A Hierarchically Reliable Transmission Scheme [*]

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Abstract - In real world the network environment is varied and the network resource is limited. How to supply real-time and reliable transmission service with less network resource under the explosive transmission scale becomes a hot spot, this paper proposed a novel transmission scheme which supports improved hierarchical feedback architecture, under this architecture the normal group and each emergent node are treated with independent transmission strategy, and under varied network environment each strategy can self-organize transmission structure and self-adjust transmission parameters to adapt different transmission conditions, this scheme also applies partial FEC base on Bayes learning to save bandwidth. Approach was tested on MG3500 embedded platform; experiments showed this scheme can decrease approximate 60% of original error rate on average and save about half network bandwidth compared to original FEC method error.

Index Terms - Hierarchical Feedback, Bayes Learning, Partial FEC, Adaptive Transmission Strategy

1. Introduction

With the generation of computer network technology since last half century, the streaming media technology as H.264 codec standard, RTP/RTCP Protocol has become domination in the market [1], [2]. Now, streaming media transmission still has many problems to deal with, such as how to guarantee real-time performance under large transmission scale and how to transmit information reliably in varied network environments with limited network resource[3], [4].

Traditional RTCP feedback framework often causes prodigious interval under large transmission scale [5]. A. V. Babich suggests using an extended RTCP feedback path to remove the bandwidth of RTCP from RTP transmission path [6], Longgen Liao applies Extended Report (*XR*) instead of Receiver Report (*RR*) [7], and to compress the bandwidth of *XR*, he encodes the *XR* at first. Ling-ling Wang [5] improves the Hierarchical Feedback Architecture, in his method receivers interact with senders through the summarization node, the emergent information will be sent prior, thus the sender can rapidly response to emergent changes.

Because of the difference of network condition and receive device, the transmission strategy should be different for each receiver, several approaches are based on SVC framework or the partition of encode data [8], [9], [10], XIE Ke argues that the Qos should be managed with the attribute of receivers [11], this approach supplies a new view that unequal treat could be operated on each receiver instead of encode data.

In real world, the network environment often changes a lot, the fixed transmission structure can not adapt the varied network conditions will cause an acute shake in the receiver end. Jiao Feng proposes an adaptive FEC algorithm by balancing the trade-off between the Qos of video transmission and the bandwidth utilization ratio in wireless IP networks [12], and Fisal, N. combines FEC with cross layer mechanism to adapt varied network condition [13].

In fact, not all bits in a packet will be noised or all packets in a packet group will be lost after transmitted, there is no necessary to protect all data with FEC, partial FEC is a good idea to save bandwidth while protecting weak data [14], [15].

Here, we propose a novel hierarchically reliable transmission scheme, in this scheme, each receiver is divided as normal or emergent node , all the normal nodes form a normal group, transmission strategies are independently designed for each emergent node and normal group, under this architecture sender can rapidly response the emergent RTCP feedback and unequally treat receivers with less calculation, to increase the adaptation to varied network, we proposed a new self-organizing and self-adjusting transmission strategy which can automatically select data process operations and parameters, unlike other adaptive strategy we use a smooth constraint to avoid parameter shake, in order to further save network bandwidth we proposed a partial FEC based on Bayes learning, it only encode partial data which is more possibly noised and it can handle the situation of varied network due to the feature of Bayes learning, thus it will be more accurate.

To evaluate the proposed scheme, we designed a series of experiments under different network environments on MG3500 codec platform. The results indicated proposed scheme could largely improve the reliability and timeliness of transmission and this result is steady under varied network condition.

