Research on Denoising Method in Pseudo-analog Video Transmission

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Abstract. With the rapid development of mobile communication technology and the applications of 5G technology, video transmission, compared with file transmission, audio transmission and other media forms, has been more and more widely used. Today, the mobile video broadcasting needs to overcome some difficulties like the transmission noise. A knowledge-enhanced mobile video broadcasting (KMV-Cast) is a scheme utilizing joint source-channel coding and the correlated information in clouds, but in its calculation, there is still an item of noise that cannot be eliminated at the receiver side. In this paper, as same to KMV-Cast, the new scheme also exploits the hierarchical Bayesian model, the correlated information distillation in the clouds and Bayesian estimation algorithm to improve video quality. After the video reconstruction at the receiver, based on the items of the signal and the noise, selectively adds a Wiener filter to reduce the effect of noise. The simulation results show that the proposed KMV-Cast scheme with a proper Wiener filter at the receiver side is superior to that scheme without the Wiener filter and it achieves about 2 dB more of the peak signal-to-noise ratio (PSNR) gain at low-SNR channels (i.e., −10 dB) and about 1.5 dB more of PSNR gain at high-SNR channels (i.e., 10 dB).

Keywords: Wiener filter · Correlated information · Wireless video transmission

1 Introduction

With the prediction of Cisco Annual Internet Report 2020, over 70% of the global population will have mobile connectivity by 2023 and the total number of global mobile subscribers will grow from 5.1 billion (66% of population) in 2018 to 5.7 billion (71% of population) by 2023 [1]. The wireless communication technology, such as WiFi, LTE and so on, cannot meet the needs of the future with the increasing number of mobile users. So, reforming the traditional video transmission scheme is one of the current research hotspots of the mobile communication technology development.

As we all known, the traditional wireless video transmission adopts source-channel separation coding scheme and the coding between sources and channels limits the quality of transmission. When the channel quality is below a certain threshold, the quality of the received video declines linearly, which is called cliff effect. Cliff effect is

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caused by the separation of source and channel coding and to solve this problem the new combined source-channel coding scheme was proposed [2]. It realized the joint control of source and channel coding and was applied into image transmission. Then, some joint source-channel coding schemes were proposed.

Among them, a conventional joint source-channel coding scheme proposed by Szymon Jakubczak and Dina Katabi, called Softcast [3], overcomes the cliff effect of a wireless video transmission well. The signal-to-noise ratio of the reconstructed image is linearly correlated with the channel quality. KMV-Cast is a brand-new video transmission framework and it is a joint source-channel coding scheme [4]. It can also overcome the cliff effect of a wireless video transmission like Softcast. Besides, it also makes a full use of correlated information to improve the quality and efficiency of reconstructed video and it utilizes the corresponding calculation to remove the mutual interference. But there is still a part of noise that cannot be eliminated through calculations and makes the image clearly segmented. In this paper, we mainly try to get rid of this part of noise and the Wiener filter is chosen to add into the KMV-Cast scheme.

During the transmission, we assume the noise in the channel is the additive white Gaussian noise, so the noise of the second item also follows the Gaussian distribution. It can be seen that the least mean square (LMS) principle is widely used in the noise elimination [5–9] and has a relatively good effect. For Wiener filter, the essence is to minimize the mean square value of the estimation error (defined as the difference between the expected response and the actual output of the filter), and the LMS algorithm is to minimize the mean-square error (MSE) performance function, define as $E\left\{e^2\right\}$ [6]. When using a Wiener filter, it needs prior knowledge of the power spectral density of the noise [8], which can be satisfied by its assuming noise Gaussian distribution. From above, adding a Wiener filter is a proper method to remove the second noise item of KMV-Cast scheme.

In this paper, firstly, we choose to add a Wiener filter to each block, to filter out certain noise and overall, there is an evident effect. But to some perfect blocks whose SNR is already higher, the effect is not ideal. This will be introduced in details later. Therefore, we decide to take block as a unit to selectively import the Wiener filter. The main functions are: 1) at the transmitter, correlated information extraction, evaluating and determining whether transmit and whether need to add the corresponding Wiener filter; 2) at the receiver, utilization of such information and Wiener filter for fast video recovery. We firstly search and extract correlated information in clouds based on certain criteria [10]. Secondly, based on KMV-Cast scheme [4], remove mutual interference and make full use of correlated information for image reconstruction. At last, selectively add Wiener filter to eliminate noise.

