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Determination of the Optimal Receive Energy Gain of MME to ME coding for Wireless Sensor Networks

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Abstract – Wireless sensor networks (WSNs) are composed of numerous battery limited sensor nodes communicating wirelessly. Since replacing or recharging batteries of the nodes is hard for most of the applications, energy efficiency is crucial importance parameter for WSN design. There are many studies including protocols and coding schemes about energy efficiency of WSNs in the literature. Thanks to its simplicity, On-Off Keying (OOK) is one of the most preferred modulation types for WSNs. Minimum Energy (ME) coding scheme is proposed in order to improve energy efficiency of OOK transmitter. When ME coding is employed with OOK modulation, its aim is to reduce energy consumption in digital transmitters. MME coding scheme is a variant of the ME coding. It aims at reducing energy consumption further with sleep policies at the receiver. ME and MME coding schemes have similar bit error probabilities, but MME outperforms ME only in the case of low data rate and large codewords. In this study, an analytical expression is derived for the optimal value of receive energy gain for MME to ME coding in WSNs.

Keywords – Wireless Sensor Networks, ME Coding, MME Coding, Energy Gain

I. INTRODUCTION

Wireless sensor networks (WSNs) consist of many energy constrained sensor nodes and recharging or replacing the batteries of the nodes is not possible in most of the applications. Therefore, energy efficient solutions are required. There are numerous kinds of coding schemes proposed in the literature. When the energy constraints of the sensor nodes and the power consumption number of complex codes are considered, the codes with lower complexity should be preferred.

Minimum Energy Coding (ME) and Modified Minimum Energy Coding (MME) are techniques used to reduce the power consumption of digital circuits. They achieve this by minimizing the switching activity in a circuit, which is the number of times a circuit's outputs change state., ME and MME are typically used in digital signal processing (DSP) applications, where power consumption is a critical consideration. By minimizing the switching activity in a DSP circuit, ME and MME can reduce the dynamic power consumption of the circuit without affecting its functionality.

ME and MME coding play a crucial role in modern communication systems, ME and MME coding allow for more efficient use of bandwidth, while also adapting to the characteristics of the signals. This can result in improved signal quality, even in low-bandwidth situations. By using different bit rates or encoding modes, ME and MME coding can maximize the use of available bandwidth. This is especially important in mobile networks, where bandwidth is often limited and shared among many users.

The aim of this paper is to determine the optimal value for receive energy gain of and Modified Minimum Energy coding (MME coding) to and Minimum Energy coding (ME coding) in Wireless

Sensor Networks (WSNs) consisting of OOK transmitters without any simulation or experiment. First of all, OOK modulation is going to be described in section II. Then the operations of ME coding and MME coding are going to be investigated in detail in sections III and IV respectively. In section V, the optimal receive energy gain of MME to ME coding is analyzed. Finally, the conclusion is given in section VI.

II. OOK (On-Off Keying) Modulation

For low data-rate wireless applications, simplest form of digital modulation technique like On-Off keying (OOK) can also be considered. In OOK, the base band signal modulates a carrier wave at a higher frequency and transmits it as RF waves. That is, a carrier signal is transmitted when a bit-1 is to be sent and no signal is transmitted when a bit-0 is to be sent. Figure 1 shows OOK transmitted signals for a sequence of bits [1].

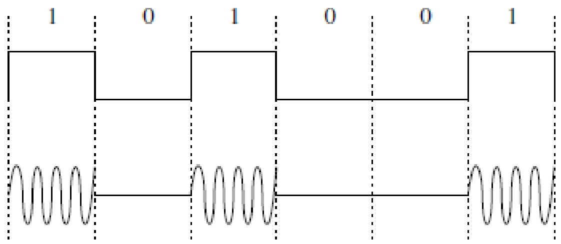

Fig. 1. Typical OOK Modulation Scheme [1].

Since the transmitter does not transmit the bit 0, OOK modulation supplies energy saving. Thanks to its properties like low complexity and cost efficiency, it is a good option for WSNs [2].

III. ME Coding (Minimum Energy Coding)

There have been many recent works in the field of wireless microsensors to bring about energy efficiency at both system level and circuit level. Wang et. al. have considered the issues of many low power wireless microsensor applications [3].

Many approaches have been discussed to optimize the energy consumption problem and Minimum Energy Coding (ME coding) which is an efficient source coding scheme for information transmission in wireless environment has been proposed [4].