2. Hierarchically unequal transmission architecture

The hierarchical architecture was proposed by Julian Chesterfield to increase the speed of RTCP response [16], all the receivers are located in its local tree based on the IP address and linked to a summarization node, the summarization node is added to generate RTCP RR reports that unicast to the summarization node at a higher level, the generated report is then transmitted to the media source, Fig.1 shows the framework of this architecture.
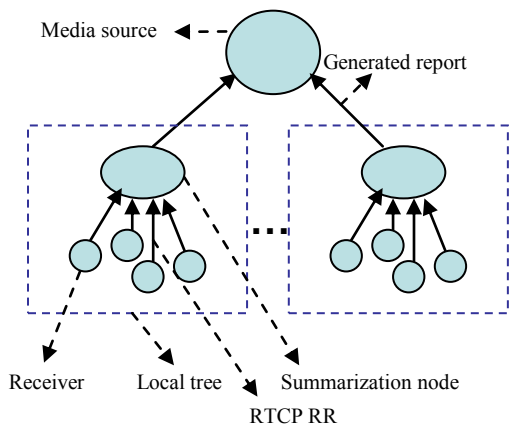
Fig.1 the framework of hierarchical architecture

To strengthen the emergent feedback, Ling-ling Wang suggests to divide all receivers as normal and emergent node [5], the emergent node is the receiver which has a serious packet-lost rate or bit-error rate, the summarization node will combine all RR reports and send them to sender when there is no emergent node, when there exists emergent nodes the summarization node will just send the RR reports of emergent nodes and abandon other normal RR reports. This feedback architecture could largely increase the efficiency as it is unicasted and the summarization node fuses many receivers as one, but when network condition is fine which means there is no emergent node, all the normal RR reports are just combined together, the bandwidth is not saved compared to classic feedback architecture, and when network condition is bad there will lack the normal report.

As the local tree is formed according to IP address, the network condition of each normal node in the same local tree is approximately the same. Thus we could treat all normal nodes in the same local tree as one and the emergent nodes are still independent as Fig.2 shows, the normal nodes are combined as a normal group, when network condition is fine the summarization node will just send the average report of normal group and when network condition is bad the summarization node will not abandon the normal report as there is only one average report for all normal nodes, this will largely decrease the bandwidth when network is fine and increase the normal feedback when network is bad.

Considering the difference of network condition and receive device, the transmission strategy should be independent for each receiver, but it is insufferable to design every single strategy for each receiver under large transmission scale, under this proposed hierarchical feedback architecture when sender adjusts transmission strategy, only each emergent node and the normal group will be treat unequally, all nodes in the normal share the same strategy as the sender receives average report of normal group and it will treat all normal nodes as one, through this feedback mechanism, the transmission strategy of every emergent node can be independently considered to improve its transmission reliability and all normal nodes only need to be considered once, thus we can take both heterogeneity and homogeneity

into account, as the number of normal nodes is usually much larger than emergent nodes the calculation can be extremely decreased.
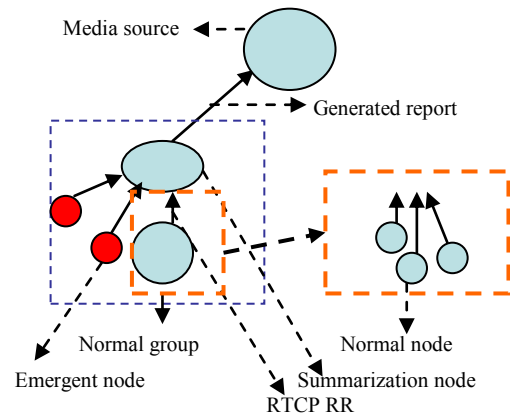

