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Adaptive FEC coding and cooperative relayed wireless image transmission

Hansong Xu[a], Kun Hua[b,*], Honggang Wang[c]

[a]*Electrical and Computer Engineering Department, Lawrence Technological University, Southfield 48075, USA*
[b]*Electrical and Computer Engineering Department, Lawrence Technological University, Southfield 48075, USA*
[c]*Electrical and Computer Engineering Department, University of Massachusetts, Dartmouth, 285 Old Westport Road, North Dartmouth, MA 02747, USA*

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Cooperative Diversity (CD)

Abstract
High quality image transmission through smart devices requires high transmission rate, throughput and low Bit Error Rate (BER). At the same time, energy efficiency is always the top issue for the battery-based smart devices such as smart phone, tablets, etc. In this paper, an adaptive Forward Error Correction (FEC) coding and cooperative relayed image transmission system is proposed, through which both transmission quality and energy efficiency could be promised under complex mobile communication channel environment. There are four steps in the proposed scheme: (1) Discrete Wavelet Transform (DWT) and wavelet based Decomposition, (2) Pixel-Position (PP) information and Pixel-Value (PV) information split based unequal image resource allocation, (3) transmission through channel fading and AWGN communication environment, (4) multiple-relays and adaptive channel coding. Comparing to traditional methods, our proposed method is more practical to transmit high quality images through battery-limited smart phone platforms.

Introduction

Comparing to traditional mobile communication terminals, larger display screen and higher data transmission rate are main characters of nowadays' smart devices, onto which hundreds of applications can be installed. To satisfy customer's expectations, newly released smart phones are coming with much higher pixel camera for high quality pictures instead of regular sizes from traditional cameras. Thereby, due to limited battery energy supply, energy usage efficiency is required for high quality image transmission, especially under severely noisy channel.

We apply Embedded Zero-tree Wavelet (EZW) for efficient image compression. Firstly, Discrete Wavelet Transform (DWT) was used to extract the coefficient of an original image; after

*Corresponding author.
Tel.: +1 2482042557; Fax: +1 2482042527.
E-mail address: khua@ltu.edu (K. Hua).
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wavelet based decomposition, Pixel-Position information and Pixel-Value information will be extracted form original image; after wavelet decomposition, image was extracted to large group of number ‘0’ which can be compressed largely, followed by a couple number of none zero values. The large group of zeros contains Pixel-Position (PP) information, which is more important, the number of large value containing Pixel-Value (PV) information, which is less important for image transmission [2]. In this paper, an adaptive Forward Error Correction (FEC) was applied on the important part of the image information, under bad communication channel, several mobile terminal as relays are used to set up a transmission network. For overcome the MIMO system's limitation such as limited size and hardware complexity in wireless cellular system, Cooperative Diversity (CD) is used to ‘extend’ the antenna number. Convolutional coding method is also used for protect important part of image information (Pixel-Position), to achieve low BER and high data rate.

Our contributions for this work are as follows:

1. Unequally allocated energy to transmit important Pixel-Position information and unimportant Pixel-Value information, due to the unequal importance of Pixel-Value and Pixel-Position for image information containing.
2. Proposed an adaptive Forward Error Correction (FEC) scheme, for achieving low BER under multipath fading channel and AWGN channel environment. Plus, evaluated the BER performance under complex channel conditions.
3. Applied Cooperative Diversity with convolutional coding and multiple-relays in quality promised image transmission channel. Also, we analyzed the tunable coding ratio and relay number performance.

Symbols and Parameters shown as below:

Symbol	Definition
S	Sender
R	Receiver
BS	Base station
R1, R2	Relay1, Relay2

Fig. 1 shows the proposed system model with adaptive FEC and cooperative relays. At the transmitter side, unequal error protection (UEP) is applied based on Pixel-Position and Pixel-Value (PP and PV) unequal allocation. EZW (Embedded Zero-tree Wavelet) was applied for image compression. Then, we proposed A-FEC (Adaptive Forward Error Correction) and Cooperative relays for quality promised image transmission. Those relays and convolutional coding are needed for noisy channel and long transmission distance. Our four components are explained in *Methodology* section. (Figs. 2 and 3)