2 Related Work

2.1 Related KMV-Cast Transmission Scheme

From proposed KMV-Cast scheme, it can be seen that the reconstructed signal, at the receiver side, can be represent as [4]

$$\hat{\theta} = \left(\alpha^2\sigma_0^{-2}I + \Omega^{-1}\right)^{-1}\alpha\Phi^T\sigma_0^{-2}y = p\theta + \frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1} + \frac{\alpha\sigma_0^{-2}\vec{\theta}_i\vec{\theta}_i^T\Phi^T\nu}{(Cr+1)(Cr+C+1)}. \quad (1)$$

Here, each video frame is evenly divided into small pixel blocks (i.e., 8×8, $m = 64$), θ is the transmitted signal normalized vector ($m \times 1$), Φ is an $m \times m$ unitary matrix to reduce the peak-to-average power ratio, α is the power scaling factor, v is an independently and identically distributed Gaussian noise of a zero-mean and a known variance σ_0^2, $C = \alpha^2\sigma_0^{-2}$ is defined as the power scaling parameter, variance r is determined by maximum SNR, and p is donated as followings [4]:

$$p^2 = \left\{\left(\frac{Cr+1}{Cr}\right)^2\left[\frac{K^2}{[r(Cr+C+1)]^2} - \frac{2K^2}{[r(Cr+C+1)]} + 1\right]\right\}^{-1}. \quad (2)$$

where $K = \left(\vec{\theta}_i^T\theta\right)$ is the correlation coefficient of the pixel block. Since both the transmitter and the receiver know the information in clouds $\vec{\theta}_i$, we can remove the mutual interference item and get the final reconstructed signal expression [4]:

$$\hat{\theta} = p\theta + \frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1}. \quad (3)$$

The noise power in Eq. (3) can be represented as [4]

$$P_N = E\left\{tr\left\{\left(\frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1}\right)\left(\frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1}\right)^T\right\}\right\} = E\left\{tr\left\{\frac{\alpha^2\sigma_0^{-4}r^2\Phi^T\nu\nu^T\Phi}{(Cr+1)^2}\right\}\right\} = \frac{Cr^2m}{(Cr+1)^2}. \quad (4)$$

We donate two new variables for the easier calculation [4]

$$t = r(Cr+C+1) \quad (5)$$

$$A = \frac{\sqrt{C}(t+1)}{\sqrt{K^2 - 2K^2(t+1) + (t+1)^2}}. \quad (6)$$

The corresponding signal-to-noise ratio SNR_1 of the KMV-Cast model is [4]

$$SNR_1 = \frac{P_S}{P_N} = \frac{p^2}{P_N} = \frac{(Cr+1)^2p^2}{Cr^2m} \quad (7)$$

and take formular (2), (5) and (6) into the expression of SNR_1.

$$SNR_1 = \frac{A^2}{m}. \quad (8)$$

2.2 Wiener Filter Principle

The essence of Wiener filtering is to minimize the mean square value of the estimation error. The main process of the system can be represented as the following picture (Fig. 1):

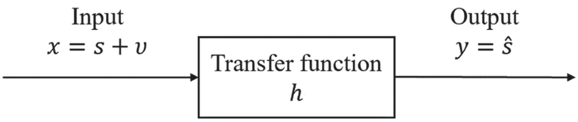

Fig. 1. The Wiener filter diagram.

where the signal and noise are both vectors. The transfer function is the matrix that we determine. The input of the filter is the origin signal and the noise of the transmission, and the optimal output of the filter is the origin signal without the noise. The estimation error is

$$e = |\hat{s} - s| = |x * h - s| \tag{9}$$

and the mean square value of the estimation error can be represented as:

$$E\{e^2\} = E\left\{(x * h - s)^2\right\}. \tag{10}$$

The goal is to get a proper transfer function h to minimalize the above formular (9), so we utilize its derivative with respect to h, like the following:

$$\frac{\partial E\{e^2\}}{\partial h} = 2E\{(x * h - s) * x\} \tag{11}$$

The point where its derivative is zero is the extreme point, so set the formular (11) equal to zero, and we can get:

$$HR_{xx} - R_{xs} = 0 \tag{12}$$

where H is the matrix of the optimal transfer function. R_{xx} is the autocorrelation matrix of the input signal and R_{xs} is the correlation matrix of the input signal and expected signal. The input signal consists of the origin signal and noise in the transmission, and the two parts are uncorrelated. As a result, we determine the transfer matrix as