Fig.2 the improved framework

3. Adaptive Transmission Strategy

As decoder is very sensitive to the correctness of received encode data [17], it is very necessary to guarantee the reliability of transmission, reliable transmission system usually is in closed-cycle mode with RTCP feedback. The transmission path is comprised of sender, data processing and receiver as Fig.3 shows.
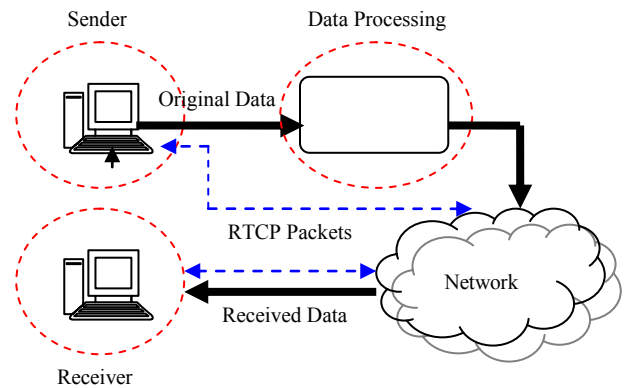

Fig.3 the framework of transmission path

Network dose not ensure reliable transmission [18], thus the task of guaranteeing quality of service (Qos) is moved to transmission application itself. Data processing as Fig.3 shows is the key part of transmission system.

Data processing is comprised of all or partial operations of block interleaved, out-packet FEC, in-packet FEC and energy diffusion. Classic methods usually use fixed structure and parameters such as FEC parameters and block interleaved parameter, which can not fit varied network condition and may waste network resource. Here we propose a novel transmission strategy which not only can adaptively adjust processing parameters, but also can adaptively select processing operation. It is showed in Fig.4.
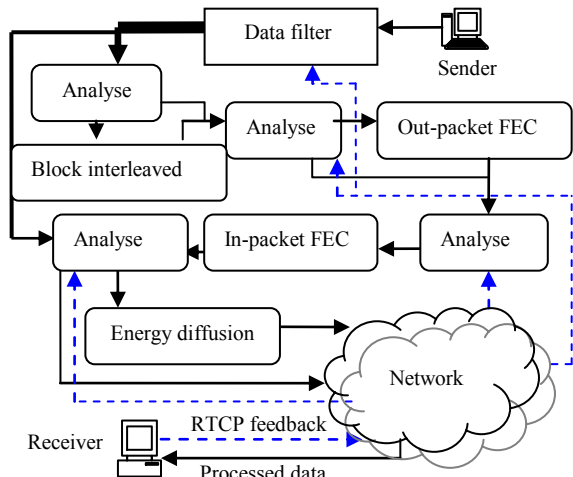
Fig.4 the structure of data processing

A. Self-organize structure

Every operation in data processing part has particular function [19], block interleaved can change burst error into random error which is easier for following FEC to handle, out-packet FEC often is used for handling the situation of losing packet while in-packet FEC is usually used for handling the situation of noising bit and energy diffusion is commonly applied in modulated transmission. As every operation needs the sacrifice of transmission efficiency, it is not wise to apply all of them to process encode data before sending to network, thus the structure of data processing should be self-organized under different network condition.

Basic RTCP feedback packets can not supply the bit error rate of transmission; the bit error rate can be calculated by sender via test packets sent by receiver per two minutes, and the burst error can be calculated as the number of error block whose size is larger than *30* as Fig.5 shows or the number of packet group which has more than *5* continuously lost packets
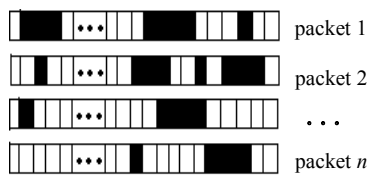

Fig.5 the model of test packets

Block interleaved: if the burst error is severe such as the number of error block whose size is larger than *30* exceeds *10* per test packet, this operation will be added to data processing structure.

Out-packet FEC: if the packet-lost rate of RTP packets which achieved from RTCP feedback exceeds 2×10^{-4}, this operation will be added to data processing structure.

In-packet FEC: if the bit-error rate which achieved from test packets exceeds 2×10^{-4}, this operation will be added to data processing structure.

Energy diffusion: if data is transmitted by long-distance or modulated channel, this operation will be added to data processing structure.

As RTCP feedback packets and test packets will be sent to sender all the time, the data processing structure will be self-organized at any time in time according to upper strategy.