Peer work review

Paper [1] introduced an efficient image compression method named Embedded Zero-tree Wavelet (EZW). The compression processes are as following: first, Discrete Wavelet Transform (DWT) was applied to original image for coefficient decomposition, and then, the digital bits of image are generated as importance order in bit stream, the low frequency parts are set to zeros, which are regarded as Pixel-Positions (PP), and can be compressed largely,and the high frequency information containing less important information is regarded as Pixel-Value (PV). The amount of zeros (low frequency part) can be compressed largely by using the numbers of zeros instead of transmit exactly all zeros in the Pixel-Position (PP) information. By this way, EZW compression method achieves high compression ratio and at the same time, it promises image quality. While, in their work, they did not apply this method on image transmission via mobile devices, which means they did not evaluate image transmission among smart devices under different communication environments. Then, paper [2], provided a method for image compression based on unequal importance of the pixel-position and Pixel-Value information. Besides this, unequal error protection (UEP) has used in this paper for information protection and energy saving. While, the transmission for compressed image through smart device is not considered yet. Besides, paper [3] explained the concept of data transmission through noisy communication channels by using Cooperative Diversity. In their work, a cooperative communication network has been built up to achieve high energy efficient, and handle high noise interference, for individual smart devices data transmission such as smart phone or PDAs. While, they have been only considered 1-D signal communication, but lack of research on 2-D image transmission. Recently, paper [5] provided a cooperative wireless communication network based on Alamouti communication technic. Compared with Maximum Ratio Combining (MRC), the balanced Cooperative Diversity network is more efficient and robust under complex channel environments. But they did not compress the preprocessed image first, which can largely reduce the energy cost for multi-media communication.

Comparisons of aforementioned research work are shown in Table 1

Methodology

A. Pixel-Position and Pixel-Value unequal resource allocation

For original high quality images, wavelet transform is applied to extract wavelet coefficients, then, the coefficients were stored in a matrix which is X-Y sized. After that, the matrix was scanned through the importance order from most important to least important. If the magnitude is larger than the threshold, it is called as larger value, or it is small value if smaller than threshold. Small values of coefficient are represented by Pixel-Position values, in which, zeros are grouped and represented by position data [1,6]. After compression, Pixel-Position data and Pixel-Value data are listed as a decreasing importance order. Any incorrect bits of Pixel-Position data may cause an avalanche of following bit errors. Thereby Pixel-Position data should be highly protected, under the same level of noise channel, a missing or failed transmission of Pixel-Position data may cause greater image quality degradation than errors of Pixel-Value data. In other words, bits missing occurs in Pixel-Value data may not hurt much for reconstructed image, but bits missing at Pixel-Position data will normally

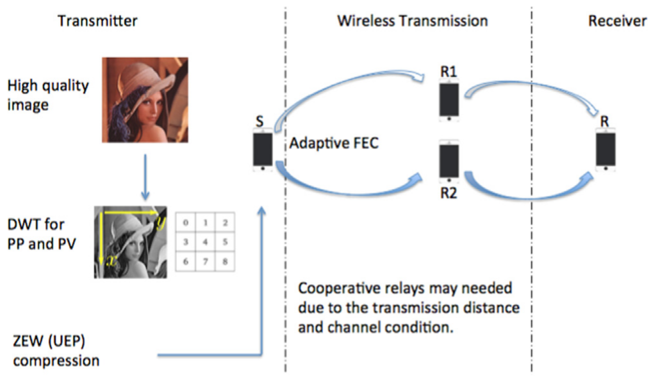

Fig. 1 System model.

cause more severe image damages. Thereby, it is necessary to set a higher priority to protect Pixel-Position data rather than Pixel-Value data.

The EZW algorithm is as follows:

Input: threshold (T), coefficient (C), original image (OI), Discrete Wavelet Transform (DWT),

Output: Pixel-Position data (PP), Pixel-Value data (PV).

1. Apply DWT on entire OI, for coefficient(C) extraction. Then, fit the decomposition wavelet coefficient in X-Y matrix.
2. Encoding coefficients(C) with decreasing threshold (T), Coefficients (C) are scanned as decreasing importance order from left to right in the X-Y matrix.
   - Set threshold(T),

Fig. 2 With EZW compression, from left to right, under different levels of communication channel noise.

Fig. 3 Without EZW compression, from left to right, under different levels of communication channel noise.

- if coefficient(C) < threshold(T),
- encoding as '1',
- or encoding as '0',
- then '0' reconstructed as 0,
- threshold(T) decrease
- return If
- end

3. Then coefficients (C) are split to be large value (coefficients (C) > threshold(T)) and small value (coefficients (C) < threshold (T)), small value coefficients represent the position of large value coefficient.
4. Encoded for the large value coefficients, then all coefficients are labeled as positive or negative.
   - If the coefficient is significant,
   - then, encoded as positive or negative value,
   - else if, coefficient is not significant, while, it is descendant is significant,
   - then coded as isolated zero,
   - Else, coefficient is zero tree root,
   - Then, coded as zero-tree root, the descendant reconstructed to zero in same threshold level.
   - End if
   - End
5. Output Pixel-Position data (PP) and Pixel-Value data (PV) from original image (OI).

