Adaptive FEC Coding and Cooperative Relayed Wireless Image Transmission

Hansong Xu¹, Kun Hua², Honggang Wang³

¹Electrical and Computer Engineering Department, Lawrence Technological University, Southfield, 48075, USA
²Electrical and Computer Engineering Department, Lawrence Technological University, Southfield, 48075, USA, Assistant Professor, Senior Member of IEEE, Corresponding Author
³Electrical and Computer Engineering Department, University of Massachusetts, Dartmouth, 285 Old Westport Road, North Dartmouth, MA 02747, USA, Assistant Professor, Senior Member of IEEE

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, iPad, 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 key components in the proposed scheme: 1. Discrete Wavelet Transform (DWT) and wavelet based Decomposition 2. Split of Pixel-Position (PP) information and Pixel-Value (PV) information based unequal image resource allocation 3. Transmission through selective fading channel. 4. Multiple-relays and adaptive channel coding. Comparing to traditional methods, our proposed method is more practical to transmit high quality images through battery-constrained smart phone platforms.

Keywords: Image compression, Embedded Zero Tree Wavelet (EZW), Discrete Wavelet Transform (DWT), Forward Error Correction (FEC), Cooperative Diversity (CD).

Introduction

Comparing to traditional mobile communication terminals, smart devices in nowadays demand larger display screens, higher data transmission rates and extremely low transmission error rate, onto which high resolution cameras are assembled for high quality pictures instead of regular sizes from traditional cameras. Thereby, due to limited battery energy supply, energy efficiency is required especially under severely noisy channel.

We apply Embedded Zero-tree Wavelet (EZW) for efficient image compression. Firstly, Discrete Wavelet Transform was applied to extract coefficients of an original image; after wavelet based decomposition, pixel-position information and pixel-value information will be extracted form original image; after wavelet decomposition, part of aforementioned information is turned to a couple of groups of number ‘0’ which can be compressed largely, followed by a couple number of none zero values. Such large group of zeros contains pixel-position (PP) information, which is more important, comparing to large value pixel-value (PV) information for image transmission [2]. In this paper, an adaptive Forward Error Correction (FEC) was applied over the important part of the image information, under severe communication channel. Convolutional coding method is also used for protect important part of image information (pixel-position), to achieving low BER and high data rate. Furthermore, several mobile terminal as relayers are used to set up a cooperative transmission network. To overcome MIMO system’s limitation such as limited size and hardware complexity in wireless cellular system, Cooperative Diversity (CD) is considered as a more practical solution to ‘extend’ the antenna number.

Our contributions in this paper are as follows:

1. Unequally allocated energy to transmit important Pixel-Position information and unimportant Pixel-Value information, due to the unequal importance of image information;
2. Designed an adaptive Forward Error Correction (FEC) scheme, to achieve low BER under both AWGN and selective fading channels. And evaluated their BER performances under complex channel conditions;
3. Applied cooperative diversity with adaptive convolutional coding and adjustable multiple-relays in quality promised image transmission.

![Image: Model of Adaptive FEC Coding and Cooperative Relayed Wireless Image Transmission]
Explanation of icons in Fig.1 is shown as below:

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>📡</td>
<td>Base Station communication zone</td>
</tr>
<tr>
<td>📱</td>
<td>Smart devices: smart phone</td>
</tr>
<tr>
<td>🛠️</td>
<td>Wired communication between Base Station</td>
</tr>
<tr>
<td>🦃</td>
<td>Smart device signal condition</td>
</tr>
<tr>
<td>📈</td>
<td>Distance measure</td>
</tr>
<tr>
<td>📰</td>
<td>Wireless communication between devices, and BS</td>
</tr>
<tr>
<td>⬛️</td>
<td>Sender device, receiver, Base Station, relays 1, relays 2.</td>
</tr>
</tbody>
</table>