B. Self-adjust parameter based on Memory Evolution

Besides the structure, the select of block interleaved parameter and FEC parameters will mainly decide the efficiency of transmission. Here, we proposed a novel memory evolution strategy to self-adjust the parameters.

We expand the local database of sender with three pair memories, the block interleaved parameter pair memory, out-packet FEC pair memory and in-packet FEC pair memory, each pair memory is comprised of one success memory and one fail memory.

Assume now, the block interleaved parameter is *k*, the parameter pair for out-packet FEC is（*m,n*）and the parameter pair for out-packet FEC is（*p,q*）, where *m* and *p* denote the length of message, while *n* and *q* denote the length of FEC encode word, receiver will send some test packets encode with different parameters around current parameters such as using *k-1,k+1* as block interleaved parameter,（*m,n-1*）,（*m,n+1*）as out-packet FEC parameter,（*p,q-1*）,（*p,q+1*）as in-packet FEC parameter, the memories will be updated as follows after sender decodes these test packets.

For the block interleaved parameter memory pair, if the burst error with parameter *x* is smaller than current, then the success memory will be updated as

$$B_s(x) = B_s(x) + 1 \tag{1}$$

Otherwise, the fail memory will be updated as

$$B_f(x) = B_f(x) + 1 \tag{2}$$

For the out-packet FEC parameter memory pair, if the packet-lost rate with parameter *(u,v)* is smaller than current, then the success memory will be updated as

$$O_s(u,v) = O_s(u,v) + 1 \tag{3}$$

Otherwise, the fail memory will be updated as

$$O_f(u,v) = O_f(u,v) + 1 \tag{4}$$

For the in-packet FEC parameter memory pair, if the bit-error rate with parameter *(u,v)* is smaller than current, then the success memory will be updated as

$$I_s(u,v) = I_s(u,v) + 1 \tag{5}$$

Otherwise, the fail memory will be updated as

$$I_f(u,v) = I_f(u,v) + 1 \tag{6}$$

Then we can update the select weight for each parameter as

$$W_B(x) = \frac{\sum_{i=0}^{n} B_s(x)}{\sum_{i=0}^{n}(B_s(x)+B_f(x))} \times \frac{1}{|k-x|}$$

$$W_O(u,v) = \frac{\sum_u \sum_v O_s(u,v)}{\sum_u \sum_v (O_s(u,v)+O_f(u,v))} \times \frac{1}{\sqrt{(p-u)^2+(q-v)^2}} \qquad (7)$$

$$W_I(u,v) = \frac{\sum_u \sum_v I_s(u,v)}{\sum_u \sum_v (I_s(u,v)+I_f(u,v))} \times \frac{1}{\sqrt{(m-u)^2+(n-v)^2}}$$

The second multiplier on the right side of each equation is the smooth-adjust constraint used to avoid large shake of parameters, thus the decode quality of receiver will not shake too much under the varied network.

4. Partial FEC based on Bayes Learning

When a packet or a group of packets need to be protected by FEC before sending to network, classic method usually encode all bits in the packet or all packets in the group. In fact, not all bits in the packet will be noised as Fig.5 shows, and so are the packets in the group, only encode the bit which is easier noised with in-packet FEC and the packet which is easier lost with out-packet FEC can save a lot of calculation time and network resource, this partial FEC strategy is just like a data filter as Fig.4 shows, in order to find which bit or packet should be encoded, we apply the Bayes learning [20], [21] model to solve this problem.