EZW parameters:

EZW-encoding threshold	**30**	**50**	**100**	**250**
Parameters	The bitrate is 0.71 bpp The psnr performance is 27.65 dB	The bitrate is 0.31 bpp The psnr performance is 26.21 dB	The bitrate is 0.12 bpp The psnr performance is 23.53 dB	The bitrate is 0.05 bpp The psnr performance is 21.01 dB

Equations parameter:

Symbol	Define
PP, PV	Pixel-Position data, Pixel-Value data
$\varepsilon(j)$	Total distortion reduction
$\rho PP(j)$, $\rho PV(j)$	Distortion reduction for both PP and PV, separately
$\varepsilon(E)$	Total energy cost for transmit entire image
$\overline{\varepsilon PP(j)}$, $\overline{\varepsilon PV(j)}$	Energy cost for transmit PP data and PV data, individually.
S, R	Sender and receiver for image transmission
P1, P2	Relays between S and R (In this paper, set 2 as example)
F1, F2, F3, F4, F5, F_{ij}	Channel fading in both paths and relays.
γij, ζij, (K_{ij}), (ζ_{ij})	K_{ij}, ζ_{ij}, are the mean value and power value of the of channel fading F_{ij}

Our Pixel-Position (PP) and Pixel-Value (PV) unequal resource allocation is based on EZW image compression. In Eq. (1), we set *N* as the size of total transmission data, set PP(j) and PV(j) as distortion reduction, which represent the distortion are decreasing with the successive transmit and reconstruction [7]. The reduced distortion PP(j) and PV(j) can be calculated by the improvement of image quality, the same as to measure the wavelet coefficient; then set $\varepsilon(j)$ equals to the total expectation of distortion reduction, and ρPP(j) and ρPV(j) to represent the loss ratio of Pixel-Position (PP) and Pixel-Value(PV) respectively. Then the total distortion reduction calculation can be shown as

$$\varepsilon(j)=\sum_{i=0}^{N-1}\{\left(\sum_{j=0}^{i}PP(j)\right)\prod_{j=0}^{i}(1-\rho PP(j))+\left(\sum_{j=0}^{i}\rho PV(j)\right)\prod_{j=0}^{i}(1-\rho PP(j))\prod_{j=0}^{i}(1-\rho PV(j))\}*\rho PP(i+1) \quad (1)$$

Above equation, which represents the total distortion reduction, shows that the Pixel-Position data distortion represented

Table 1 Comparison of peer work.

Time	Researcher	Pros	Cons
1993	Jerome M. Shapiro [1]	Provided an efficient way for image compression, and achieved high compression ratio, with promised high quality	Lack of analysis for compressed image transmission for communication purpose
2005	R.Sudhakar, Ms R Karthiga [4]	Provided couple image compression methods like EZW (ZEW), SPIHT, SPECK, WDR, ASWDR, for obtain high compression ratio and high quality promised	Only discussed image compression methods, but omitted the design of data transmission
2008	Wei Wang, Dongming Peng [2]	Applied efficient compression method for image compression, and UEP for image information protection, besides, signal communication method (ARQ) was also applied.	Did not consider the transmission of compressed images through smart devices
2008	Kun Hua, Won Mee Jang [3]	Used Cooperative Convolutional Coding (CCC) for signal protection, combined with Cooperative Diversity (CD) with promised energy efficiency	Only concerned 1-D signal coding method, not 2-D image signal protection
2012	Kun Hua, Honggang Wang, Wei Wang [5]	Evaluated various communication techniques to improve multi-media transmission efficiency, e.g. an Alamouti based cooperative wireless network	Limited analysis about complex communication channel issues, did not cover multimedia signal pre-compression