$$H = R_{ss}(R_{ss} + R_{vv})^{-1}. \tag{13}$$

2.3 KMV-Cast + Wiener Filter

Add Wiener Filter at the Receive Side

Now we add a Wiener filter to reduce some noise in the second item of the formular (3). From formular (13), we can see that the transfer function of the Wiener filter only depends on the autocorrelation matrixes of the signal and noise, and the two autocorrelation matrixes can be calculated like the followings:

$$R_{ss} = E\left\{p^2\theta\theta^T\right\} = p^2E\left\{\theta\theta^T\right\} = p^2\Omega = p^2rI + p^2\vec{\theta}_i\vec{\theta}_i^T \tag{14}$$

$$R_{vv} = E\left\{\frac{\alpha^2\sigma_0^{-4}r^2\left(\Phi^T\nu\right)\left(\Phi^T\nu\right)^T}{(Cr+1)^2}\right\} = \frac{Cr}{(Cr+1)^2}I. \tag{15}$$

So the transfer function can be shown as

$$H = R_{ss}(R_{ss}+R_{vv})^{-1} = \frac{(Cr+1)^2p^2}{(Cr+1)^2p^2+Cr}I + \frac{Cr(Cr+1)^2p^2}{\left[(Cr+1)^2p^2+Cr\right]\left[(Cr+1)^2p^2(r+1)+Cr^2\right]}\vec{\theta}_i\vec{\theta}_i^T. \tag{16}$$

The output signal through the Wiener filter can be written as

$$H\hat{\theta} = H\left(p\theta + \frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1}\right) = p\theta + H\frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1} - (I-H)p\theta. \tag{17}$$

As a result, the noise of the signal processed again is changed into

$$noise = H\frac{\alpha\sigma_0^{-2}r\Phi^T\nu}{Cr+1} - (I-H)p\theta. \tag{18}$$

As the same to the KMV-Cast, we can calculate the noise power through

$$P_N = E\left\{tr\left\{noise \times noise^T\right\}\right\} \tag{19}$$

After calculations, we can get the expression of SNR_2.

$$SNR_2 = \left\{\frac{1+r^2A^2-2rA}{(rA^2+1)^2} + \frac{[(-2r-1)A^4-2A^2]K^2+\left[2r(r+1)A^5-2A\right]K+[2r(r+1)A^4+(2r+1)A^2]}{(rA^2+1)^2[(r+1)A^2+1]^2}\right\}^{-1}. \tag{20}$$

From (5), we can calculate [4]:

$$r = \frac{-(C+1)-\sqrt{(C+1)^2+4Ct}}{2C}. \tag{21}$$

Determining Whether to Transmit and Whether to Add Wiener Filter
There are three ways to reconstruct the pixel blocks: (1) use the relevant information in the clouds and don't need to transmit or use Wiener filter. (2) use the KMV-Cast scheme without Wiener filter to some blocks with high power scaling parameters. (3) use the KMV-Cast scheme adding a proper Wiener filter.

If we use the relevant information and transmit the index of the similar pixel block $\vec{\theta}_i$, the SNR of reconstructed block is [4].

$$SNR_0 = \frac{1}{|\Delta|^2} = \frac{1}{2(1 - |K|)}. \tag{22}$$

Compared three formulars (8), (20) and (22), we can choose how to deal with the pixel block.

Power Scaling
In order to maximize the peak signal-to-noise ratio (PSNR) of the reconstructed video, we should minimize the total noise power of all transmitted pixel blocks with the given constrain of signal power P. Assume $l_{j(t)}$ is the noise power of the jth reconstructed block and it can be decided with the condition of maximum SNR.

The total noise power can be written as [4]

$$min\left\{\sum_{j=1}^{M} \frac{\lambda_j^2 l_{j(t)}}{C_j}\right\} \tag{23}$$

with the constraint condition [4]:

$$\sum_{j=1}^{M} C_j \leq P/\sigma_0^2 \tag{24}$$

where $\lambda_j^2 l_{j(t)}/C_j$ is the noise power of the jth reconstructed block. In order to minimalize the total noise of the reconstruct video, we need to allocate the power scaling parameter C_j by Lagrange multipliers, like the followings [4]:

$$C_j = \frac{\sqrt{\lambda_j^2 l_{j(t)}}}{\sum_{k=1}^{M} \sqrt{\lambda_k^2 l_{k(t)}}}, j = 1, 2, \ldots, M. \tag{25}$$

3 Experimental Results

In this section, we evaluate the performance of the proposed KMV-Cast + Wiener filter transmission scheme in terms of PSNR. We assume that the transmission channel is slow fading and its distortion can be cancelled by the equalizer. Besides, we compared the simulation results under additive white Gaussian noise channel. We mainly choose three typical transmission schemes to compare with the new proposed way, which are uncoded transmission, Softcast and KMV-Cast.

