Packet Loss Modelling for H.264 Video Transmission over IEEE 802.11g Wireless LANs

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***Abstract*— In this paper, a packet loss model aimed at H.264 video transmission over IEEE 802.11g Wireless LANs is developed. The work was performed in the context of the EU FP6 WCAM project. Loss patterns are first generated from measured data, and a methodology evaluation is performed with emphasis given to the burst order k_0. The proposed Gilbert-Elliot model is a two state Markov chain approach whose validity has been investigated by comparing the transition probabilities, α and β, and the burst length probability density function from measured and modelled data for various k_0. In order to generate an accurate model, a novel iterative approach is used to determine the most appropriate value of k_0, comparing original and generated loss pattern signatures. Loss patterns are then generated for various scenarios using the Gilbert-Elliot model with the chosen parameters. The model enables H.264 robustness strategies to be evaluated in terms of error resilience and sensibility to packet loss.**

I. Introduction

The EU FP6 WCAM (Wireless Cameras and Audio-Visual Seamless Networking) project aims to study, develop and validate a wireless, seamless and secure end-to-end networked audio-visual system for video surveillance and multimedia distribution applications [1]. The OFDM-based IEEE802.11g [2] standard at 2.4GHz has been chosen for the physical layer alongside the IEEE 802.11 Medium Access Control layer (MAC) [2]. This paper describes the generation of packet loss patterns from measurement data obtained from a trial site selected for WCAM. The work also characterises packet loss behaviour and develops a model for use in the testing of robust H.264 video transmission.

Wireless channels are known to generate bursty errors [3]. Erroneous data packets are not available above the IEEE 802.11 MAC layer, since the MAC drops corrupted packets. With a UDP/IP transmission link based on the 802.11 MAC, lost packets at the application layer have several origins: i) *channel errors* that the MAC layer ARQ can not mitigate, ii) *congestion* when the incoming packet rate is unable to be sent and iii) *collision* when the WLAN co-exists with other devices operating in the same frequency band.

In this paper, packet loss behaviour is studied and modelled from measurement based statistics. The paper is organised as follows. Section II describes the measurements. An evaluation methodology of the measured loss patterns is presented in section III. The proposed Gilbert-Elliot model is detailed in section IV and validated in V. Section VI describes the loss pattern generation based on the proposed model. Video transmission simulations are introduced in section VII. Finally, section VIII concludes the paper.

II. Measurement Platform

The measurement platform consists of a client/server software pair running on two Windows XP based laptops connected in ad-hoc mode using PC card based IEEE 802.11b/g units. The client/server software pair has been developed by ProVision Communications Ltd [4] using Visual Studio 6.0^{TM} and includes the UDP/IP stack implemented using $Microsoft^{TM}$ Winsock32 API Version 2. The software implements an RTP-like layer after the application layer with a 16 byte header. One laptop implements the static server while the other implements the static (or mobile) client used to collect the transmission statistics as log files. Logged data is recorded at the RTP-like layer, hence after the MAC ARQ process, and includes cross-layer parameters such as packet delay, RSSI, transmission mode, application throughput and jitter. The maximum number of MAC ARQs is set in the WLAN card to 32. However, the actual number of ARQs a packet encounters is not known and will depend on the channel and traffic conditions. A packet counter in the RTP-like header allows us to determine which packets are missing at the application layer and to generate loss patterns with "0" meaning that the packet has been received and "1" that the packet is missing. Six data sets were gathered including static, mobile and range test measurements with UDP transmissions for different packet sizes and transmission rates. This results in a total of 46 loss patterns covering a broad range of scenarios.

III. Evaluation Methodology

A. Burst Definition

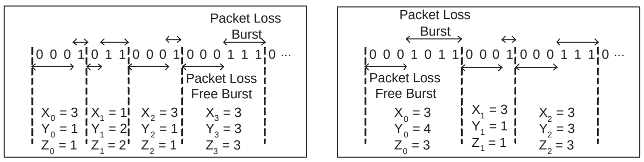
A *packet loss-free burst* of order k_0 is observed in the loss pattern when at least k_0 consecutive packets are correctly received. A *packet loss burst* order k_0 starts and finishes with a missing packet ("1") and is composed of at most $k_0 - 1$ consecutive received packets [3].

B. Indicator Sequences

Measurements and error patterns are traditionally evaluated using *indicator sequences* [5], [6]. Using the previous definitions, a *packet loss indicator sequence* (PLIS) $i_0 i_1 \ldots i_m$ of length *m* is segmented into *p* alternating packet loss-free bursts and packet loss bursts. The PLIS is represented by: $PLIS = (X_j Y_j Z_j)_{j=0 \ldots p-1}$, where

- X_j is the length of the j^{th} packet loss-free burst
- Y_j is the length of the j^{th} packet loss burst
- Z_j is the actual number of “1s” inside the packet loss burst.