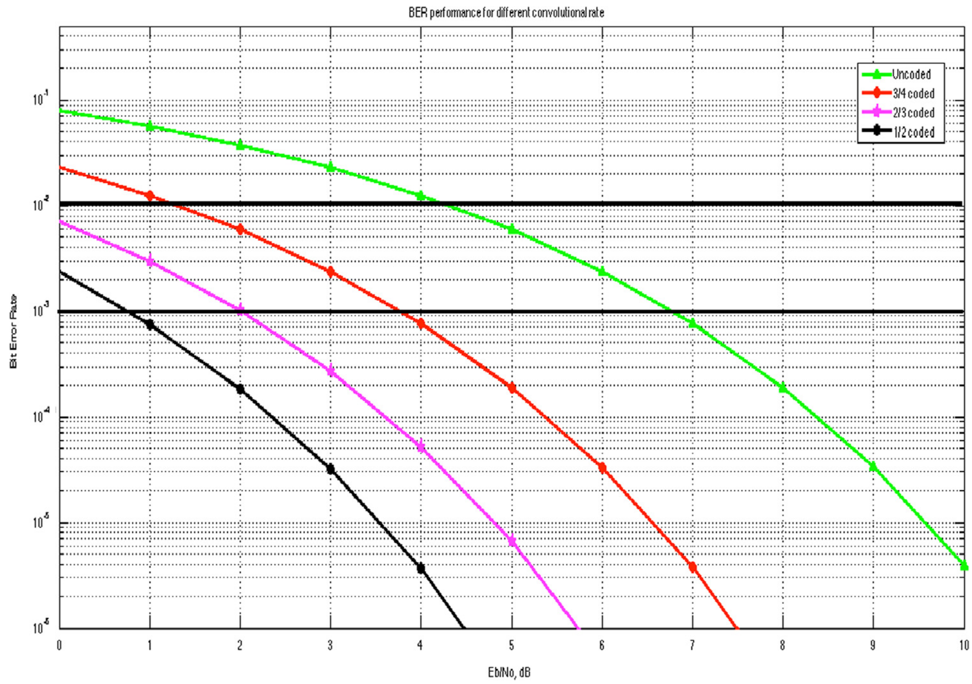

Fig. 4 Different convolutional coding performance under AWGN.

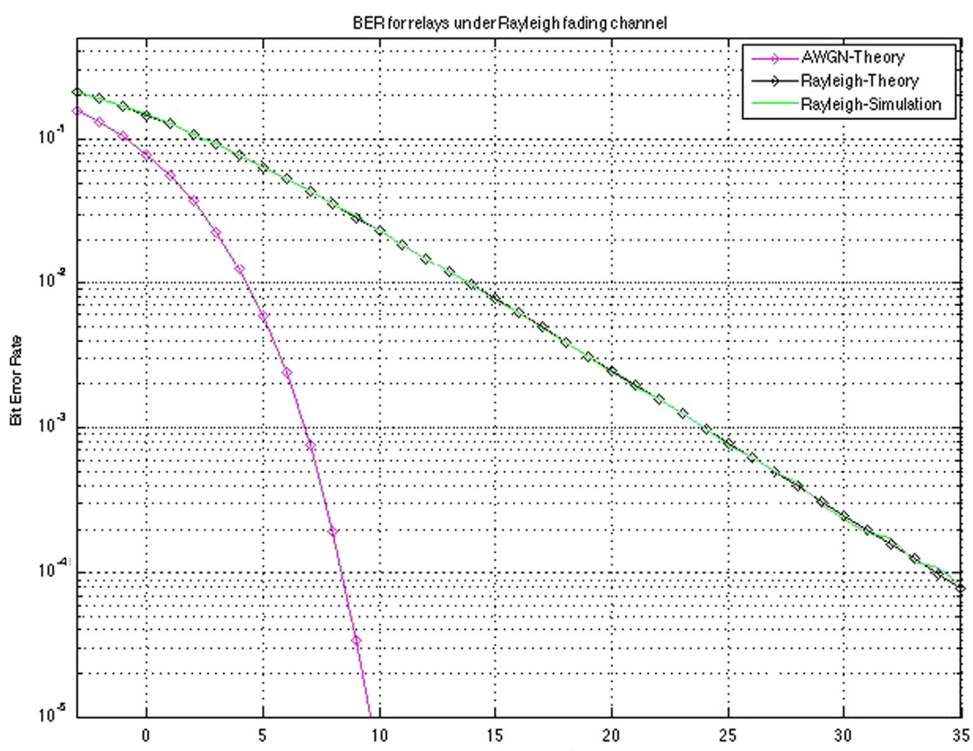

Fig. 5 BER performance for relays under AWGN and Rayleigh fading channel.

as $\sum_{j=0}^{i}\rho PP(j)$ combined with the probability for decoded PP data as$\prod_{j=0}^{i}(1-\rho \mathrm{PP}(j))$. The Pixel-Value (PV) data distortion expectation, which is shown as $\sum_{j=0}^{i}\rho \mathrm{PV(j)}$is combined with$\prod_{j=0}^{i}(1-\rho \mathrm{PP}(j))\prod_{j=0}^{i}(1- \rho \mathrm{PV}(j))$, because each of Pixel-Value data are based on the all Pixel-Position (PP) and all Pixel-Value (PV) at previous decoding. Then, we can say that the Pixel-Position (PP) contributes largely for the image information transmit, thus, PP should be higher protected rather than the PV. In Eq. (2). The expected total energy cost for transmit an image can be calculate as $\varepsilon(E)$, from sender to destination. Set $\overline{\varepsilon PP(j)}$ and $\overline{\varepsilon PV(j)}$ as energy needed for transmit Pixel-Position (PP) data and Pixel-Value (PV) data respectively.

