Saving Energy for Wireless Transmission: An Important Revelation from Shannon Formula

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Abstract: The reduction of power consumption is important for wireless communications and networks. To develop the energy-saving technologies for future wireless transmissions and networks, this paper presents two basic study points: 1) The multiple events are merged into a single event; 2) the high-order mode is changed to the low-order mode. For this reason, we seek that multiple events in wireless transmission links are fused into a single event from Shannon formulas. We also analyze the relationship between the information modulation and the error correction, and give a fusion structure of error-corrected modulation. The energy-saving performance of the error-corrected modulation method is further analyzed through comparison with the traditional methods of modulation plus error correction. The results of numerical analysis demonstrate the wireless energy saving methods for wireless systems based on Shannon formulas are the achievable efficient schemes.

Keywords: wireless saving energy; extension of Shannon formula; error-corrected modulation; energy-saving performance

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1 Introduction

1.1 Motivation

The energy saving, also said as the power efficiency of wireless communications, has always been an important aim pursued for wireless communications and networks. From 3G, 4G to 5G, the energy consumption per information bit has dropped significantly.

However, on the other hand, 5G networks are pursuing extremely high peak rates and cloud network uniform management, which requires high power consumption. The failure to basically seek a solution to this problem will seriously affect the operation of 5G and the future B5G/6G development. Therefore, various energy efficient methods have been researched and developed, to optimize and reduce the energy consumption in various links of wireless communications and networks. However, some proposals and methods seem too scattered or specific, and show no systematic support from the basic theory.

In the face of increasing demands for higher transmitting rates and energy, it is necessary to find solutions by seeking enlightenment from expansion and augmentation of the most basic Shannon formula. This is an important issue facing B5G/6G in the future, which is worth studying carefully.

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1.2 Related Work

The Green Wireless Conference held in Huangshan, China in 2009 is still vivid in our memory. As an outcome of this conference, Ref. [1] summarized the preliminary research on antenna design, service transmission, network design and energy-saving function design, reflecting the results and thinking on green wireless communication technology at that time. A related R&D research project supported by National Key Basic Research Program of China ("973" Program) was subsequently launched in 2010 and has made outstanding contributions to promoting the development of energy-saving technology for wireless communications in China. Moreover, among the achievements are several representative important papers such as "Cell Zooming for Cost-Efficient Green Cellular Networks"[2] and "Traffic-Aware Network Planning and Green Operation (TANGO)"[3]. The international communities have also been studying green wireless communications actively.

Many research papers focusing on energy efficiency and energy saving have been published around the world. These publications concern three main aspects: fundament research, cellular networks and sensor networks.

The basic concepts of energy-efficient communications can be found in Ref. [4], which also summarized some fundamental works and advanced techniques for energy efficiency, including information-theoretic analysis and multiple transmission technologies.

Based on energy conservation and the Shannon capacity theorem, the capacity-power consumption formula was proposed in Ref. [5]. The network spectral efficiency and energy efficiency functions of the cellular network were researched, and the relationship between the power consumption and the spectrum efficiency in the cellular networks was also revealed[6]. A consumption factor theory to analyze and compare energy efficient design choices for wireless communication networks was presented in Ref. [7]. These approaches provide new methods for analyzing and comparing the power efficiency of communication systems.

For 5G development, the optimization solutions to energy and cost efficiency were investigated for wireless communication systems with a large number of antennas and radio frequency (RF) chains[8]. The overall power transfer efficiency (PTE) and the energy efficiency (EE) of a wirelessly powered massive multiple input multiple output (MIMO) system were investigated in Ref. [9]. Moreover, a novel quadrature space-frequency index modulation (QSF-IM) scheme was proposed as a promising energy-efficient radio-access technology for 5G wireless systems[10]. Using dual antenna constellation, the proposed scheme can enhance data rates with no extra cost of energy consumption.

Recently, the energy-saving research on sensor networks has made further progress. A novel inter-cluster routing was proposed in Ref. [11], which simultaneously takes the energy efficiency in both intra-cluster and inter-cluster phases into account. Moreover, a novel concept of energy efficiency welfare was introduced[11]. The nonlinear fractional programming for the optimal solution to energy efficiency maximization was presented, based on which a particle-swarm optimization-based solution algorithm was proposed in Ref. [12]. An analytical framework for studying the energy efficiency trade-off of cooperation in sensor networks was presented in Ref. [13]; this trade-off is shown to depend on several parameters such as the received power, processing power and the power amplifier loss. The analytical and numerical results reveal that for small distance separation between the source and destination, direct transmission is more energy efficient than relaying.