Table 1: Explanation of icons

Peer work review

Paper [1] introduced an efficient image compression method, which is named as Embedded Zero-tree Wavelet (EZW). It firstly applies Discrete Wavelet Transform (DWT) over original image for coefficient decomposition, and then, the digital image bits are converted into bit stream with importance order; furthermore, the low frequency parts are forced to zeros, which are regarded as Pixel-Positions (PP), and can be compressed largely; meanwhile, the high frequency information containing less important information is regarded as Pixel-Value (PV). The amount of zeros can be compressed largely by using how many numbers of zeros instead of transmit exactly all zeros in the Pixel-Position (PP) information. In this case, EZW image compression method achieves high compression ratio and at the same time, it promises image quality. While in [1], they didn’t yet apply this method onto image transmission via mobile devices, which means image transmission among smart devices were not evaluated under different mobile communication environments. Then, paper [2], provided a method for image compression based on unequal importance of the pixel-position and pixel-value, and unequal error protection (UEP) has been used in this paper for information protection and energy saving. But in this paper, transmission for compressed image through smart device is not considered. Furthermore, paper [3] explained the concept of cooperative diversity transmission through noisy communication channels. In their work, a cooperative communication network has been built up through individual smart devices, such as smart phone or PDAs, to achieve high energy efficient, and overcome high noise interference. A problem in their work is that, only 1-D signal communication was considered, but solutions for 2-D image transmission were left blank. Recently, paper [5], provided a cooperative wireless communication network based on Alamouti, compared with Maximum Ratio Combining (MRCA balanced cooperative diversity network is developed, which is efficient and robust under complex channel environments, but they didn’t consider compression method for preprocessing the image for multi-media communication. Comparisons of aforementioned research work are shown in Table 2:

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

Table 2: Comparison of peer research work

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 are stored in a matrix which is X-Y sized; after that, the matrix is scanned through the importance order from most important to least important, if the magnitude is larger than the threshold, it is called as large value, or it’s small value if smaller than threshold. Small values of coefficients 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 in a decreasing 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 cause much 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),
   - 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’s 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-location data (PP) and pixel-value data (PV) from original image (OI).

<table>
<thead>
<tr>
<th>EZW-encoding threshold</th>
<th>30</th>
<th>50</th>
<th>100</th>
<th>250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>The bitrate is 0.71 bpp, The psnr performance is 27.65 dB</td>
<td>The bitrate is 0.31 bpp, The psnr performance is 26.21 dB</td>
<td>The bitrate is 0.12 bpp, The psnr performance is 23.53 dB</td>
<td>The bitrate is 0.05 bpp, The psnr performance is 21.01 dB</td>
</tr>
</tbody>
</table>

Table 3: EZW parameters

Figure 2: Transmission with EZW compression, from left to right, under different level of communication channel noise.
Our Pixel-Position (PP) and Pixel-Value (PV) unequal resource allocation is based on EZW image compression. In equation (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 $\rho_{PP(j)}$ and $\rho_{PV(j)}$ to represent the loss ratio of Pixel-Position (PP) and Pixel-Value (PV) respectively. Then the total distortion reduction calculation can be shown as [2]

$$
\varepsilon(j) = \sum_{i=0}^{N-1} (\sum_{j=0}^{i} PP(j)) \Pi_{j=0}^{i} (1 - \rho_{PP(j)}) +
(\sum_{j=0}^{i} PV(j)) \Pi_{j=0}^{i} (1 - \rho_{PV(j)}) \Pi_{i=0}^{N-1} (1 - \rho_{PP(i + 1)})
$$

Above equation, which represents the total distortion reduction, shows that the Pixel-Position data distortion represented as $\sum_{j=0}^{i} PP(j)$ combined with the probability for decoded PP data as $\Pi_{j=0}^{i} (1 - \rho_{PP(j)})$. The Pixel-value (PV) data distortion expectation, which is shown as $\sum_{j=0}^{i} \rho_{PV(j)}$ is combined with $\Pi_{j=0}^{i} (1 - \rho_{PP(j)}) \Pi_{j=0}^{i} (1 - \rho_{PV(j)})$, 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.

For energy cost equation, set $\varepsilon(E)$ as expected total energy cost for transmit an image, from sender to destination. Set $\varepsilon_{PP}(j)$ and $\varepsilon_{PV}(j)$ as energy needed for transmit Pixel-Position (PP) data and Pixel-Value (PV) data respectively. Thus:

$$
\varepsilon(E) = \sum_{j=0}^{N-1} \varepsilon_{PP}(j) + \varepsilon_{PV}(j)
$$

(2)

B. Adaptive Forward Error Correction (FEC).

Adaptive FEC algorithm

Input: sender (S), receiver (R), SNR at receiver side, BER at receiver side

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) for no protection.

3. If SNR>7dB (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<=10^-1, then the lowest convolutional coding ratio will be chosen to promising the BER and energy efficient, based on figure 6).
4. Else if $4\text{dB}<\text{SNR}<7\text{dB}$
   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 $\text{SNR}<4\text{dB}$ then, apply convolutional coding for $1/N+2$ and $M+2$ relays for preparing transmission. Ask for BER acknowledgment, If BER$>10^8$-1, ready for retransmission, Else complete image transmission.
End if
End if
End if
End if

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.