The lost or error probability density of the bit or the packet x has an intimate relationship with its local data environment [22], we use $P(x,l_0,l_1,r_0,r_1)$ to denote that probability density, to in-packet FEC x represents a bit, l_0 stands for the number of continuous 0 on the left of this bit, and l_1 stands for the number of continuous 1 on the left of this bit, r_0 stands for the number of continuous 0 on the right of this bit, r_1 stands for the number of continuous 1 on the right of this bit. To out-packet FEC, x represents a packet, l_0 stands for the number of forward continuous packets which contain at least $3/5$ bit 0 in the whole packet, l_1 stands for the number of forward continuous packets which contain at least $3/5$ bit 1 in the whole packet, r_0 stands for the number of afterward continuous packets which contain at least $3/5$ bit 0 in the whole packet, r_1 stands for the number of afterward continuous packets which contain at least $3/5$ bit 1 in the whole packet.

We assume that $P(x,l_0,l_1,r_0,r_1)$ satisfies multivariate normal distribution as

$$P(X) = \frac{1}{(2\pi)^{\frac{d}{2}}|\Sigma|^{\frac{1}{2}}} \exp\{-\frac{1}{2}(X-u)^T \Sigma^{-1}(X-u)\} \qquad (8)$$

Where X denotes the vector (x,l_0,l_1,r_0,r_1), d is the dimension of X, u is the average of X, and Σ denotes the covariation matrix of X

The unknown parameter u and Σ describes the feature of network that decides which bit will be noised and which

packet will be lost, as the network condition is always varied, the parameter u and Σ will also change meanwhile, Bayes learning is a good tool for parameter estimation and it can handle the situation that parameters vary which is exactly fit for our requirement, what's more it has better estimation result than maximize like-hood as it considers the distribution of parameters[21].

Unlike maximize like-hood, Bayes learning solve problems based on minimizing average cost $\bar{R}$ for error estimation as

$$\bar{R} = \int R(\hat{\theta}|X)p(X)dX \qquad (9)$$

Where $\quad R(\hat{\theta}|X) = \int_{\Theta} \lambda(\hat{\theta}|\theta)p(\theta|X)d\theta \qquad (10)$

Here, θ denotes the real parameter vector (u, Σ), $\hat{\theta}$ denotes the estimation of θ, and $\lambda(\hat{\theta}|\theta)$ is the cost for wrong estimating θ to $\hat{\theta}$, Θ is the range of θ, and $p(\theta|X)$ is post probability under sample set X.

Usually the cost is defined as

$$\lambda(\hat{\theta}|\theta) = (\hat{\theta}-\theta)^2 \qquad (11)$$

Thus the estimation $\hat{\theta}$ of θ is calculated as

$$\hat{\theta} = E(\theta|X) = \int_{\Theta} \theta p(\theta|X)d\theta \qquad (12)$$

To simplify the calculation of this algorithm, we assume that the probability density distribution of u and Σ satisfies

$$P(u) = \frac{1}{\sqrt{2\pi}\sigma_0} \exp(-\frac{(u-u_0)^2}{2\sigma_0^2})$$

$$P(\Sigma) = \frac{1}{\sqrt{2\pi}\sigma_1} \exp(-\frac{(\Sigma-u_1)^2}{2\sigma_1^2}) \qquad (13)$$

$$P(u,\Sigma) = P(u)P(\Sigma) = \frac{1}{2\pi\sqrt{\sigma_0\sigma_1}} \exp(-\frac{(u-u_0)^2}{2\sigma_0^2} - \frac{(\Sigma-u_1)^2}{2\sigma_1^2})$$

Where u_0,u_1 denote the average of u,Σ, and σ_0,σ_1 denote the variance of u,Σ, we also assume that u,Σ are independent to each other as (13) shows, then the algorithm flow of estimating θ can be showed as follows

Step1: calculate the union probability density $p(\chi|\theta)$ of sample set χ $(X_1,X_{21},X_3...X_n)$ by

$$p(\chi|\theta) = p(X_1,X_{21},X_3...X_n|\theta) = \prod_{i=1}^{n} p(X_i|\theta) \qquad (14)$$

Step2: calculate the post probability density of θ by

$$p(\theta|\chi) = \frac{p(\chi|\theta)p(\theta)}{p(\chi)} = \frac{p(\chi|\theta)p(\theta)}{\int_{\Theta} p(\chi|\theta)p(\theta)d\theta} \qquad (15)$$

Step3: calculate the estimation $\hat{\theta}$ by replacing X with χ in (12).