The joint research of spectrum efficiency and energy efficiency in wireless communications is also one of the most important topics in the next-generation wireless networking area, which is attracting more and more attention from industry, research, and academia[14]. In Ref. [15], the energy efficiency and spectrum efficiency in underlay device-to-device (D2D) communications enabled cellular networks were investigated.

In summary, since 2009, the research on improving energy efficiency and energy saving has achieved many results. However, compared with the prediction made by Green Touch's research that the net energy consumption in communications networks would be reduced by up to 98% by 2020 relative to 2010[16] or that the energy efficiency would be increased by a factor of 1 000 compared to the 2010 level[17], it is far from being achieved. Therefore, from the enlightenment of expending Shannon formulas, this paper will study the foundation and new methods of energy saving in wireless transmission and network coverage to meet the needs of future B5G/6G development.

1.3 Contributions

Energy saving has always been an important aim pursued from 3G, 4G to 5G. The energy consumption per information bit has dropped significantly. However, it is still far away from the future B5G/6G development requirement.

To develop the energy-saving technologies for future wireless transmissions and networks, this paper presents two basic study points: 1) The multiple events are merged into a single event, or the opposite; 2) The high-order mode is changed to the low-order mode, or the opposite.

Making the joint study of the two points above, we seek that the multiple events are merged into a single event in wireless transmission links, from Shannon channel capacity formula, to obtain a new relationship between the information modulation and the error correction, and give a new method of fusing constellation structures of error correction and modulation. Further, the energy-saving performance of the given fusion structure is analyzed, and compared with traditional method of modulation plus error correction.

The research results indicate the given method of wireless saving energy with the revelation from the Shannon formula has high energy efficiency.

The remainder of this paper is organized as follows. Section 2 is the problem formulation. Section 3 gives a fusion method of error correction and modulation with revelation from the Shannon channel capacity formula. Section 4 analyzes the energy-saving performance of the given method. Finally, in Section 5, we conclude this paper.

2 Problem Formulation

Facing the future communications, high transmission speed, low energy consumption and short time delay are important requirements that must be met. The historical experience tells us that the solution to major problems must begin from the analysis and demonstration of basic theories.

From the perspective of theoretical analysis of saving energy, the topology structures of two basic study points presented by this paper can be written into two expressions.

The first topology structure is to transform the processing with two or more sub-events into a simple event (or vice versa). It can be expressed as

$$A = \sum_{j=1}^{g} A_g \quad \Leftrightarrow \quad B, \tag{1}$$

where the g sub-events of event A are turned into event B; the event B is turned into g sub-events of event A.

The second expression of topology structure is that the high-order event is transformed into the multiple low-order sub-events to improve the energy efficiency (or vice versa), which can be expressed as

$$A^e \Leftrightarrow q(A^{e-1}), \tag{2}$$

where the exponential order $e-1$ of event A^{e-1} is lower than the exponential order e of A^e, and not as complicated as A^e. q is the coefficient of the parallel lower-order.

Therefore, this paper discusses the mathematic expressions of energy-saving ability of the two topology structures, including the performance evaluation of energy saving.

2.1 Evaluation Function of Power Consumption

When wireless communication event A is considered, such as modulation/demodulation (Mod/Dem), the required power consumption P_a, for achieving transmission capability S_a, can be expressed as

$$P_a = f_a\left(S_a ; Q_a\right), \tag{3}$$

where Q_a is other resource consumption items required for achieving expected capability S_a. This formula represents the energy consumption to realize the transmission capacity S_a. In general, the unit of power consumption is mW and the unit of transmission capability is bit.

Given the other resource consumption items Q_a, such as the frequency bandwidth and the time delay, the relationship between the fluctuation in achievable performance and the increase or the decrease in power consumption can be derived by the partial differentiation of the power consumption in Eq. (3) as

$$\frac{\partial P_a}{\partial S_a} = \frac{\partial f_a(S_a ; Q_a)}{\partial S_a}\Big|_{Q_a = Q}, \tag{4}$$

where Q is a given value of other resource consumption. This formula represents the energy consumption for one-bit increase of the transmitted information, which is the incremental relationship between energy consumption and information bits.

Therefore, we define the energy-saving evaluation function of event A as

$$\eta_a = \frac{1}{\frac{\partial P_a}{\partial S_a}\Big|_{Q_a = Q}} = \frac{\partial S_a}{\partial P_a}\Big|_{Q_a = Q}, \tag{5}$$

where η_a is the amount of information that can be obtained per added unit of power, and it must be greater than zero. As long as $\eta_a > 1$, the performance improvement will be greater than the increased energy consumption, and it is possible for improving the energy-saving effect. The larger η_a, the greater the energy efficiency, or vice versa.

