GEO-PREDICTIVE ERROR CORRECTION ADAPTATION FOR BROADCAST SERVICES

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ABSTRACT

This article presents an error protection method that uses error-condition forecasting. The forecasting procedure uses a-priori acquired knowledge of the Probability-of-Error (PoE), along a route that a mobile client (MC) is expected to traverse. Additional parity data, called Geo-Predictive forward error correcting codes (GP-FEC), is computed over each source block and broadcast before the source block. A mobile client (MC) forecasts the error conditions it could experience in the future, and if needed, fetches and uses GP-FEC. Forecasting and time-diversity due to staggered transmission of GP-FEC, results in improved error robustness. The superior performance of the presented method against conventional broadcasting is verified in simulations using the Digital Video Broadcasting-Handhelds (DVB-H) environment.

Index Terms— Geo-Prediction, Context, DVB-H, Broadcasting, Streaming, FEC.

1. INTRODUCTION

Forward error correcting codes (FEC) are used by wireless broadcasts to counter fading errors. Packet based FEC code is computed over a group of source data packets called a *source block*. The resulting coded data is called an *FEC block*. It is desirable to have long FEC blocks to correct long burst errors. However, an increase in FEC block length also increases synchronization and processing delay at the receiver. This limits the size of source blocks.

Fast fading causes small burst errors that are correctable using some reasonably sized FEC block. However, due to the FEC block size constraint, long burst errors caused by slow fading, may remain uncorrected. Fortunately, slow fading exhibits location dependency. This location dependency of slow fading is harnessed in this article. The method of predicting locations where long burst errors are probable, and a receiver adapting to the predicted error conditions, is called *Geo-Predictive Error Correction Adaptation*.

While the basic principle of Geo-Predictive Error Correction Adaptation can be applied to a large number of wireless broadcast protocols, the illustration in this article uses the Digital Video Broadcasting-Handhelds (DVB-H) [1] protocol. For data robustness, DVB-H uses a virtually time-interleaved systematic Reed-Solomon FEC, at the link layer. This link layer protection, called MPE-FEC, can handle errors below some threshold of burst error length. Longer burst errors require other methods of error correction.

In [2], the authors investigated an application layer FEC (AL-FEC) protection mechanism to combat errors of longer duration. Raptor [3] coded packets, computed over IP packets are packed into MPE-FEC frames and transmitted as time-sliced bursts. They are transmitted after the original burst has been transmitted. Receivers that are unable to decode the original burst use the additional burst to recover lost data.

Another technique called MPE-IFEC was introduced in [4]. MPE-IFEC, is a multi-burst method able to protect data across multiple time-sliced bursts. However, this multi-burst protection requires an increase in the interleaving duration.

A technique where the error correction data is transmitted before the actual data was presented in [5]. In this paper, a copy of the source data was transmitted ahead of the actual stream. The presented method required that the redundant copy of the stream is always received and buffered in order to achieve the additional error robustness.

This article proposes a method that uses error forecasting. It assumes that the occurrence of long burst errors, due to shadowing and path-loss, can be statistically forecasted. MPE-FEC code-rates for DVB-H transmission are fine-tuned to correct small burst errors, while a new Geo-Predictive Forward Error Correcting Code (GP-FEC) is used to correct long burst errors. The transmission of GP-FEC is staggered with respect to the transmission time of its corresponding source media data. The time diversity achieved in the staggered transmission of GP-FEC and media data, along with the ability to forecast errors with some amount of statistical reliability, results in better media robustness than conventional broadcast methods.

The rest of this article is organized as follows. Location dependency of slow fading and harnessing this dependency is described in Section 2. Transmitter modifications to enable geo-prediction for broadcasts is described in Section 3. Section 4 describes the operation methodology for mobile clients (MC) using geo-prediction. Implementation of geo-prediction using a DVB-H broadcast system is explained in Section 5. The simulation setup used to evaluate the geo-prediction is detailed in Section 6. Section 7 analyses and explains the results obtained from the simulations. Finally the article ends with some conclusions and future work in Section 8.