As we can see from (12), if the range of Θ is very large, the calculation of $\hat{\theta}$ may be unacceptable, considering the fact that the network condition often changes gradually, the parameter u and Σ will not shake too much, so the Θ can be

set as a small value, in this algorithm we set it as $(\theta^{'}-0.2,\theta^{'}+0.2)$, $\theta^{'}$ denotes the earlier parameter, to further accelerate the calculation, we use online learning as (16) to instead (15)

$$
\begin{aligned}
p(\theta\mid\chi^{N}) &= \frac{p(\chi^{N}\mid\theta)p(\theta)}{\int_{\Theta}p(\chi^{N}\mid\theta)p(\theta)d\theta} \\
&= \frac{p(X_{N}\mid\theta)p(\chi^{N-1}\mid\theta)p(\theta)}{\int_{\Theta}p(X_{N}\mid\theta)p(\chi^{N-1}\mid\theta)p(\theta)d\theta} \\
&= \frac{p(X_{N}\mid\theta)p(\chi^{N-1})p(\theta\mid\chi^{N-1})}{\int_{\Theta}p(X_{N}\mid\theta)p(\chi^{N-1})p(\theta\mid\chi^{N-1})d\theta} \\
&= \frac{p(X_{N}\mid\theta)p(\theta\mid\chi^{N-1})}{\int_{\Theta}p(X_{N}\mid\theta)p(\theta\mid\chi^{N-1})d\theta}
\end{aligned}
\tag{16}
$$

After estimating the parameter u and Σ, we could get the $P(x,l_0,l_1,r_0,r_1)$ by (8), and then we will just encode the bit with in-packet FEC or the packet with out-packet FEC which has the $P(x,l_0,l_1,r_0,r_1)$ larger than the average value, the location of selected bit or packet is stored in RTP extend header to remind receiver that which bit or packet has been encode with partial FEC.

5. Experiments

In order to evaluate the proposed scheme, we made several experiments on MG3500 embedded platform under emulational transmission channel.

MG3500 is a H.264 HD codec chip system developed by Mobilygen Company [23]; it integrates a 240MHz arm9 processor inside and can be equipped with a Linux operating system.

The emulational transmission channel is designed as follows

Step1: get a random number α between 0 and 10^5.

Step2: if α is smaller than λ, go to step 3, else go to step4.

Step3: get a random number β between 1 and 3, then abandon β packets in the RTP packet sequence as burst error, then skip β packets and go back to step 1.

Step4: if α is larger than σ, then overturn the current bit from *0* to *1* or *1* to *0*, then skip one bit and go back to step 1.

The parameter λ would decide the burst error of network and σ would decide the bit random error of network, so we could change the network condition by adjusting these parameters.

In the experiment, there is one sender S_1 and three receivers (R_1, R_2, R_3) and each transmission channel is different from others.

To test the adaptability of proposed scheme under varied network condition, we change the parameter λ and σ of emulational transmission channel to get different bit-error rate and packet-lost rate, the experiment is operated between S_1 and R_1. Results are showed as

Fig.6 shows change of parameter λ and σ in the left picture, as these parameters indicate the bit-error rate and packet-lost rate of emulational transmission channel, it could simulate the real varied network, the block interleaved parameter change route under this network is showed in the right picture, it means this operation was turned off when its value was 0.
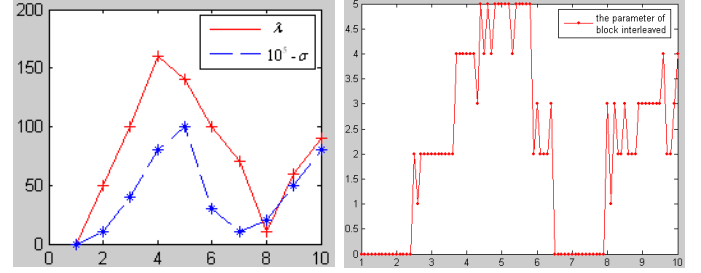