Obviously, Eqs. (3), (4) and (5) are also suitable for event B.

As in Eq. (1), wireless event A consists of g sub-events and the energy consumption is $P_a = P_{a1} + \ldots + P_{ag}$. Then the incremental relationship between energy consumption and information bits is

$$\frac{\partial P_a}{\partial S_a} = \sum_{j=1}^{g} \frac{\partial f_{a_j}(S_{a_j} ; Q_{a_j})}{\partial S_{a_j}}\Big|_{Q_{a_j} = Q}, \tag{6}$$

and the energy-saving evaluation function of event A is rewritten as

$$\eta_a = \sum_{j}^{g} \frac{\partial S_{a_j}}{\partial P_a}\Big|_{Q_{a_j} = Q_a}. \tag{7}$$

Therefore, in wireless communications, how to seek an achievable technical method to obtain high energy-saving efficiency is an important problem.

2.2 Energy Saving of Combining Multiple Events

Now, we consider to develop a new event (event B), which is synthesized by the g sub-events of event A. Also we will complete the design for selecting event B or original event A depending on the consumed energy P_b. Based on the principle of minimum energy expenditure, Eq. (8) can be used to choose the best design of a new event according to the principle of consuming less energy.

$$\begin{aligned}&\text{if } P_a > P_b,\ \text{choose } B,\\&\text{if } P_a < P_b,\ \text{choose } A.\end{aligned} \tag{8}$$

In fact, the design above is not that simple. For example, are the changes of energy consumption of event A and event B for the change of transmission ability the same? When the transmission capability S of event A and that of event B are the same, the answer to this problem is

$$P_a > P_b \text{ and } \frac{\partial \sum_{i=1}^{g} P_{a_i}}{\partial S_a} > \frac{\partial P_b}{\partial S_b}, \tag{9}$$

and then we must choose event B, and vice versa.

Therefore, in-depth research is needed to find a better method and effective design for achieving the given wireless event, which facilitates minimizing the energy expenditure.

2.3 Energy Saving of High-Order Event

There is a wireless event with e-order, denoted as A^e, of which the power consumption is P_{a^e}. For the order reduction processing, we transform event A^e into event A^{e-1}, reducing the event from e-order to (e-1)-order. Generally, the energy consumption of event A^{e-1} will be less than that of event A^e, and its performance will also be less than the performance of event A^e.

Thence, we need to confirm how many events A^{e-1} have the same performance with the single event A^e, and carefully study if their power consumption is less than that of the single event A^e. The comparison of the achievable performance and the energy consumption between the high-order event and q low-order events, when the transmission capability S of event A and that of event B are the same, can be expressed as

$$P_{a^e} > P_{a^{e-1}} \text{ and } \frac{\partial P_{a^e}}{\partial S_{a^e}} > q\frac{\partial P_{a^{e-1}}}{\partial S_{a^{e-1}}}, \tag{10}$$

and then, we must choose event B, and vice versa.

Eq. (10) represents that the higher the energy efficiency, the lower the energy consumption required for performance improvement and the better the design.

Thence, the energy-saving issue of wireless communications and networks is divided into two research topics:

1) When an event having multiple sub-events compares with another single event, which one has smaller energy consumption?

2) Comparing a high-order event and multiple low-order sub-events, which one has smaller energy consumption?

Here, we have presented the mathematical expressions of two types of energy-saving problems. The next sections will show the revelation from the Shannon formula and accordingly provide energy-saving solutions to the problems.

3 Revelation from Shannon Channel Capacity Formula

As is well known, the channel capacity formula of Shannon theory is a very important theoretical foundation of wireless communications. It is also very important for our research on energy saving for wireless transmission links, wireless area coverage, wireless networking, etc.

Here, we discuss energy-saving issues of the wireless transmission link that includes two parts: the error correction coding/decoding (codec) and the modulation/demodulation (Mod/Dem), as shown in **Fig. 1**. This link is a stable transmission flow for a given channel. In this regard, some researchers have made considerable efforts, trying to combine the error correction and the modulation into one event. However, they have not yet obtained good usable results. From the perspective of saving energy, it is worth deep studying.

Therefore, we suggest seeking the inspiration and methods by extending the Shannon formula, study the fusion of the error correction codec and the modulation/demodulation, and analyze the relationship between the information rate and power consumption in the fading channel.

