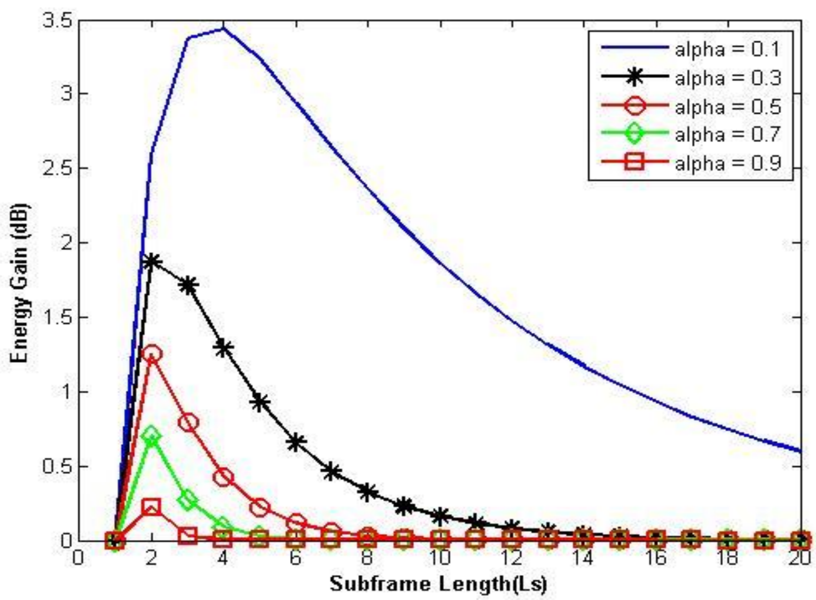

Figure 5: Results of received energy gain of MME coding relative to ME coding

5. CONCLUSION

In this paper, phase coded SSMA with modified minimum energy coding has been analyzed. Results indicate that MME coding greatly reduce both multiple access interference and transmit energy of phase coded SSMA system. Results have been compared to the previously proposed system [9] which without MME coding scheme, MME coding 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 due 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.

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7. REFERENCES

[1]. Yoon, Y. C., Kohno, R., and Imai, H. (1993): "Spread-spectrum multi-access system with co-channel interference cancellation for multipath fading channel," *IEEE J. Selected Areas Communication*, Vol. 11, No.7, pp. 1067- 1075, September 1993.

[2]. Akylidiz, I. F.; Sankara Subramaniam, W. Y.; and Cayirci, E. (2002): "A survey on sensor networks," *IEEE Communications Magazine*, pp. 102–114, August 2002

[3]. Andrew, Jaeweon Kimand Jeffrey G. **(**2005**):** "Energy Efficient Source Coding And Modulation Scheme For Wireless Sensor Network," *IEEE 6th Workshop on Signal Processing Advances in Wireless Communications*; Year: 2005

[4]. Heinzelman, W. R.; Sinha, A.; Wang, A., and Chandrakasan, A. P. (2000): "Energy-scalable algorithms and protocols for wireless micro sensor networks," IEEE Int. Conf. on Acoustics, Speech and Signal Processing' 2000, vol. 6, pp. 3722–3725, June 2000.

[5]. Fischione, C., Bonivento, A., Sangiovanni Vincentelli, A., Santucci, F., Johansson, K., H. (2006): "Performance analysis of collaborative spatio-temporal processing for wireless sensor networks," in Proc. IEEE Consumer Commun. Conference, January 2006

[6]. Fischione, C.; Johansson, K. H.; Sangiovanni Vincentelli, A.; and Zurita Ares, B. (2009): "Minimum Energy Coding in CDMA Wireless Sensor Networks" IEEE transactions on wireless communications, vol.8, no. 2, pp: 985-994; February 2009.

[7]. Fischione, C.; Zurita Ares, B.; and Johansson, K. H. (2007): "Energy consumption of minimum energy coding in CDMA wireless sensor networks," in Proc. 4th European Conf. Sensor Networks: 2007, pp: 211-227; January 2007.

[8]. Liu, C. H., and Asada, H. H. (2002): "A source coding and modulation method for power saving and interference reduction in DS-CDMA sensor network systems," American Control Conf. '2002, vol. 4, pp. 3003–3008, May 2002.

[9]. Pursley, M. B. (1977): "Performance evaluation for phase-coded spread spectrum multiple-access communication System analysis: part-I," IEEE Transactions on Communications, vol. 25, no. 8, pp. 795–799, August 1977.

[10]. Raghunathan, V., Schurgers, C., Park, S., Srivastava, M., B. (2002): "Energy-aware wireless microsensor networks," IEEE Signal Processing Magazine, vol. 19, pp. 40–50, March 2002.

[11]. Shih, E.; Calhoun, B. H., Choand S.; and Chandrakasan H. A. (2001): "Energy-efficient link layer for wireless micro sensor networks," IEEE Computer Society Workshop on VLSI '2001, pp. 16–21, April 2001.

[12]. Varanasi, M. K., and Aazhang, B. (1990): "Multistage detection in asynchronous code-division multiple access systems," IEEE Trans. Communication, vol. 38, Issue: 4, pp. 509-519, April 1990.

[13]. Verdu, S. (1986): "Minimum probability of error for asynchronous Gaussian multiple-access channels," IEEE Trans. Inform. Theory; vol.: 32, pp. 85-86, January 1986.

[14]. Wang, A. Y., and Chandrakasan, A. P. (2002): "Energy efficient DSPS for wireless sensor networks," IEEE Signal Processing Magazine, pp. 68–78, July 2002.