X_j, Y_j and Z_j are k_0 dependent. Figure 1 shows an example of this PLIS representation with $k_0 = 1$ and $k_0 = 2$.



(a) $k_0 = 1$ (b) $k_0 = 2$

Fig. 1. Example of Packet Loss Indicator Sequence

From this representation, the data statistics can be derived and are detailed in table I. Probability Density Functions (PDF) of burst length duration d can also be derived for loss and loss-free bursts, $PDF^{msr}_{good}(d)$ and $PDF^{msr}_{bad}(d)$ respectively. The probability that packet $i+1$ is in a loss burst given that packet i is in a loss burst and the probability that packet $i+1$ is in a loss-free burst given that packet i is in a loss-free burst can be computed and are represented as β_{msr} and α_{msr} respectively. Note that these statistics are all k_0 dependent.

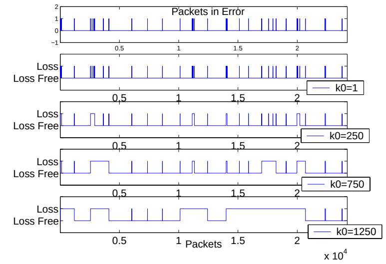
TABLE I

PLIS STATISTICS

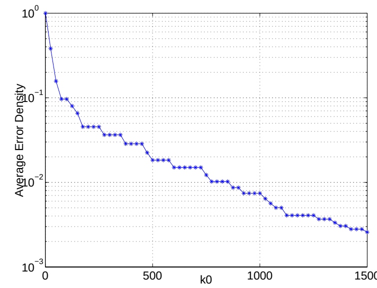
Name	*Notation*	*Formula*
Average. PER	PER_{msr}	$\frac{\sum_{j=0}^{p-1} Z_j}{\sum_{j=0}^{p-1} (X_j+Y_j)}$
Average loss free duration	$\bar{X}$	$\frac{1}{p} \times \sum_{j=0}^{p-1} X_j$
Average loss duration	$\bar{Y}$	$\frac{1}{p} \times \sum_{j=0}^{p-1} Y_j$
Loss Density	$d_{loss}(j)$	$\frac{Z_j}{Y_j}$

C. Interpretation

The methodology and the results depend highly on the definition of k_0, as shown in figure 2 for a particular static scenario. A common approach for packet loss is to use $k_0 = 1$ [3], [6]. However, a small k_0 allows very few packets to be received in a loss burst, leading to an average loss density close to one. This does not depict accurately the bursty behaviour of the channel, where packets might be received among many lost packets, especially if ARQ is used. As k_0 increases, more packets are allowed to be received in a loss burst, decreasing the loss density. A large k_0 induces large bursts and provides a too general view of the bursty characteristics. The choice of k_0 is therefore critical. The average loss density (figure 2(b)) provides an overall distribution of loss density and an accurate numeric trace of the burstiness of the channel for a large range of burst orders. This data provides a useful signature of the observed packet loss patterns.



(a) Packet Bursts



(b) Average Loss Density - Signature

Fig. 2. Influence of k_0 on bursts statistics

IV. GILBERT-ELLIOT MODEL

A common model used to characterise bursty channel behaviour is the Gilbert model [7], [8], based on a discrete two-state Markov Chain as shown in figure 3. When the channel is in the “Good” state, there are very few packet losses, whereas when the channel is in the “Bad” state, many packets are lost. Packet losses in the bad and good states are independent and occur with rates PER_{bad} and PER_{good} respectively. The Gilbert-Elliot model is a simplified version of the Gilbert model where all the packets are received correctly when the system is in the good state, leading to $PER_{good} = 0$.

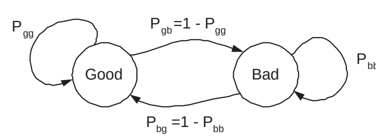


Fig. 3. Gilbert Elliot loss model

The Gilbert-Elliot model is characterised by its transition matrix, which is composed of transition probabilities from one state to another: P_{gg}, P_{gb}, P_{bg} and P_{bb}. For the remainder of this paper, the probabilities of staying in the good and bad states P_{gg} and P_{bb} are noted as α_{mkv} and β_{mkv} respectively. The average packet loss is given by [9]:

$$PER_{mkv} = PER_{bad} \times \frac{1 - \alpha_{mkv}}{2 - (\alpha_{mkv} + \beta_{mkv})} \quad (1)$$

Table II details various statistics of the model [9], [10].