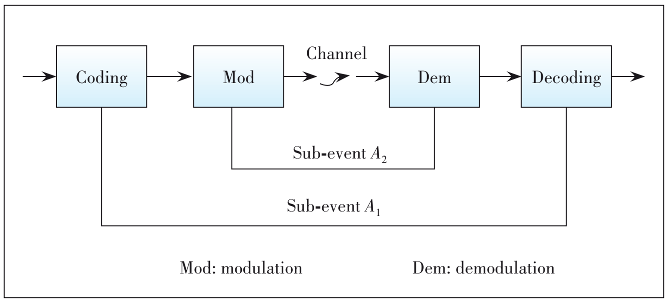
3.1 Fusion of Error Correction and Modulation

If the input signal is $x(t)$ and the output signal is $y(t)$ through the Gaussian fading channel, the characteristic of the Gaussian channel is h, and the channel noise is N_0, the relationship between input and output is

$$y(t) = hx(t) + N_0. \tag{11}$$

According to the Shannon formula of channel capacity[18], the wireless transmission capacity $C_{(x,y)}$ can be written as

$$C_{(x,y)} = \underset{P(x)}{\mathrm{Max}}\, H(y) - H(N_0), \tag{12}$$



▲Figure 1. Current wireless transmission link where $C_{(x,y)}$ is the entropy of the output signal y when the input is x, i.e., the channel capacity; $H(N_0)$ is the lost entropy due to channel noise; $P(x)$ is the statistics function determined by the transmitted signal source $x(t)$. Generally, $\text{Max}\,H\left(y\right)$ is the entropy of the input signal x, i.e. $\text{Max}\,H\left(y\right) = H(x)$. $H(x)$ is an integral from negative infinity to positive infinity, which is unavailable in practical applications.

For this reason, we can define the confidence of the cumulative probability distribution as a reference variable, which is denoted as ω, and get the accurate entropy under the given confidences.

We assume ω is the achievable confidence of the signal $x(t)$, the reliable channel capacity C_ω under the given confidence is the difference of the entropy of input signal $H(x)$ and the entropy of noise $H_{N_0,(1-\omega)}$, which contains the noise entropy and the out-of-confidence discarding entropy. Therefore, the achievable transmission capacity C_ω under the confidence ω is expressed as

$$C_\omega = H_x - H_{N_o,(1-\omega)}. \tag{13}$$

If $H_{N_0,(1-\omega)} > 0$, $C_\omega < H_x$ and $\omega < 1$. It was only when ω =100% and N_0 =0 that we may achieve the lossless capacity, $C_{x,\omega} = H_x$.

When the input signal $x(t)$ has n symbols, $\left(x_1,...,x_n\right)$ and the Gaussian channel is a normal distributed channel, the mean probability of errors appearing at the Gaussian channel is $\bar{p}(N_{0,i}) = 1/C_i^n$, where C_i^m is the number of combinations of i in n. Then the entropy of N_0, which causes i error symbols in the output, is expressed as

$$H_{N_0,i} = \log\frac{n!}{i!(n-i)!}. \tag{14}$$

In this way, the reliable transmission capacity C_ω based on the confidence ω can be expressed as

$$C_\omega = n - \log\sum_{i=0}^{k} C_i^n,\ C_i^n = \frac{n!}{i!(n-i)!}, \tag{15}$$

where k is the maximum number of the error symbols that can be corrected at the same time.

If there is only one error or error-free in n output symbols, the $n+1$ symbol combination states in the output will be only received, and the reliable transmission capacity C_ω can be simplified to

$$C_\omega = n - \log_2(1+n),\ \text{for}\ k = 1. \tag{16}$$

The channel capacity C_ω is the amount of receivable information (denoted as m) transmitted by n symbols. For example, if the signal x has three symbols ($n = 3$), x_1, x_2 and x_3 will be treated as a block, including one information symbol (m=1), and input into the Gaussian fading channel. The possible states received are one error-free state, and three states with a single error. The total is four combination output states (**Fig. 2**).

Here we express the probability of the right symbol and the wrong symbol as p_i and q_1, respectively. If the appearing probabilities of the four output states are all the same, i.e., $p_i = q_1 = 1/4$ for $i = 1, 2, 3$, the confidence of this block is ω =3/4 = 75% and the reliable channel capacity of correcting one error is C_ω=3−log$_2$(1+3)=1 bit.