Minimum Energy Coding (ME Coding) is a coding scheme used to minimize power consumption in devices portable devices by consuming power only when high bits ("1" bits) are transmitted, the power used in the device is small and negligible when low bits are transmitted[5].

ME coding is employed with OOK modulation to reduce energy consumption in digital transmitters [4]. Hence transmitter expends energy only when transmitting a signal for bit-1. Thus, for a system that uses OOK modulation technique, the obvious way to reduce the energy consumed would be to reduce the number of bit-1's transmitted compared to the bit-0's. Since there is no control over the information source, the only way to reduce the high bits (bit-1s) would be to map a set of information bit sequence to a constant length codeword (ME Code) which has less number of bit-1's in it. This is originally based on the idea proposed by Erin and Asada [4]. The power optimization problem for wireless communication applications with message source of known statistics has been formulated. There are two steps to reduce energy consumption. Using a set of codes having less number of high bits in it is the first step. The second one is to assign these set of codes with lesser number of ones to messages of higher probabilities. For the sources with unknown statistics, ME coding cannot be used.

The block diagram of ME mapping scheme is shown in Figure 2. Information bits (1's and 0's) are generated by the information source and fed to ME coding block. A sequence of bits having a decreased number of bit-1s is produced by ME encoder. In the modulator block, OOK modulation is applied to the encoded bits. The RF transmitter sends them bit-by-bit.

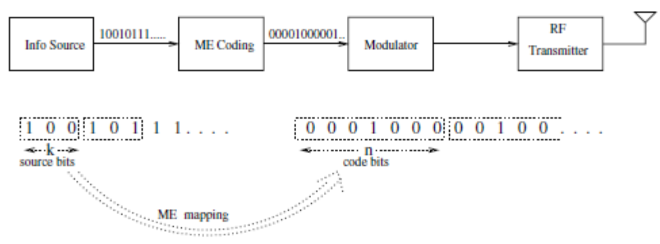

Fig. 2. Basic Transmitter-side Block Diagram [1].

In conclusion, ME coding is a useful technique for optimizing energy consumption in various wireless communication systems. Its applications range from WSNs to cognitive radio networks and it continues to be an active area of research in the field of wireless communication systems [6].

IV. MME CODING (MODIFIED MINIMUM ENERGY CODING)

Modified Minimum Energy Coding (MME coding) is the modified version of ME coding as its name suggests. A MME codeword consists of several subframes. The first bit of each subframe is the indicator whether there is one or more high bits in that subframe [5]. The principles of ME and MME coding schemes are given comparatively in Figure 3.

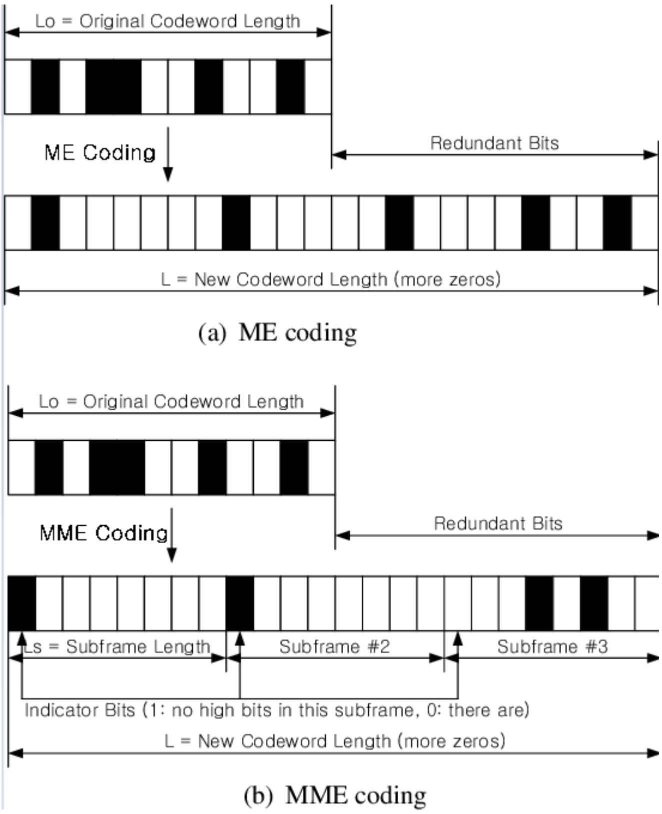

Fig. 3. The principles of ME and MME coding schemes [5].