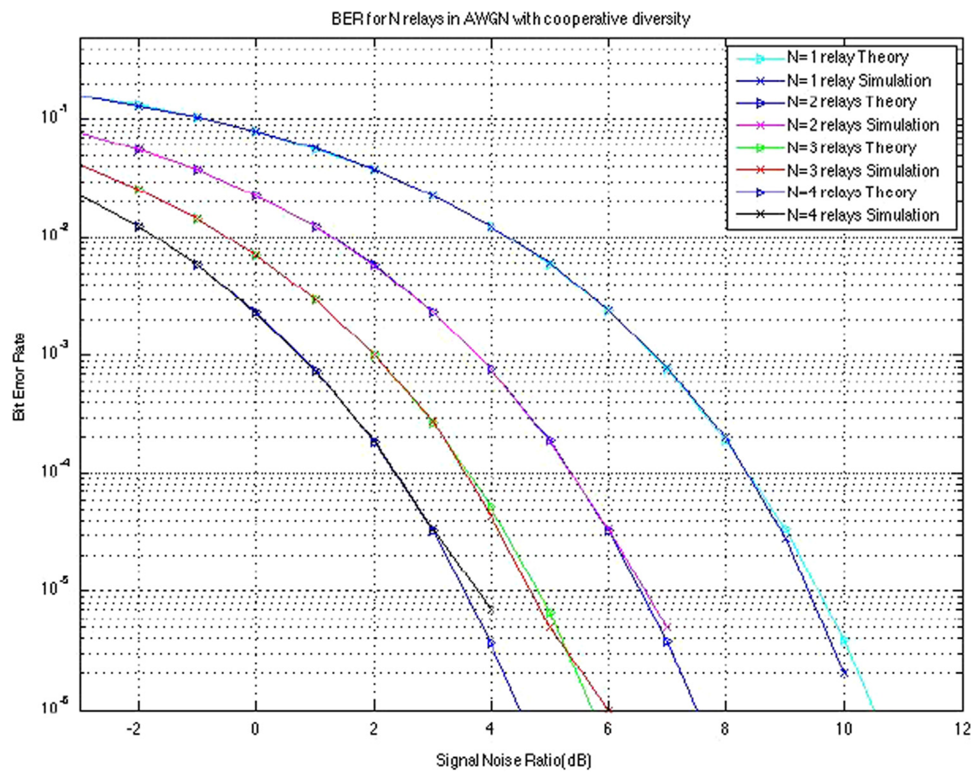

Fig. 6 BER performance for *N*-relays in AWGN channel with Cooperative Diversity.