V. MODEL VALIDATION

In this section, for a given value of k_0, the validity of the corresponding Gilbert-Elliot model for the packet loss

TABLE II
GILBERT-ELLIOT STATISTICS

Name	*Notation*	*Formula*
Average loss free duration	$T_{good}(d)$	$\frac{1}{1-\alpha_{mkv}}$
Average loss duration	$T_{bad}(d)$	$\frac{1}{1-\beta_{mkv}}$
PDF of bad burst length	$PDF_{bad}^{mkv}(d)$	$\beta_{mkv}^{d-1} \times (1-\beta_{mkv})$
PDF of good burst length	$PDF_{good}^{mkv}(d)$	$\alpha_{mkv}^{d-1} \times (1-\alpha_{mkv})$

model at the UDP layer is studied. Table III summarises the parameters that need to be identified using PLIS in order to define the proposed model. PER_{good} is equal to 0 and PER_{bad} is assumed to be the average loss density. Moreover, these parameters are k_0 dependent.

TABLE III
STATISTICS PARAMETERS IDENTIFICATION WITH PLIS

Transition Probabilities	*Loss Probabilities*
$\alpha_{mkv} = 1 - 1/\bar{X}$	$PER_{good} = 0$
$\beta_{mkv} = 1 - 1/\bar{Y}$	$PER_{bad} = \sum_{j=0}^{p-1} Z_j / \sum_{j=0}^{p-1} Y_j$

For a particular k_0, we compare the measured and modelled α, β, average PER, PDF_{good} and PDF_{bad}. The error distance used is the log square error (LSE) defined by:

$$LSE = (\log(P_{mkv}) - \log(P_{msr}))^2 \qquad (2)$$

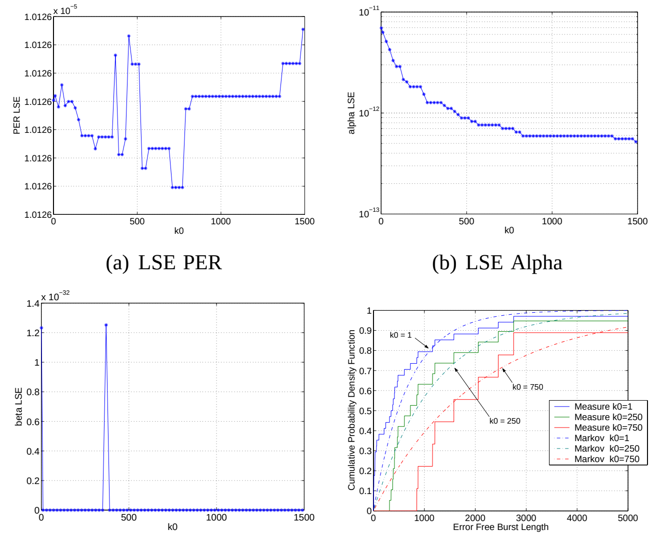
where P_{msr} and P_{mkv} are the parameters under study. Figures 4(a), 4(b) and 4(c) show the model validation as a function of k_0 in terms of the LSE of α, β and PER for one of our measurement routes. Figure 4(d) shows a comparison between the measured and modelled cumulative PDFs of packet loss free length for a static case. It can be seen that the proposed model statistics are very close to the measured values. The PER LSE is always smaller than 2×10^{-5} and the values of LSE for α and β are near zero. Moreover, the cumulative PDF for the packet loss-free length of the proposed model follows closely the measured PDF. Similar results were obtained for the packet loss burst and for all other scenarios. The Gilbert-Elliot model appears to represent an appropriate model for the received packet and packet loss mechanisms in a UDP transmission based on the IEEE 802.11g PHY.

VI. LOSS PATTERN GENERATION

In this section, loss patterns are generated using the model developed in the previous section. Markov parameters are extracted from the measurements for each value of k_0 using PLIS and table III.

A. Determination of k_0

The statistics of table III are k_0 dependent. In order to generate the most accurate model, a novel iterative approach is used here to determine the most appropriate k_0. Previous studies in the literature [5], [6] did not provide a justified choice of k_0. In our new approach, the generated pattern from



(a) LSE PER (b) LSE Alpha

(c) LSE Beta (d) Cumulative Pdf of packet loss - free burst

Fig. 4. Model Validation (a-b-c): route, Data 7, 300 bytes at 2000 kbits/s; (d): static, Data 11, 600 bytes at 2000 kbits/s