In the MME coding, the number of "1" bits (high bits) in a codeword can be increased compared to ME coding because of that indicator bit. On the other hand, timing synchronization at the receiver is improved thanks to that indicator bit. MME coding provides energy efficiency because the sensor node uses most of the time for receiving data rather than transmitting [5].

V. OPTIMAL RECEIVE ENERGY GAIN

The energy gain of MME coding compared to ME coding, with respect to subframe length (L_s), is calculated for different values of the α coefficient (0.1, 0.3, 0.5, 0.7, and 0.9), as illustrated in Figure 4. The two factors that affect the receive energy gain of MME coding relative to ME coding are α and L_s. As L_s increases, the energy gain decreases due to longer receive time. Additionally, lower values of α result in higher energy gain.

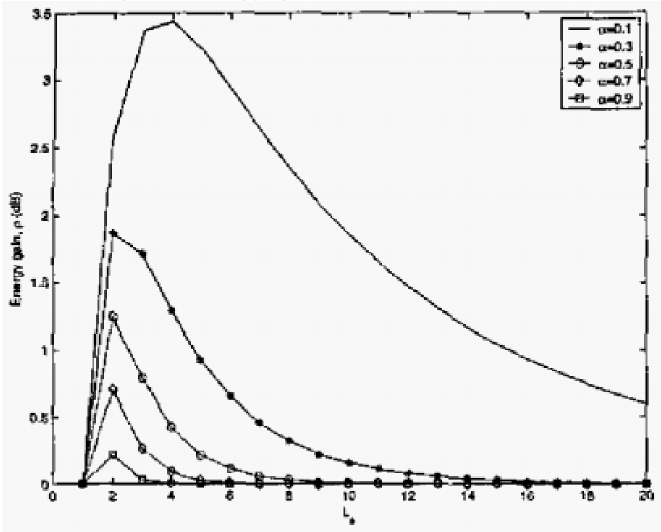

Fig. 4. Receive energy gain of MME coding relative to ME coding [5].

It is observed that the energy gain reaches a maximum value and then starts to decrease. There is an optimal receive energy gain as a function of L_s for each value of α. The aim of this study is to determine the subframe length value providing maximum energy gain for any given α value directly without any simulation or experimentation. For this purpose, the following computation steps are performed to obtain the $L_{s_{opt}}$ which is the subframe length giving the maximum energy gain for any given α value.

For ME coding, the decoding time T_{on,r_x}^{ME} is given by the equation (1) [5]:

$$T_{on,r_x}^{ME} = LT_b \quad (1)$$

For MME coding, the average receiver on-time T_{on,r_x}^{MME} is computed by the equation (2) [5]:

$$T_{on,r_x}^{MME} = N_s[L_s(1-(1-\alpha)^{L_s-1}) + (1-\alpha)^{L_s-1}]T_b \quad (2)$$

The receive energy gain of MME to ME coding is calculated by putting the equation (1) and (2) into the equation (3) [5]:

$$\rho = \frac{E_{r_x}^{ME}}{E_{r_x}^{MME}} = \frac{T_{on,r_x}^{ME}}{T_{on,r_x}^{MME}} = \left(1 + \frac{1-L_s}{L_s}(1-\alpha)^{L_s-1}\right)^{-1} \quad (3)$$

By taking the derivative of the energy gain and setting this equal to zero, then solving it $L_{s_{opt}}$ is found as:

$$L_{s_{opt}} = 0{,}5\left(1 + \sqrt{1 - \frac{4}{\ln(1-\alpha)}}\right) \quad (4)$$

For any given α value, $L_{s_{opt}}$ is calculated directly. There is no simulation required to find $L_{s_{opt}}$, it is computed analytically thanks to the equation (4).

VI. CONCLUSION

MME to ME coding can achieve significant energy savings in WSNs. This paper presents an investigation into the optimal value determination for receive energy gain of MME to ME coding in WSNs. The optimal value of receive energy gain for MME to ME coding in WSNs depends on subframe length (L_s) and α coefficient and a mathematical optimization model can be used to determine the optimal value. Thanks to the mathematical analysis in this study, the optimal value of receive energy gain for MME to ME coding in WSNs is found directly for any α coefficient. The effects of other parameters on the optimal energy gain are going to be investigated in more detail in further study.

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