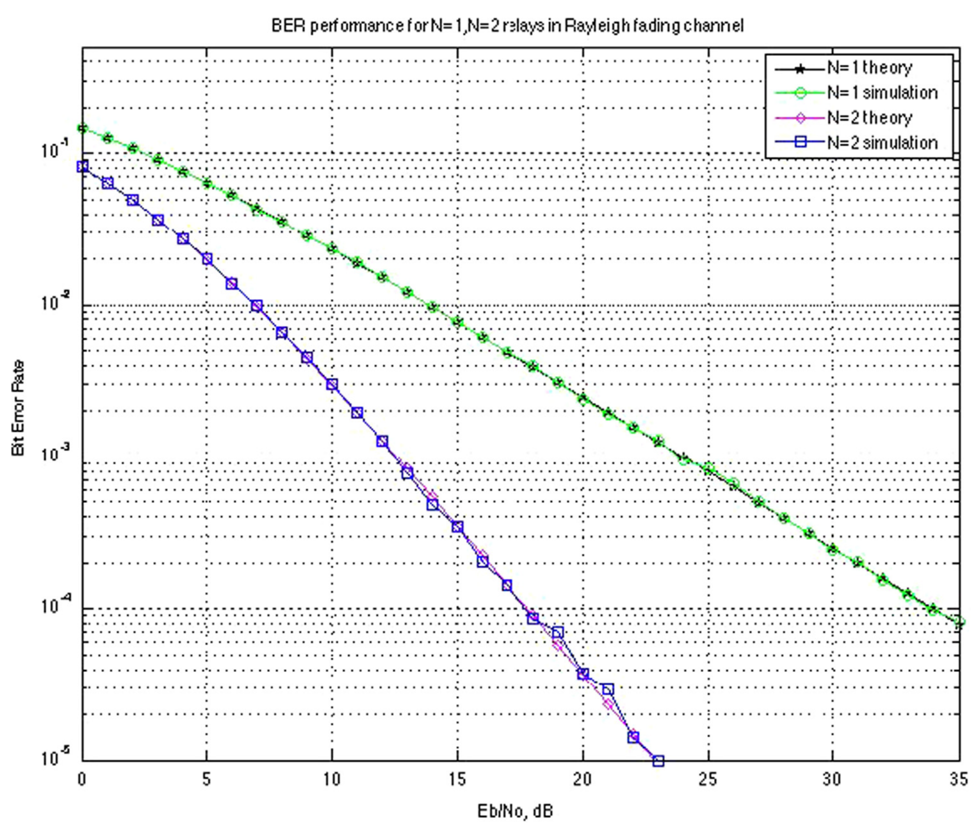

Fig. 7 BER performance for N=1,2 relays, under Rayleigh fading channel.

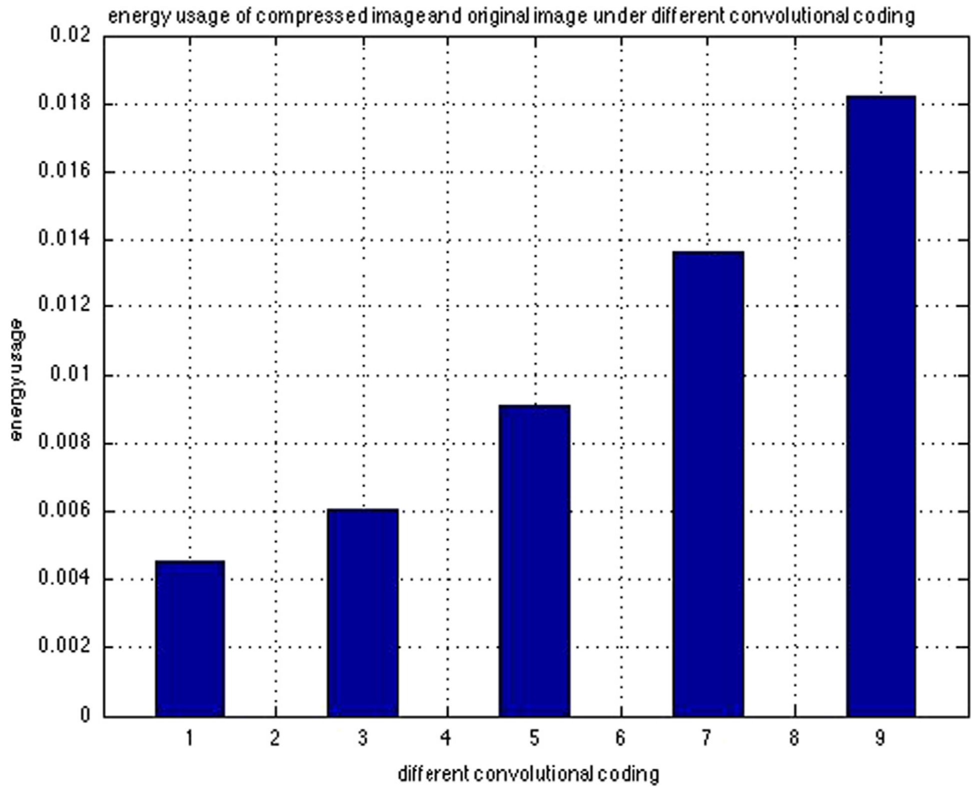

Fig. 8 Energy usage of compressed image and original image under convolutional coding rate at'1/1, 3/4, 1/2, 1/3, 1/4'.

Thus:

$$\varepsilon(E) = \sum_{j=0}^{N-1} \overline{\varepsilon PP(\mathrm{j})} + \overline{\varepsilon PV(j)} \quad (2)$$

B. Adaptive Forward Error Correction (FEC).

Adaptive FEC algorithm
Input: SNR at receiver side, BER at receiver side, sender (S), receiver (R),
Output: convolutional coding ratio ($1/N$), relay numbers (M).

1. Sender (S) sends out frame size (256*256(Lena) for example), then, requests communication channel condition of the receiver (R) side. Prepare for the whole image transmission.
2. Receiver (R) feedback to sender (S) about receiver (R) side channel environment including: Signal Noise Ratio (SNR), and tested Bit Error Rate (BER).
3. If $SNR > 7$ dB (at receiver side),
   Apply convolutional coding for $1/N$ and ask for M relays, (for $1/N$, the convolutional coding ratio is changing through the change of channel noise, for satisfy the total $BER <= 1\hat{0}-1$, then the lowest convolutional coding ratio will be chosen to promising the BER and energy efficient, based on Fig. 7).
4. Else if $4\,\text{dB} < SNR < 7$ dB
   Then, apply convolutional coding for $1/N+1$ and ask for $M+1$ relays, (when channel environment are decreasing, we can higher the convolutional coding ratio accordingly, and add more relays at receiver side for achieve lower BER)
5. Else if $SNR < 4$ dB then, apply convolutional coding for $1/N+2$ and $M+2$ relays for preparing transmission.