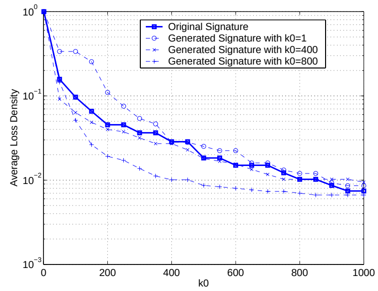
the model should provide a similar signature to the measured original. For each measured loss pattern, the original signature is computed. With the iterative algorithm, for each k_0 of the original signature, a loss pattern is generated with the Gilbert-Elliot model using their respective α, β and PER_{bad} parameters. Its signature is computed and compared with the original signature using the mean LSE. The k_0 that minimises the mean LSE provides the closest signature to the original and this then determines the chosen value of k_0. For statistical purposes, 20 loss patterns are generated for each k_0 value and the mean LSE is then computed over this set. Figure 5 shows examples of these signatures for different k_0 values. Clearly, for this specific scenario, $k_0 = 400$ provides the closest match. This is illustrated with the mean LSE on figure 5(b), where the minimum mean LSE is reached for a k_0 value of around 300-400. k_0 has been determined for each measurement scenario in a similar manner.

B. Gilbert-Elliot Parameters

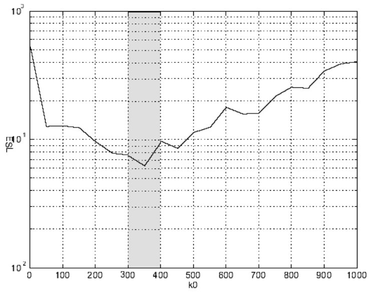
Once the appropriate k_0 is determined, the appropriate Markov parameters can be extracted. Table IV gives a sample of $1-\alpha$, $1-\beta$, PER_{bad} and the corresponding PER_{av} to use for further generation of loss patterns for a route measurement. On a first approximation, losses occur in the loss burst with a uniform distribution and with a probability equal to the loss density. A more advanced approach would be to consider a loss model in the bad state that uses a similar two state-model. This approach is not explored further in this paper.

VII. VIDEO TRANSMISSION

The previous study provides us with an error modelling tool for evaluating the error resilience H.264 [11] using channel statistics derived from on-site measurements. Here, we provide



(a) Signature Comparison



(b) Mean Log Square Error

Fig. 5. k_0 determination

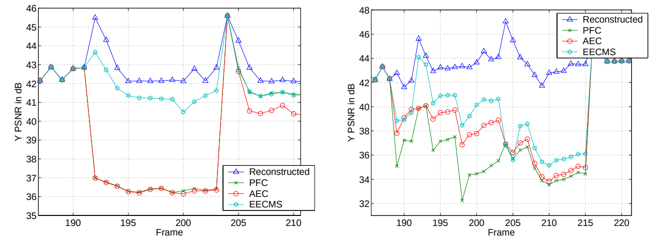
TABLE IV
DATA 7

Scenario	$1-\alpha$	$1-\beta$	PER_{bad}	PER_{av}
500kbits/s - 300 bytes	7.43e-04	4.92e-03	1.97e-02	2.58e-03
500kbits/s - 1200 bytes	2.90e-03	2.89e-02	1.14e-01	1.04e-02
2000kbits/s - 300 bytes	2.50e-04	2.49e-03	1.66e-02	1.51e-03
2000kbits/s - 1200 bytes	7.30e-04	6.79e-03	4.12e-02	4.00e-03

an example of the use of generated patterns by comparing two different concealment methods: i) previous frame copy (PFC) and ii) advanced concealment (AEC) from the H.264 reference software [12]. We also compare enhanced concealment techniques developed in [13] (EECMS). Figure 6 compares the PSNR of the received *hall* and *foreman* sequences encoded at 2000kbits/s and with a 300 byte packet length for a static transmission using the three previous techniques. From figure 6, it can be seen that the EECMS provides better concealment than the AEC and the PFC. Using our generated packet loss patterns we can perform more accurate evaluations of the various resilience and robustness options (compared to the common assumption of uniform packet loss).

VIII. CONCLUSIONS

In this paper, packet loss behaviour was characterised and loss patterns extracted from measurement data. The measurement platform and the method developed to extract the loss patterns were described. The burst order k_0 was shown to be a key parameter in the definition of a loss/loss-free burst model and its choice was shown to be critical. The average density loss within a loss burst was considered as a signature of the loss pattern. It provides a useful approach to characterise the observed bursty channel behaviour. For a given k_0, the



(a) Hall (b) Foreman

Fig. 6. Example of the use of generated pattern: PSNR comparison for H.264 Error Concealment Algorithm, $PER = 2 \times 10^{-3}$

proposed Gilbert-Elliot model was validated by comparing the transition probabilities from the measurements and the model, as well as the probability density functions. In order to generate accurate Gilbert-Elliot loss patterns, the appropriate value of k_0 was determined using a new iterative approach that compared the signature of the observed original pattern with that of the synthetically generated patterns. This provided us with an accurate and numerically justified choice of k_0. The resulting model provides us with a powerful tool to evaluate new error resilience video coding techniques.

ACKNOWLEDGMENT

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