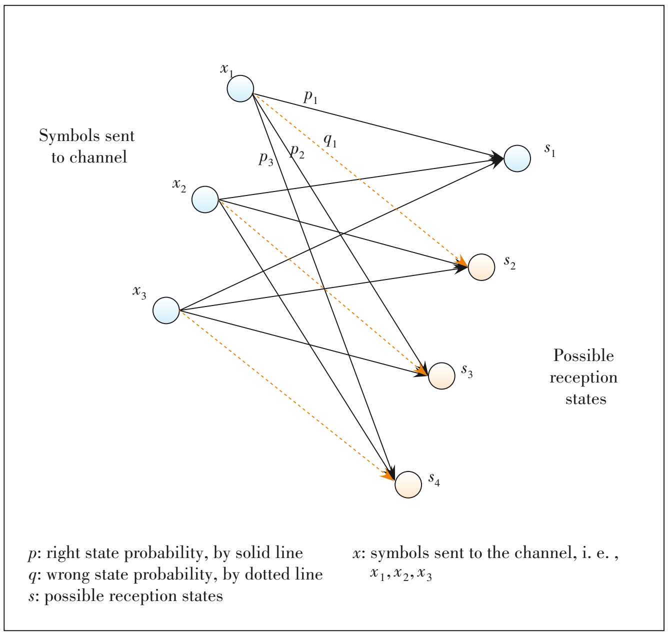
Therefore, based on Eqs. (15) and (16), we can give an error-corrected modulation method. For example, in the 1/3 code block shown in Fig. 2, x_2 is the information bit while the others are check symbols. In this way, one symbol error can be corrected and the transmission efficiency is 1/3. Similarly, we can build error-corrected modulation of 2/5 code, 3/7 code, 4/9 code, 5/11 code, 6/13 code, 7/15 code, etc.

3.2 Constellation Diagram of Error-Corrected Modulation

Based on the above modulation method, we can combine the error-correction function with modulation structure.

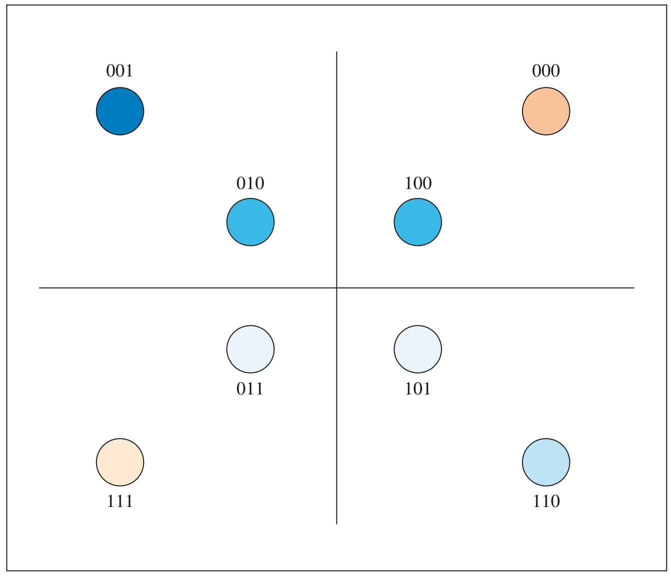
The error-corrected modulation method is a constellation modulation structure with the error correction capability.

To construct the constellation diagram of the error-corrected modulation, the processing steps are divided into three parts: 1) planning the constellation point with the information bit plus check bit as a code; 2) choosing a location of the constellation point suitable for transmitting information bits; 3) dividing the constellation area of the correctable error, where the erroneous information bit can be directly detected by the receiver.



▲**Figure 2. Modulation block with one error correction**

Fig. 3 shows the (3,1) modulation code with 3 symbols as an example, where one information bit and two check symbols are included and the single error can be corrected. Therefore, the information symbol of the (3,1) code is 0 or 1 and the added error check symbols can be 00, 11, or 01, 10. The modulation coding has one of two structures with no error: (0,0,0) (1,1,1) or (0, 0, 1) (1, 1, 0). This modulation code with the constellation points can correct one error.



▲**Figure 3. Error-corrected modulation constellation of (3, 1) coding**

4 Analysis of Energy-Saving Efficiency

4.1 Energy Consumption of Two Modulation Methods

Based on the above processing, this section analyzes the power consumption of two structures of the error correction plus modulation and the error-corrected modulation for wireless transmission links, to find which method saves more energy.

First, let us consider the traditional transmission link, in which the error correction codec is event A_1 and the Mod/Dem is event A_2, to analyze the energy-saving efficiency.

The power consumption of event A_1 can be expressed as

$$P_{a_1} = \left(f_T(S_{a_1}; Q_{a_1}) + f_R(S_{a_1}; Q_{a_1})\right)\Big|_{Q_{a_1}=1} \approx \left(f_T(S_{a_1}) + f_R(S_{a_1})\right)P_0. \tag{17}$$

In general, the coding process is addition operation depending on the coding length n, and the power consumption of the coding process can be expressed as the function of i_T-order coding length n. For simplicity, the power consumption of the decoding process can be expressed as the function of i_R-order coding length n. Then, the power consumption of the coding and decoding processing of the (n,m) code can be respectively simplified to

$$f_T(S_{a_1}) \approx \alpha_T(n^{i_T}),\ \ f_R(S_{a_1}) \approx \alpha_R(n^{i_R}). \tag{18}$$

Therefore, the total power consumption of the coding and decoding processing of the (n,m) code for the corrected error $k = 1$, i.e., the total of event A_1, is

$$P_{a_1} \approx \left(\alpha_T(n)^{i_T} + \alpha_R(n)^{i_R}\right)P_0 , \tag{19}$$

where the subscript T means the transmitting process, R means the receiving process, and P_0 is the power consumption of a single addition operation ($i = 1$) of one symbol. Moreover, $i = 1$ means the addition operation, and $i = 2$ and $i = 3$ are respectively the multiplication operation and the convolution or iteration operation.