2. LOCATION DEPENDENCY OF SLOW FADING

Slow fading, which is a combination of path-loss and shadowing, has a strong location dependency. Path-loss at a location is related to the separation of the location from the transmitter, and shadowing is related to the surrounding environmental clutter at that location.

Consider a MC moving from location A to location B, along a route labeled AB, as shown in Figure 1. The route AB is sampled at regular intervals, δ, forming a finite well ordered set, $\mathbf{L} = \{l_0, l_1, l_2, ..., l_n\}$. All locations in between $(l_i - \delta/2)$ and $(l_i + \delta/2)$ is called the *near-neighborhood* of l_i.

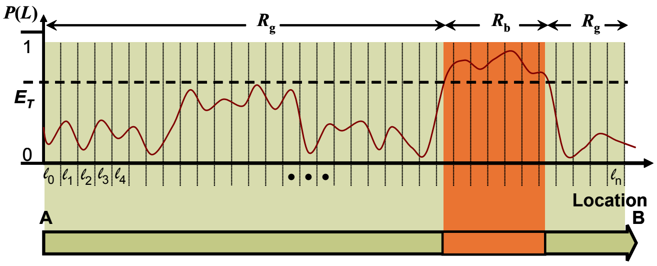


Fig. 1. Expected PoE along a route AB.

Error rates are estimated for every $l_i \in \mathbf{L}$. For example, error rates in DVB-H are measured by computing the ratio of the number corrupt transport stream (TS) packets received, to the total number of TS packets received in the near-neighborhood of l_i. This ratio normalized gives the probability of Errors (PoE) in the near neighbourhood of l_i. With a sufficiently large number of collected measurements, fast fading errors (due to multi-path and Doppler effects) average out. Using the measurements collected during many distinct journeys along *AB*, an expected *Probability of Error* (PoE) function, as shown in Figure 1, can be computed. The expected PoE is then a stochastic random process indexed on the location set, $\mathbf{L}$. Expected PoE is a good measure of errors due to slow fading, and shows location dependencies.

With a-priori knowledge of expected PoE, the route *AB* can be segmented into regions of similar error conditions. For example, in Figure 1, *AB* is divided into regions of *good* and *bad* reception by selecting a PoE threshold, E_T. The location points, $l_i \in \mathbf{L}$, along *AB* can be partitioned into two regions, $\mathbf{R}_g = \{l_i : P(l_i) < E_T\}$ and $\mathbf{R}_b = \{l_i : P(l_i) \geq E_T\}$, where $P(l_i)$ is the expected PoE as a function of $\mathbf{L}$. $\mathbf{R}_g$ indicates locations along *AB* where the expected PoE is low enough to be corrected by a traditional MPE-FEC. The region $\mathbf{R}_b$ indicates regions where additional error protection mechanisms, such as the one presented in this article is needed. The choice of threshold E_T depends on the maximum correctable errors of an FEC block.

Forecasting of errors is useful, only if the broadcast transmitter provides methods and data that a receiver can use to recover a predicted data loss. The broadcasting method, described in the next section, uses intelligent scheduling of parity and media data to achieve this.

3. BROADCASTING ADAPTED FOR GEO-PREDICTION (BAG)

Broadcasting using geo-prediction is enabled by some transmitter modifications. These transmitter modifications are collectively termed *Broadcasting Adapted for Geo-Prediction* (BAG). The *Staggered Broadcasting Scheme* (SBS), presented in this article, is an algorithm in the BAG class.

3.1. Staggered Broadcasting Scheme (SBS)

The media, $\mathbf{M}$, is first segmented into n partitions, $\mathbf{M} = [\mathbf{m}_0 \cdot \mathbf{m}_2 \cdot \mathbf{m}_3 \cdot \ldots \cdot \mathbf{m}_{(n-1)}]$. Transmission of $\mathbf{m}_i$ is between time instants $[t_i, t_{i+1}]$. The duration in time, $\Delta_i^{\mathbf{m}}$, when $\mathbf{m}_i$ is transmitted is given by

$$\Delta_i^{\mathbf{m}} = (t_{(i+1)} - t_i).$$

Let $\mathbf{p}_i$ be the parity data computed for $\mathbf{m}_i$, using some parity encoder. Then, $\mathbf{P} = [\mathbf{p}_0 \cdot \mathbf{p}_2 \cdot \mathbf{p}_3 \cdot \ldots \cdot \mathbf{p}_{(n-1)}]$, forms an auxiliary data stream, called *Geo-Predictive Forward Error Correcting codes* (GP-FEC).