Ask for BER acknowledgment, If $\text{BER} > 1\hat{0}-1$, ready for retransmission,
Else complete image transmission.

End if
End if
End if
End

C. Cooperative Diversity for multi-hopping and multi relays

Cooperative Diversity technique is applicable for the cellular wireless network or sensors network, in which, devices or sensors are sharing the same base station for communication. In this case, devices, smart phones, or sensors can transmit data cooperatively. In this paper, convolutional coding, as an example of forward error correction method, was applied with Cooperative Diversity to transmit PP and PV data under complex communication channels. A smart phone terminal based communication network, in which, Pixel-Position data and Pixel-Value data can be transmitted through wireless smart devices from sender (S) to receiver (R) with two relaying smart devices ($P1$, $P2$), is able to relay signals for data re-correction. And a complex communication channel with channel fading coefficients $F1$, $F2$, $F3$

(from sender to $P1$, $P2$), and F4, F5 (from $P1$, $P2$ to receiver), assuming that the same AWGN noise was add to all channel from sender to relays and to receiver.

After that, in this proposed scheme, the general idea is to apply cooperative convolutional coding for data protection, across cooperative smart device relay network under complex communication channel. Here convolutional coding was applied for this Cooperative Diversity system against channel fading [8].

For BER performance analysis, we assume the mean and power of cannel fading (F_{ij}) are same with (K_{ij}) and (ζ_{ij}). Then, the signal noise ratio (SNR) can be represents by Eq. (3).

$$\gamma ij = \zeta ij\left(\frac{P_x}{N_O}\right) \tag{3}$$

In Eq. (3) Px/N_o is the signal noise ratio in an AWGN channel without channel fading at receiver side. The SNR at receiver side with diversity shown as

$$\gamma z = \sum_{k=2}^{3}\frac{\gamma 1k \times \gamma k0}{\gamma 1k + \gamma k0} + \gamma 10 = \sum_{k=2}^{3}\frac{1}{\frac{1}{\gamma k0}+\frac{1}{\gamma 1k}} + \gamma 10 \tag{4}$$

In Eq. (4), assume constraint length $K=3$, and convolutional coding ratio=1/3.

At cooperative coding, we assume the modulation with BPSK over fading channel. The BER with 2 relays nodes, $M=2$ shows as [9]:

$$BER = \left(\frac{2M+1}{4}\right) * M^{-(M+1)} * \frac{1}{\gamma 10} * \prod_{k=2}^{3}\left(\frac{1}{\gamma 1k}+\frac{1}{k0}\right) \tag{5}$$

$$BER = \frac{5}{32}\left(\frac{1}{(\frac{E_b}{N_o})^3}\right)\left(\frac{1}{\zeta 12}+\frac{1}{\zeta 20}\right)\left(\frac{1}{\zeta 13}+\frac{1}{\zeta 30}\right)\frac{1}{\zeta 10} \tag{6}$$

To represent the performance of cooperative convolutional coding, we provide a D_{zero} as the free distance term for calculating the union bounded BER performance under high and medium (SNR) signal to noise ratio [3,10]

$$BER = Q\left(\sqrt{k\sum_{d=1}^{D} c_d\left(\sum_{k=2}^{M+1}\frac{\gamma_{1k}^d * \gamma_{k0}^d}{\gamma_{1k}^d+\gamma_{k0}^d} + \gamma_{10}^d\right)}\right) \tag{7}$$

In Eq. (7), in which we define $D_{zero} = \sum_{d=1}^{D} c_d$, then $c_d$means in number dth coding rate, for cooperative convolutional coding rate, the γ_{1k}^d and γ_{k0}^d was set to represent SNR for each relays in the kth Cooperative Diversity and dth of cooperative coding rate, similarly, $\gamma_{10}^d$is for the direct path. Then the BER can be calculated as

$$BER = \frac{\prod_{i=1}^{t+1} 2i-1}{2(t+1)k^{(t+1)}} * \frac{1}{t!}\prod_{d=1}^{D} v_0^d \tag{8}$$

Set $\left(\prod_{i=1}^{t+1} 2i-1/2(t+1)k^{(t+1)}\right) * \frac{1}{t!}$=q, combined with Eq. (7) $D_{zero} = \sum_{d=1}^{D} c_d$, for the it have N relays for Cooperative Diversity, then:

$$BER = q\prod_{d=1}^{D}\prod_{k=2}^{M+1}\left(\sum_{j=0}^{N}\frac{x_{0k}^{dj}}{c_d}\right)\frac{z_0^d}{c_d} \tag{9}$$