Second, event A_2 is the n-order quadrature amplitude modulation (QAM) modulation. By the Shannon theory, the transmitted signal symbol rate in unit bandwidth and unit time is

$$n = \log\left(1 + \frac{P_{a_2}}{N_0}\right) \approx \log\frac{P_{a_2}}{N_0},\ \ P_{a_2} \approx 2^n N_0 , \tag{20}$$

where n is the number of transmitted signal symbols in a block. The receiving demodulation of event A_2 is similar to code demodulation, with only multiplication and comparison; the power consumption can be expressed as $(\beta_R n^{i_R})P_0$.

Therefore, the power consumption of Mod/Dem with n symbols is

$$P_{a_2} = f_T(2^n(N_0)) + f_R(n^r) \approx (\beta_T 2^n)N_0 + (\beta_R n^r)P_0 , \tag{21}$$

where N_0 is the power of channel noise; $f_R(n^r)$ is the power consumption of the receiver, which is proportional to the code length n.

Therefore, the total power consumption of coding/decoding plus Mod/Dem can be expressed as

$$P_a = P_{a_1} + P_{a_2} \approx \left(\alpha_T n^{i_T} + \alpha_R n^{i_R} + \beta_R n^r\right)P_0 + (\beta_T 2^n)N_0 . \tag{22}$$

When $i_T = i_R = r = 2$, all power operations in P_0 item of Eq. (22) are multiplication operation. The power consumption of the operation of one symbol is denoted as P_0, and is equal to the unit noise power N_0. If $P_0 = N_0$, Eq. (22) can be simplified as

$$P_a \approx N_0\left((\alpha_T + \alpha_R + \beta_R)n^2 + \beta_T 2^n\right). \tag{23}$$

Fig. 4 shows the power consumptions of event A under different sending/receiving parameters with $k = 1$ and $N_0 = P_0 = 1\ \mu$W. Obviously, the power consumption increases exponentially as n increases. With the increase of the sending/

receiving parameters, the power consumption also increases significantly.

Fig. 4 demonstrates that for every additional bit of information in error correction coding, from m to m+1, the code length must be increased by two symbols at least, from n to n+2, that is m=(n-1)/2. Therefore, (3, 1) code, (5, 2) code, (7, 3) code, (9, 4) code, (11, 5) code, (13, 6) code, (15, 7) code, etc. are all such coding.

Based on Eq. (5) in Section 2, the evaluation function of power consumption of event A can be expressed as

$$\eta_a = \frac{\partial S_a}{\partial P_a} \approx \frac{1/N_0}{(\alpha_T + \alpha_R + \beta_R)\left((n+2)^2 - n^2\right) + \beta_T\left(2^{n+2} - 2^n\right)}. \quad (24)$$

If $\alpha_T = \beta_T = 1$ and $\alpha_R = \beta_R = 3$, the evaluation function of power consumption of event A can be expressed as

$$\eta_a \approx \frac{1/N_0}{7\left((n+2)^2 - n^2\right) + \left(2^{n+2} - 2^n\right)}. \quad (25)$$

Based on different lengths of symbol blocks and information bits (n, m), the evaluation function of the power consumption for error correction and modulation separation in the traditional transmission link is shown in **Fig. 5**.

Now, let us consider the fusion structure of error-corrected modulation of event B. Only Mod/Dem processing is taken for C_j^n combination states shown in Eq. (15), where $j = 0, 1, ..., k$ (k is the number of error correction symbols of a block). Then, the power consumption of event B can be simplify as