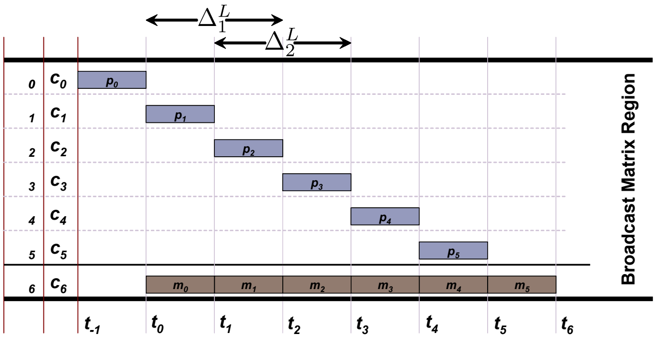


Fig. 2. The Staggered Broadcasting System.

The physical channel, C, is conceptually divided into $(n+1)$ logical channels; i.e. $C = \{c_0, c_1, ..., c_n\}$, with bandwidths $\Pi = \{\pi_0, \pi_1, ..., \pi_n\}$. The last logical channel, c_n, always carries the stream $\mathbf{M}$. The remaining n logical channels, c_0 to $c_{(n-1)}$, carry GP-FEC segments. SBS is diagrammatically presented in Figure 2.

3.2. GP-FEC Transmission

Recovery of any media segment, $\mathbf{m}_i$, with minimal delay requires $\mathbf{p}_i$ to arrive before $\mathbf{m}_i$. Furthermore, if the forecasted PoE indicates that $\mathbf{m}_i$ is very likely to have errors, the MC must have enough time after the forecast to obtain $\mathbf{p}_i$.

Let the time when forecasting of errors for a segment $\mathbf{m}_k$ be triggered at some time, t_θ. Since the forecast for $\mathbf{m}_k$ should be known before $\mathbf{m}_k$ is transmitted, $t_\theta < t_k < t_{(k+1)}$. The time duration, $(t_{(k+1)} - t_\theta)$, is called the *maximum look-ahead time* (MLT), Δ_k^L. It is assumed that the transmission time of $\mathbf{p}_k$ and $\mathbf{m}_k$ do not overlap in time. This is to minimize the chance that both $\mathbf{p}_k$ and $\mathbf{m}_k$ are prone to the same error conditions. Further, because transmission of $\mathbf{p}_k$ requires some finite amount of time after t_θ, the MLT is lower bounded by

$$\Delta_k^L \geq \Delta_k^{\mathbf{p}} + \Delta_k^{\mathbf{m}} \tag{1}$$

where, $\Delta_k^{\mathbf{p}}$ is the time duration when $\mathbf{p}_k$ is transmitted.

In the exposition of the proposed method, it is assumed for the sake of simplicity that, forecasting of PoE is always triggered at segment boundaries. Hence, $t_\theta \in \{t_i : i \in \mathbb{N}; 0 \leq i \leq (n-1)\}$, where $\mathbb{N}$ is the set of non-negative integers. Furthermore, to minimize buffering times, the GP-FEC data is sent immediately ahead of their relevant media data. These assumptions turns the inequality in Equation 1 into the equality,

$$\Delta_k^L = \Delta_k^{\mathbf{p}} + \Delta_k^{\mathbf{m}}. \tag{2}$$

By tuning channel bandwidths, $\{\pi_i : 0 \leq i \leq (n-1)\}$, and the GP-FEC code rate, SBS can be designed such that $\mathbf{p}_k$ is transmitted between times $[t_{(k-1)}, t_{(k)}]$, i.e. during the period when $\mathbf{m}_{(k-1)}$ is transmitted. In other words, $\Delta_k^{\mathbf{p}} = \Delta_{k-1}^{\mathbf{m}}$, and $\Delta_k^{\mathbf{L}} = t_{(k+1)} - t_{(k-1)}$.