In our work, we assume the channel fading are existing, in this case, the SNR shows as $(1/\bar{\gamma})e^{(-\gamma/\bar{\gamma})}$, Eq. (9) can be shown as

$$BER = q\prod_{d=1}^{D}\prod_{k=2}^{M+1}\left(\sum_{j=0}^{N}\frac{1}{c_d\bar{\gamma}_{1k}^{dj}}\right)\frac{1}{c_d\bar{\gamma}_{10}^{d}} \tag{10}$$

Experiment results

Fig. 4 shows the BER performance based on different ratios of channel coding, in which, convolutional coding is applied for image bits protection with SNR ranged from 0 dB to10 dB. It shows that higher ratio of convolutional coding can lower the Bit Error Rate (BER) in noisy communication channels. To obtain expected BER performances, (e.g., BER=10^{-2} and BER=10^{-3}, as two black parallel lines marked on Fig. 4), we consider using minimum convolutional coding ratio to minimum the energy cost. For example: To achieve BER<10^{-2}, when SNR>8 dB, we do not need any convolutional coding, since the BER is already below the black line. While if 4<SNR<8 dB, we consider applying convolutional coding rate 3/4, in which, the BER is maintained below the upper black line and the convolutional coding ratio is minimum as well. If SNR<2 dB, we chose convolutional coding rate as 2/3. It can be concluded that we can apply different convolutional ratios depending on the expected BER performance requirements adaptively and keep the minimum energy cost as well.

Fig. 5 shows BER performance of signal transmission under AWGN and Rayleigh fading channel. As shown below, the BER under fading channel is higher than AWGN channel as expected. In this case, we need more protection for important image data (PP data), especially under fading channel. Both simulation and theoretical results of relayed transmissions are shown as Fig. 5.

N relays (relays number N=1,2,3,4) BER performance has been plot in Fig. 6. We can observe that, the more relays, the better transmission qualities. When the noise level turns severely worse (SNR<4), multiple relays can help improve the transmission accuracy [11].

Fig. 7 shows BER performance for N=1,2 relays, under Rayleigh fading channel. For the N=2 relays, the BER reduced largely comparing with N=1 under fading channel environment (SNR>10 dB). In this case, we can achieve better performance by adjusting the tunable relay numbers and convolutional coding ratio. With the help of Channel State Information (CSI), for example when SNR at receiver side is low, higher convolutional coding and more relays will be applied; While when SNR at receiver side is reasonable, and the BER is endurable, convolutional coding ratio and relay number will be lowered down for energy saving purpose. Therefore, our proposed method may achieve higher energy efficiency for image transmission.

We estimate the energy consumption 'E_b' for the encoded data with different coding ratios in Fig. 8. The left most bar is calculated as the energy cost of transmitting image with none-convolutional coding. Second bar is calculated as the energy cost for image delivering with convolutional ratio %, etc. For instance, energy cost in first column is calculated as $E_b = (P_{max}+P_r)(L/R_t)+(P_t+P_r)(L/R)$, where L is encoded image length, R_t is the transmitting rate, P_{max} and P_r are the transmission and receive power, P_t is the optimal transmission power and R is the scalable transmission data rate due to the SNR value. For example, when transmission data rate is 6000 kbps, data length 36 bytes (standard TinyOS packet), the energy cost $4.55 \times 10^{-3} mj$ [2]. Then, The second column is calculated as the convolutional coding is 3/4, the energy cost is 6.07 $\times 10^{-3} mj$. The energy cost at third column is $9.1 \times 10^{-3} mj$, etc. shown as Fig. 8.

In Fig. 8, we can observe that the energy usage of image transmission with tunable error protection methods (adaptive convolutional coding). The left most bar represents the total amount of frame bits with none convolutional coding and no relays (good channel condition). And the second bar from left is the total frame bits after ZEW compression, which is based on the unequal resource allocation for PP and PV values. Accordingly, the total amount of energy needed for data transmission is based on how large the data size is. So, in our energy estimate section, we compare amount of frame bits that under different compressions protection based on the channel condition.

Conclusion

In this paper, we proposed an adaptive Forward Error Correction (FEC) coding and cooperative relaying method to promise both image transmission quality and energy efficiency. Due to the limitation of battery energy supply on smart phones, energy efficiency needs to be considered. Adaptive convolutional coding is applied for image data, protection during the transmission and Cooperative Diversity resist selective fading. Comparing to traditional methods, our proposed method is more practical to transmit high quality images through battery-limited smart phone platforms.

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