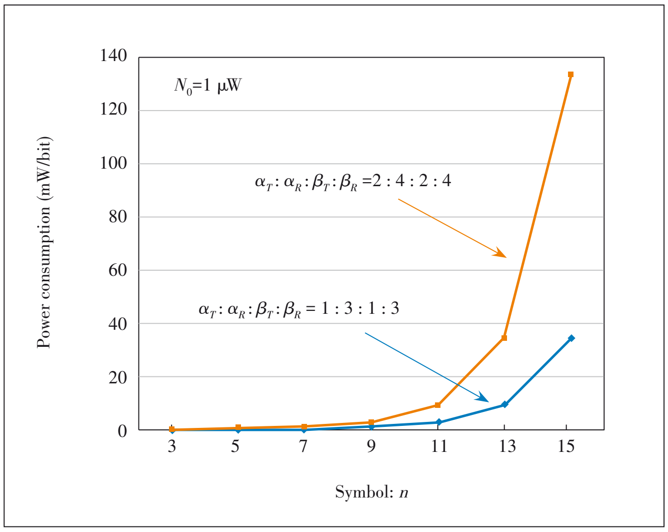
$$P_b \approx \beta_T(N_0)\sum_{j=0}^{k=1} C_j^n 2^m + \beta_R(n)^r P_0 \approx N_0\left(\beta_R n^2 + \beta_T(1+n)2^m\right), \quad (26)$$

where $i = 2$ and $P_0 = N_0$.

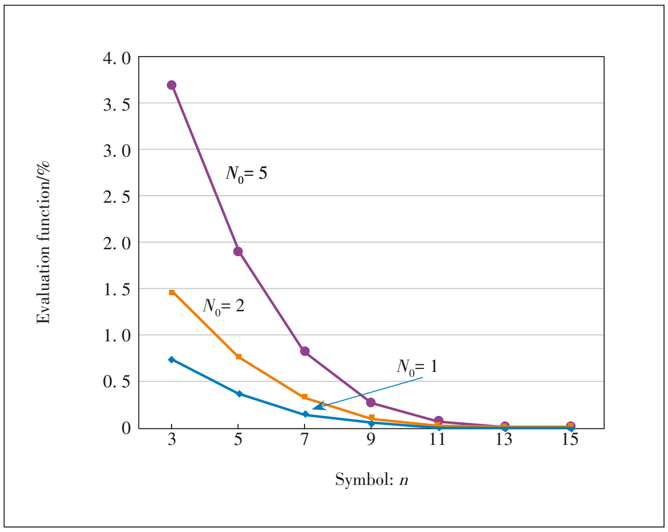
The power consumptions of event B under different sending/receiving parameters are shown in **Fig. 6**, where the parameters are $\alpha_T, \beta_T, \alpha_R$, and β_R, $k = 1$, and $N_0 = P_0 = 1$ μW. Obviously, the power consumption increases exponentially with m. Along with the increase of the sending/receiving parameters, the power consumption also increases. However, compared with event A shown in Fig. 4, the power consumption is significantly reduced.

Similar to Eq. (25), the evaluation function of the power consumption of event B can be expressed as

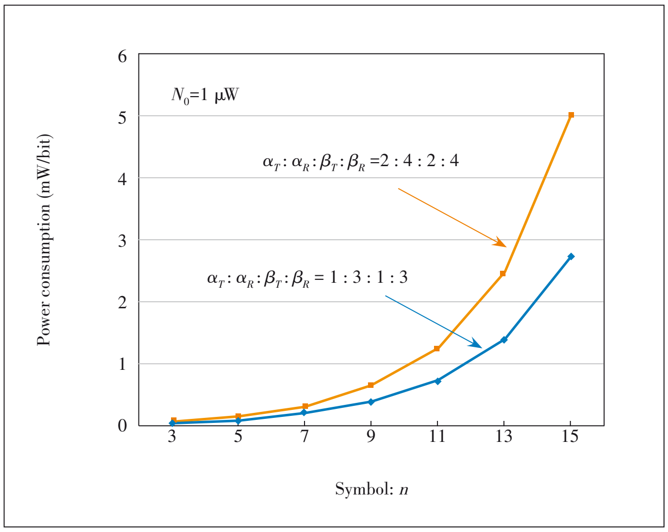
$$\eta_b \approx \frac{1/N_0}{(\beta_R)\left((n+2)^2 - n^2\right) + \beta_T\left((3+n)2^{m+1} - (1+n)2^m\right)}. \quad (27)$$



▲**Figure 4. Power consumption of event *A* under different parameters**



▲**Figure 5. Energy-saving evaluation function of the traditional link**



▲**Figure 6. Power consumption of event *A* under different parameters**

When $\alpha_T = \beta_T = 1$ and $\alpha_R = \beta_R = 3$, the evaluation function of power consumption of event B can be simplified as

$$\eta_b \approx \frac{1/N_0}{3\left((n+2)^2 - n^2\right) + \left((3+n)2^{m+1} - (1+n)2^m\right)}. \quad (28)$$

Based on different length of symbol blocks and information bits (n, m), the evaluation function of power consumption of the given modulation method for event B is shown in **Fig. 7**.