It is again stressed that, the above assumptions are only for the sake of explaining the method better. In practical implementation the forecasting need not be triggered at segment boundaries. Furthermore, the transmission of parity data, $\mathbf{p}_k$, can span any amount time duration before the media segment, $\mathbf{m}_k$. All that is required is a proper signaling method from the transmitter to the MC.

Table 1. An example decision truthtable to decide if GP-FEC is needed.

$\Delta_i^{\mathbf{p}}$	$\Delta_i^{\mathbf{m}}$	Decision
0	0	0
0	1	1
1	0	0
1	1	1

Legend

$\Delta_i^{\mathbf{p}}$ & $\Delta_i^{\mathbf{m}}$
0 : Errors are not forecasted.
1 : Errors are forecasted.
Decision:
0 : Do not use GP-FEC.
1 : Use GP-FEC.

4. MC OPERATION FOR BAG

An MC is aware of BAG using some form of signaling. The exact nature of this signaling is not in the scope of this paper. However, both BAG-aware and BAG-unaware MCs should be able to consume a media broadcast adapted for geo-prediction. This constraint requires that the media transmission protocol remains unchanged.

An MC can tune-in at any time, t_{in}, during the transmission of a broadcast. A BAG-aware MC computes the nearest time in the future, when a forecast can be obtained. As mentioned before, forecasting is assumed to be attempted at segment boundaries.

If the start time, t_0, and transmission durations for media segments, $\Delta_i^{\mathbf{m}}$, are known, the following method can be used to obtain the time of the next forecast. The first forecast is scheduled at time t_0. The boundary condition, when the parity data, $\mathbf{p}_0$, is sent before the broadcast of $\mathbf{M}$ begins, is ignored. The following forecast is at time $t_1 = t_0 + t_{\mathbf{m}_0}$. Generalizing, the time of the k^{th} forecast, t_k, is at

$$t_k = t_0 + \sum_{i=0}^{k-1} t_{\mathbf{m}_i}$$

The next forecast t_θ after the tune-in time, t_{in}, is then obtained by computing,

$$t_\theta = \min(t_i \geq t_{in}) \colon i \in \mathbb{N}; 0 \leq i \leq (n-1).$$

Let $t_\theta = t_{(k-1)}$. Then, the next media segment that can use GPE-FEC is, $\mathbf{m}_k$. The MC obtains the forecast for the duration $[t_\theta, (t_\theta + \Delta_k^L)]$. The forecast is obtained as an expected PoE distribution for this period. The period, $[t_\theta, (t_\theta + \Delta_k^L)]$, from Equation 2, is partitioned into two non-overlapping time periods. The first of these partitions, is the period when GP-FEC, $\mathbf{p}_k$ is transmitted. This is given by the time interval, $[t_\theta, (t_\theta + \Delta_k^{\mathbf{p}})]$. The second partition is the period when the corresponding media data, $\mathbf{m}_k$, is transmitted. This period is given by the time interval, $[(t_\theta + \Delta_k^{\mathbf{p}}), (t_\theta + \Delta_k^{\mathbf{p}} + \Delta_k^{\mathbf{m}})]$.

The MC then makes a decision if GP-FEC is needed or not, based on the forecasted expected PoE. A decision truth-table, like the one shown in Table 1, is used. Based on this truth-table, the MC decides that GP-FEC is needed if error conditions is at any time during $[(t_\theta + \Delta_k^{\mathbf{p}}), (t_\theta + \Delta_k^{\mathbf{p}} + \Delta_k^{\mathbf{m}})]$ is greater than the selected PoE threshold, E_T.

If the MC decides that the GP-FEC, $\mathbf{p}_k$, is required to correct the media segment, $\mathbf{m}_k$, it tunes into the logical channel, c_k, and buffers the GP-FEC. This buffering happens during the time interval, $[t_\theta, (t_\theta + \Delta_k^{\mathbf{p}})]$. Error correction of $\mathbf{m}_k$ is then attempted using the buffered $\mathbf{p}_k$ after $\mathbf{m}_k$ has fully arrived. The whole process is iterated at every segment boundary after tune-in, when forecasting is triggered.