Fig.6 partial results of experiment

According to following Fig.7, we could conclude that the out-packet and in-packet FEC operation was turned on or off based on the network condition, the bit error rate and packet-lost rate were largely decreased (60% on average) compared to original transmission channel, the structure of data-processing could be self-organized, and the parameters of block interleaved, in-packet FEC and out-packet FEC could be self-adjusted as Fig.8 showed.
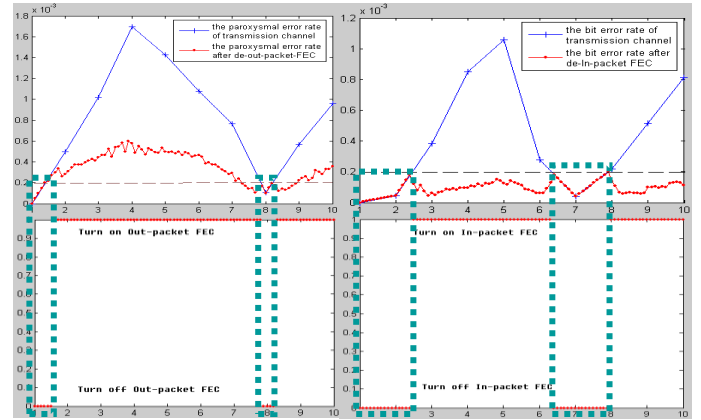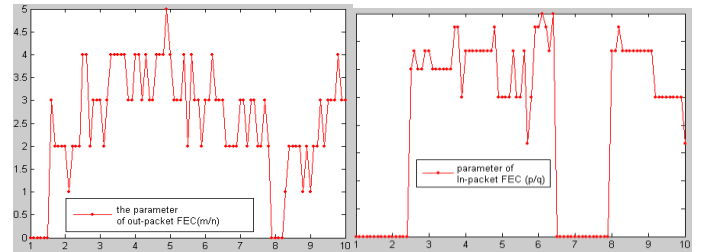

Fig.7 partial results of experiment

Fig.8 partial results of experiment

The redundancy and decode result of partial FEC with Bayes leaning is compare with classic FEC algorithm, it is showed as TABLE1.

TABLE1 the compare of classic FEC and proposed FEC

Items	Two algorithms	
	Proposed	Classic
Bit error rate	2.16×10^{-4}	1.34×10^{-4}
Packet lost error	0.11 %	0.08%
Redundancy	42%	100%
Time-delay	0.13s	0.73s

Here, we could conclude that partial FEC with Bayes learning can save a lot of time and network bandwidth, and it only needs to sacrifice a little transmission reliability which can be suffered.

6. Conclusions

Streaming media transmission needs to be real-time and reliable with as little as possible resources, but in real world the network is varied and the transmission scale becomes larger, all of these will weaken the timeliness and reliability of transmission.

This paper proposed a novel transmission scheme, by improving hierarchical feedback architecture, the sender could make rapid response to emergent information even under large transmission scale, and it also supplies an unequal treat mechanism to design independent transmission strategy for each emergent node and the normal group, the calculation is largely decreased as all the normal nodes in a normal group share the same transmission strategy, each independent transmission strategy is designed separately by self-organizing transmission structure and self-adjusting transmission parameters to adapt varied network, by applying partial FEC based on Bayes learning, the redundancy can be largely decreased and the real-time performance can be largely improved.

Approach was test on MG3500 platform; the result showed that the proposed scheme can supply real-time and reliable transmission with less network resource.

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