As same to KMV-Cast transmission framework, the transmitted video is segmented into frames and the correlated information can be known by both the transmitter and the receiver. From the standard video test sequence Foreman, we choose the 4th frame as the correlation information in clouds. As we can see from Fig. 2 and Fig. 3, we respectively choose 5th, and 215th frames as the transmitted signals which are highly correlated, and uncorrelated. On the whole, KMV-Cast with the Wiener filter is better than three other schemes. In details, from Fig. 2 with highly correlated information, compared with Softcast and KMV-Cast scheme, there are respectively more than 12.5 dB and 2.7 dB of PSNR gain for adding the Wiener filter at higher channel, but from Fig. 3 with no correlated information, there are respectively 14 dB and 1 dB of PSNR gain. So it can be seen that the advantage increases with the increase of similarities between transmitted signal and correlated information in clouds.

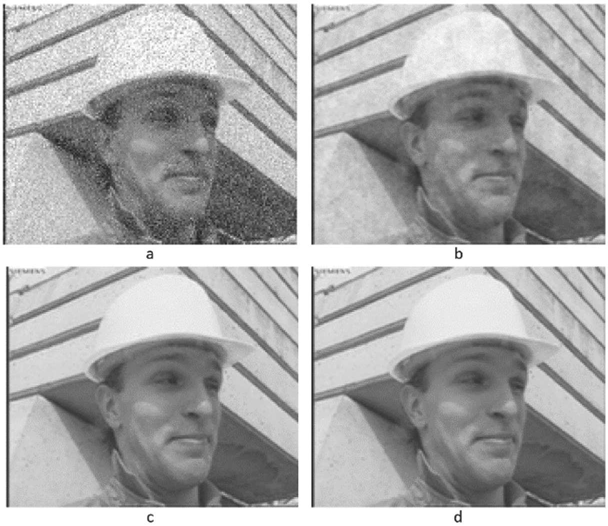

Fig. 2. Reconstructed video quality comparisons with highly correlated information in clouds. Channel SNR: 10 dB. (a) Reconstruct #5 frame using uncoded video transmission (23.71 dB). (b) Reconstruct #5 frame using SoftCast (32.89 dB). (c) Reconstruct #5 frame using KMV-Cast (42.64 dB). (d) Reconstruct #5 frame using proposed KMV-Cast + Wiener filter (45.38 dB)

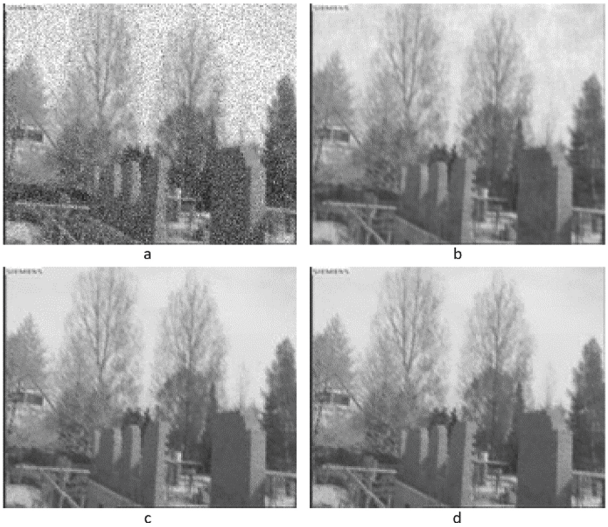

Fig. 3. Reconstructed video quality comparisons with no correlated information in clouds. Channel SNR: 10 dB. (a) Reconstruct #215 frame using uncoded video transmission (23.46 dB). (b) Reconstruct #215 frame using SoftCast (34.18 dB). (c) Reconstruct #215 frame using KMV-Cast (36.53 dB). (d) Reconstruct #215 frame using proposed KMV-Cast + Wiener filter (37.47 dB).

4 Conclusions

In this paper, the Wiener filter has been proposed to reduce the noise of the second item in KMV-Cast. The main difference with the related work is that we need to determine whether to add the Wiener filter to the transmitted pixel blocks based on corresponding expressions. This method has maximized the PSNR of reconstructed video and the simulation results have shown that selectively adding the Wiener filter performs better than the KMV-Cast scheme without a filter and others.

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