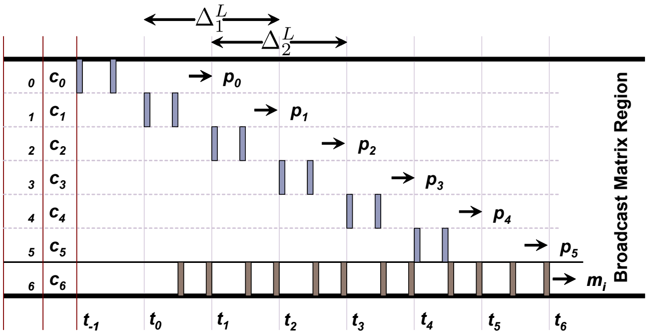


Fig. 3. The implementation of SBS in a DVB-H transmission environment.

5. IMPLEMENTATION OF BAG FOR DVB-H

DVB-H uses time-slicing and MPE-FEC to transmit data to handheld MCs. One way of implementing BAG using DVB-H is shown in Figure 3 and described here. As mentioned before, media data $\mathbf{M}$ is segmented into some n partitions, $\mathbf{M} = [\mathbf{m}_0 \cdot \mathbf{m}_2 \cdot \mathbf{m}_3 \cdot ... \cdot \mathbf{m}_{(n-1)}]$. Each segmented media partition, $\mathbf{m}_i$, is then time-sliced into, $m_i^j : 0 \leq i \leq (n-1), j \in \mathbb{N}$, where m_i^j denotes the j^{th} time-slice of the i^{th} media segment. Therefore, the broadcast media, $\mathbf{M}$, is a concatenation of the time-slices of all media segments

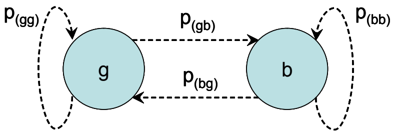
$$\mathbf{M} = \left[\underbrace{[m_0^0 \cdot m_0^1 ...]}_{\mathbf{m}_0} \cdot \underbrace{[m_1^0 \cdot m_1^1 ...]}_{\mathbf{m}_1} \cdot ... \cdot \underbrace{[m_{(n-1)}^0 \cdot m_{(n-1)}^1 ...]}_{\mathbf{m}_{(n-1)}} \right].$$

The GP-FEC data, $\mathbf{P}$, is formed by computing parity data $p_i^j : 0 \leq j \leq (n-1), j \in \mathbb{N}$. Each time-slice of GP-FEC data, p_i^j, is computed over the corresponding media time-slice, m_i^j, using some parity encoder. This is to simplify synchronization problem that could occur when error correction using GP-FEC is attempted. The auxiliary GP-FEC bit stream is formed by the concatenation of time-slices of the parity data as given by

$$\mathbf{P} = \left[\underbrace{[p_0^0 \cdot p_0^1 ...]}_{\mathbf{p}_0} \cdot \underbrace{[p_1^0 \cdot p_1^1 ...]}_{\mathbf{p}_1} \cdot ... \cdot \underbrace{[p_{(n-1)}^0 \cdot p_{(n-1)}^1 ...]}_{\mathbf{p}_{(n-1)}} \right].$$

The kind of parity encoder to be used is deliberately omitted from the discussions. This is because, this does not affect the basic principles of the proposed method. Choice of the parity encoder involves parameters such as application type, segment sizes, computational efficiency, correction method, and many more factors, which is not in the scope of this article. However, what is important is the concept that the transmission of parity data, is staggered with respect to the transmission of the media data, and with a sufficiently large amount, so as to correct long burst errors due to shadowing successfully.

The physical DVB-H channel is sub-divided into $(n+1)$ logical channels, $C = \{c_0, c_1, ..., c_n\}$. All time-slices of $\mathbf{M}$, are transmitted on the logical channel, c_n. The time-slices of the parity segment, $\mathbf{p}_{(i)}$, are sent on the logical channel, c_i. For example, the parity data $[p_0^0, p_0^1, p_0^2 ...]$ are sent on channel c_0, $[p_1^0, p_1^1, p_1^2 ...]$ are sent on channel c_1, and so on.



p	g	b
g	0.9	0.1
b	0.8	0.2

Fig. 4. Two state Markov chain used to simulate error conditions along a Route.