4.2 Energy-Saving Comparison of Two Modulation Methods

According to the above analysis, the modulation link of (n, m) code structure is divided into two modes, event A and event B. The amount of information transmitted in a block with a coding length n is m, that is, the transmission rate is m/n. Then, the power consumption of event A is $P_a \approx N_0\left((\alpha_T + \alpha_R + \beta_R)n^2 + \beta_T 2^n\right)$ and that of event B is $P_b \approx N_0\left(\beta_R n^2 + \beta_T(1+n)2^m\right)$.

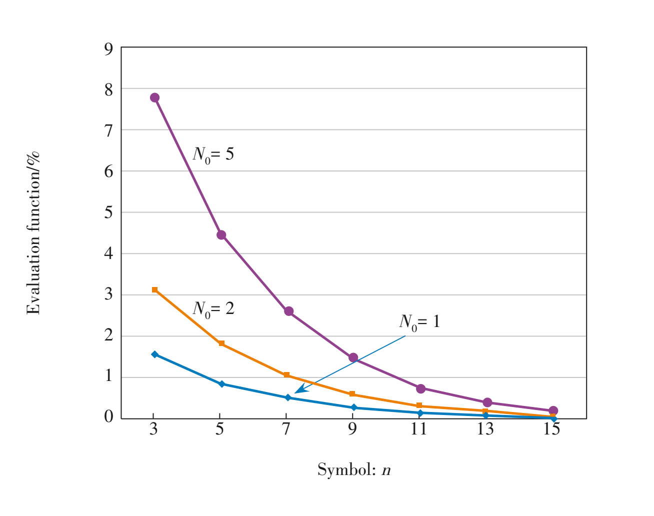
Therefore, the improved energy-saving degree from event A to event B at the same information rate m/n is defined as

$$\mu_{B/A} = \frac{\eta_b - \eta_a}{\eta_a} = \frac{(\alpha_T + \alpha_R + \beta_R)\left((n+2)^2 - n^2\right) + \beta_T\left(2^{n+2} - 2^n\right)}{(\beta_R)\left((n+2)^2 - n^2\right) + \beta_T\left((3+n)2^{m+1} - (1+n)2^m\right)} - 1. \quad (29)$$

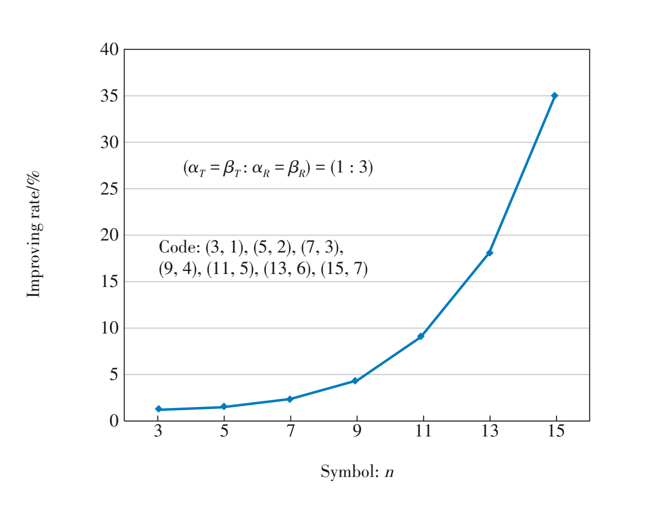
When $\alpha_T = \beta_T = 1$ and $\alpha_R = \beta_R = 3$, the improved energy-saving degree of conversion of event A into event B is

$$\mu_{B/A} = \frac{7\left((n+2)^2 - n^2\right) + \left(2^{n+2} - 2^n\right)}{3\left((n+2)^2 - n^2\right) + \left((3+n)2^{m+1} - (1+n)2^m\right)} - 1. \quad (30)$$

The improved degree of energy saving is shown in **Fig. 8**, which demonstrates that the longer the code length, the higher the improved degree in energy saving. If the length of coding is 15, the improved energy-saving degree reaches up to 35% in theory.



▲**Figure 7. Energy-saving evaluation function of the proposed modulation mode**



▲**Figure 8. Error-corrected modulation constellation of (3,1) coding**

5 Conclusions

With the widespread deployment and application of 5G networks, the requirements for wireless energy saving are getting higher and higher. This paper introduces two basic study points for wireless energy saving and gives the error-corrected modulation method and its fusing constellation structure based on extending the Shannon formulas.

This paper also analyzes and compares the energy-saving performance of two wireless transmission chains, the traditional and the proposed. The numerical analysis shows that the proposed error-corrected modulation method improves the energy-saving effect of the traditional method by 35% in theory.

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