For a smart phone terminal based communication network where pixel-position data and pixel-value data is transmitted through wireless smart devices from sender (S) to receiver (R) with two relaying smart devices (P1, P2) which 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 (White Gaussian noise) was add to all channel from sender to relays 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 the performance analysis, assume the mean and power of channel fading $(Fij)$ are same with $(Ki)$ and $(\zeta ij)$, then the signal noise ratio (SNR) can be represent by [3]

$$yij = \zeta ij \left( \frac{Eo}{No} \right)$$

(3)

In (1) $Px/No$ is the signal noise ratio in an AWGN channel without channel fading at receiver side. The SNR at receiver side with diversity show as

$$y=Px/No + \sum_{k=2}^{3} \frac{y_{ikj}*y_{k0}}{y_{ikj}+y_{k0}} + \gamma 10 = \sum_{k=2}^{3} \frac{1}{y_{ikj}+y_{k0}} + \gamma 10$$

(4)

In (2), 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 show as:

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

(5)

$$ BER = \frac{5}{32} \left( \frac{1}{\gamma 10} \right) \left( \frac{1}{\gamma 10} + \frac{1}{\gamma 20} \right) \left( \frac{1}{\gamma 10} + \frac{1}{\gamma 30} \right) \frac{1}{\gamma 10} $$

(6)

To represent the performance of cooperative convolutional coding, we provide a $D_{free}$ as the free distance term for calculating the union bounded BER performance under high and medium (SNR) signal to noise ratio [9],

$$ BER = \frac{Q\left( k \sum_{d=1}^{D} \frac{1}{y_{0}} \left( \sum_{k=2}^{M+1} \frac{y_{dkj}y_{k0}}{y_{dkj}+y_{k0}} + y_{d10} \right) \right) }{k \sum_{d=1}^{D} \frac{1}{y_{dkj}y_{k0}} } $$

(7)

In equation (7), in which we define $D_{zero}=$sum of $d$, then $c_d$ means in number $d$th coding rate, for cooperative convolutional coding rate, the $y_{dkj}$ and $y_{d10}$ was set to represent SNR for each relays in the kth cooperative diversity and dth of cooperative coding rate, similarly, $y_{d10}$ is for the direct path. Then the BER can be calculated as

$$ BER = \left( \frac{\prod_{d=1}^{M+1} 2(1-1)}}{(2+1)(2+1)} \right) * \frac{1}{c_d} \prod_{d=1}^{D} \frac{1}{y_{0}^{d}} $$

(8)

Set $\prod_{d=1}^{M+1} 2(1-1)}{(2+1)(2+1)} = q$, combined with equation (7)

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

(9)

in our work, we assume the channel fading are existing, in this case, the BER shows as $(1/y)^{e_{-1}^{y}/y}$, it can be reduced to

$$ BER = q \prod_{d=1}^{D} \prod_{k=2}^{M+1} \left( \sum_{f=0}^{N} \frac{1}{c_d} \frac{a_d}{c_d} \right) \frac{1}{c_d} $$

(10)

Experiment results

In figure 4, different ratios of channel coding were applied for image bits protection under AWGN noise level ranged from 1dB to10dB. It shows that higher ratio of convolutional coding can lower the Bit Error Rate (BER) in the noisy communication channel, and has great improvement when the Signal Noise Ratio (SNR)>4dB, While, in an even worse circumstance (SNR<4dB), ARQ may be needed.

Figure 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 which case we need to especially protect important image data (PP data). Both simulation and
theoretical results of relayed transmissions have been compared. N relays (relays number N=1,2,3,4) BER performance has been plot in figure 6. It could be observed that, the more, the better transmission qualities. When the noise level turns severely worse (SNR<4), multiple relays will help much [10]. Figure 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>10dB). 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 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.

Figure 4: Different convolutional coding performance under AWGN.

Figure 5: BER performance for relays under Rayleigh fading channel.

Figure 6: BER performance for N-relays in AWGN channel with cooperative diversity.

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

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

In Figure 8, we can observe the energy usage of image transmission for tunable protection method, for the odd
number rows, which represent the energy cost for no compression, and no cooperative diversity applied, while, to protect image we applied different channel coding from ‘1/1, 3/4, 1/2, 1/3, 1/4’, under different level of channel noise respectively. Compared with even number of rows, which represents different convolutional coding ratio from ‘1/1, 3/4, 1/2, 1/3, 1/4’ with ‘ZEW’ compression for noise channel. The even number of rows shows that energy cost for image transmission are reduced greatly, which, mainly because high compression ratio was applied, the compressed image size is reduced largely. Not only transmission quality but also energy efficiency is promised even under high noisy channel.

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-constrained smart phone platforms.

Acknowledgement

This work was supported by the contract award DUE S-STEM Grant-1154490 from the US Natural Science Foundation.

Reference