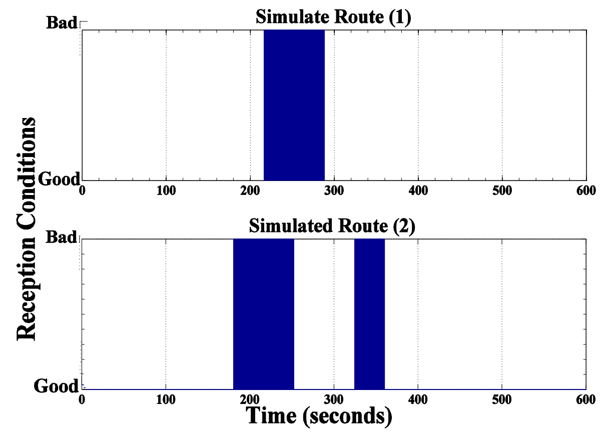


Fig. 5. Quantized PoE along the two simulated routes.

The time-slices of both media and parity data are protected using MPE-FEC, using some code-rate. This is to protect data from small burst errors. The code-rates used for the media time-slices and the parity time-slices may be different. The transmission scheduling of parity and media time-slices are flexible, so long as the rule that all time-slices of the GP-FEC segment, $\mathbf{p}_i$ is transmitted before $\mathbf{m}_i$ is adhered to.

6. SIMULATION DESCRIPTION

The video sequence, $\mathbf{M}$, was a football sequence, ten minutes in play-time duration, and coded at 192 kbps, using an H.264/AVC baseline encoder. The ten minute video sequence was obtained by concatenating a minute long video sequence ten times. The frame-rate of the coded sequence was 12.5 frames per second. Each time-sliced MPE-FEC frame contained two seconds of coded data, in terms of playback duration. Every time-slice, contained an IDR coded picture to allow an MC to tune-in during the transmission of a media time-slice. The MPE-FEC matrix used 512 rows, and error protected using a code-rate of $3/4$.

The two-step (good, bad) quantized fluctuation of PoE along a route was modeled using a two-state Markov model, as shown in Figure 4. The used state transition probabilities are also indicated in the figure. Two different routes, were simulated using this Markov model, and the resulting quantized expected route PoE is shown in Figure 5.

The motivation for using a Markov model to generate quantized expected PoE, is because it follows the Markov property. A stochastic process is said to possess the Markov property, if the conditional probability distribution of future states depends only on the current state, and not on any past state. Consider the quantized expected PoE. The conditional probability that an MC encounters a good/bad error condition depends only on the error condition in the present location, and not on any location that the MC has already traversed.

Table 2. Average burst-length and error-rate statistics used to generate TS error patterns for a Journey.

	Good State	***Bad State***
B	10	50
E	1%	10%

For each route, three journeys are undertaken. TS error patterns were generated for each journey using a two-state Markov model. Two state transition matrices, one for each state in the simulated route, were computed. The two-state transition matrices were generated by assuming the average burst length, B, and average error rates, E. The assumed values are given in Table 2. The values of P_{gg} and P_{bb} were computed by solving for them using equations, $B = 1/(1 - P_{bb})$ and $E = (1 - P_{gg})/(2 - P_{gg} - P_{bb})$.

The media time slices of $\mathbf{m}_i$ and GP-FEC time-slices of $\mathbf{p}_{(i+1)}$ were transmitted during the period $[t_i, t_{(i+1)}]$. The scheduling of time-slices of $\mathbf{m}_i$ and $\mathbf{p}_{(i+1)}$ in the physical channel is done such that all time-slices transmitted are equi-spaced in time from each other. GP-FEC parity data was computed using Reed-Solomon codes, using a code-rate of 5/6. The GP-FEC time-slices were further protected using MPE-FEC with a code-rate of 3/4.

Upon receiving an erroneous time-slice, the MC first tried error correction using the MPE-FEC transmitted in the same time-slice. MPE-FEC error correction failed when the length of burst errors were beyond some threshold. A BAG-aware MC, then tried error correction using GP-FEC, which is already buffered. Time diversity in the transmission of GP-FEC, could with a high probability correct the erroneous time-slice.

The MC used *freeze frame* form of error concealment. In a freeze frame error concealment, all pictures after an erroneous picture were replaced with the last known correctly decoded picture, until the next IDR picture was decoded correctly. An erroneous stream is perceived as discontinuous motion during playback when freeze frame is used.

7. RESULTS AND ANALYSIS

The aim of the simulations was to find out if indeed time-diversity and the a-priori knowledge of PoE can lead to a more error resilient broadcast. It must be noted that there was no attempt at optimizing code-rates. Results were collected and analyzed for the two cases: BAG aware (BAG) and BAG unaware (NBAG). An analysis of the frame-by-frame PSNR (F-PSNR) can show if GP-FEC can correct some uncorrectable errors after MPE-FEC decoding. Let ΔF-PSNR, $\mathbf{Q}^{\triangle}$, be defined as

$$\mathbf{Q}^{\triangle} = \mathbf{Q}_o - \mathbf{Q}_e$$

where, $\mathbf{Q}_o$ is the F-PSNR of the coded video without errors and $\mathbf{Q}_e$ is the F-PSNR of the coded video with errors. Figure 6 shows the comparative ΔF-PSNR for one route and a journey undertaken in that route. It can be seen that in the BAG case the number of erroneous pictures has significantly reduced compared to that of the NBAG case. This result was consistent will all other simulated cases.

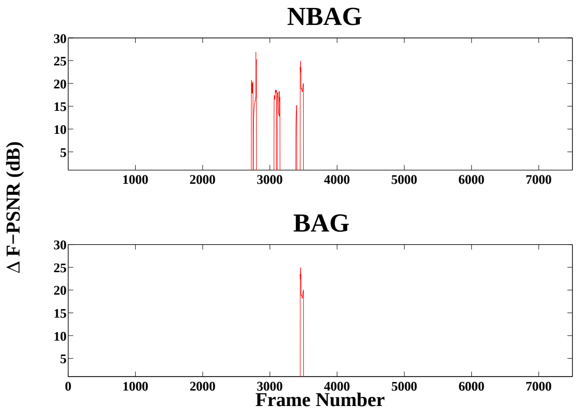


Fig. 6. Comparative plot of ΔF-PSNR for BAG and NBAG along the simulated Route (1) and Journey (3).

The reason for the reduction of errors could be attributed to the time-diversity achieved by the use of SBS.

Another performance indicator used was the Erroneous Second Ratio (ESR). ESR is percentage ratio of erroneous seconds to the duration of streaming service. Using BAG, the results presented in Table 3 shows that there is a significant decrease in ESR compared to NBAG.

However, this improvement comes with a bandwidth penalty which is also indicated in Table 3. This bandwidth penalty could be minimized by optimizing code-rates used for MPE-FEC and GP-FEC, as well as designing parity coders that are suitable for BAG.

8. CONCLUSIONS AND FUTURE WORK

This article presented a method using error forecasting to provide error robustness for broadcast data. It showed that with a-priori knowledge of the probability of error (PoE) along a route, broadcasting adapted for geo-prediction (BAG) schemes provide better robustness than conventional broadcast methods. The staggered broadcasting scheme (SBS) was introduced as one such scheme. The limited simulations showed that SBS provided better error protection than a conventional DVB-H broadcast scheme. The simulations results presented here should be considered as an initial viability tests for Geo-predictive schemes. Further research into other BAG schemes, optimization of BAG schemes and bounds for BAG schemes is planned.

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Table 3. ESR and transmission bitrate statistics for all simulated cases.

ESR %	Journey (1)		Journey (2)		Journey (3)	
	BAG	**NBAG**	**BAG**	**NBAG**	**BAG**	**NBAG**
Route (1)	3.6 %	6.4 %	1.2 %	3.8 %	0.7 %	2.9 %
Route (2)	1.8 %	5.7 %	3.8 %	6.9 %	1.0 %	4.2 %

Bitrate Statistics	BAG	NBAG	% Increase
Bitrate	318.74	217.80	46.35