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Simulation of random cell loss

Cell loss can occur unpredictably in ATM networks. This document describes a method of simulating cell loss. A specification for a packetized bitstream has been defined. A model of bursty cell loss is defined and analysed in order to allow the simulation of bursty cell loss. The proposed specification and model are simplified; no attempt is made to model actual ATM networks; the main objective of the model is to allow consistent simulation of the effects of cell loss on video coding.

1. Bitstream specification

The coded bitstream is packetized according to the following syntax. It allows cells to be marked as low or high priority. It allows cells to be marked as lost while retaining all the coded data in the bitstream file. A bitstream can easily be modified for different cell loss rates.

The coded bit stream is stored as a file of bytes. It is packetized into 48 byte cells.

Each cell is preceded by a cell identification (CI) byte. Each cell contains a four bit sequence number, a four bit sequence number protection and 47 bytes of data. The syntax is as follows:

< CI > <SN> <SNP> < 47 bytes of data >

The CI byte consists of the bit string '101101' followed by the priority bit followed by the cell lost bit. The priority bit is set to '1' for low priority cells and '0' for high priority cells. The cell lost bit is set to '1' for lost cells, otherwise '0'. The cell loss ratio for low priority cells may be different to that for high priority cells. SN is incremented by one after every cell. The sequence number protection is set to zero. For two layer coding, the bitstream produced by coding each layer is stored in a separate file.

The CI byte summarizes the five byte cell header and the effect of transmission through the network (i.e. cell loss).

2. Calculation of cell loss probabilities

This section outlines a method for determining whether any cell in a bitstream should be marked as lost. Cell loss is assumed to be random, with the probability of cell loss depending only on whether the previous cell was lost.

Firstly the mean cell loss rate and the mean burst of consecutive cells lost is calculated from the probabilities of cell loss. These equations are then rearranged in order to express the cell loss probabilities in terms of the mean cell loss rate and the mean burst of consecutive cells lost.

The following notation is used. The probability that any cell is lost is given by P, the probability that a cell is lost given that the previous one was not lost is given by P_n and the probability that a cell is lost given that the previous one was lost is given by P_l. These probabilities are illustrated in the tree diagram below.

```
                                                       |------ Lost Cell
                                                  Pl   |
                  |-------- Lost Cell --------|
                                                 1-Pl  |
               P  |                                    |---- Not Lost Cell
Unknown           |
Previous ------|
State             |
             1-P  |                                    |------ Lost Cell
                                                  Pn   |
                  |------ Not Lost Cell ------|
                                                 1-Pn  |
                                                       |---- Not Lost Cell
```

2.1. Calculation of mean cell loss rate

The mean cell loss probability is given by P. In this section a relationship between P, P_n and P_l is derived, as follows, by finding two equivalent expressions for the probability of a given cell being lost. A lost cell can occur in two ways: immediately after a cell has been lost and after a cell has been received. The probability that a cell is lost, P, is the sum of the probability that the cell is lost given the previous cell was lost multiplied by the probability that the previous cell was lost, $P * P_l$, and the probability that the cell is lost given the previous cell was not lost multiplied by the probability that the previous cell was not lost, $(1 - P) * P_n$. So,

$$P = P * P_l + (1 - P) * P_n$$

So

$$P = P_n / (1 - P_l + P_n) \qquad (1)$$

2.2. Calculation of mean burst of consecutive cells lost

A burst of lost cells is defined as a sequence of consecutive cells all of which are marked as lost. It is preceded by and followed by one or more cells that are marked as not lost. The length of the burst of lost cells is defined as the number of cells in a burst that are marked as lost. The mean burst of consecutive cells lost is defined as the mean burst length. This number must always be greater than or equal to one.

A burst starts when a cell is lost after one or more cells have not been lost. The probability that this is a burst of length one is equal to the probability that the next cell is not lost, that is, $1 - P_l$. The probability that this is a burst of length two is equal to the probability that the next cell is lost and the one after that is not lost, that is, $P_l * (1 - P_l)$. The probability of a burst of length n is $P_l^{(n-1)} * (1 - P_l)$. The mean burst length, B, is therefore given by:

$$B = (1 - P_l) + 2 * P_l * (1 - P_l) + 3 * P_l^2 * (1 - P_l) + \ldots$$

Summing this series leads to the result:

$$B = 1 / (1 - P_l) \qquad (2)$$

2.3. Calculation of cell loss probabilities

Rearranging equation (2) gives:

$$P_l = 1 - 1 / B \qquad (3)$$

Rearranging equation (1) gives:

$$P_n = P * (1 - P_l) / (1 - P)$$

Using equation (3) gives:

$$P_n = P / (B * (1 - P)) \qquad (4)$$

2.4. Simulation of cell loss

Equations (3) and (4) allow the probabilities of cell loss to be calculated from the average cell loss rate and the mean length of bursts of lost cells. Cell loss can easily be simulated using these probabilities: assume that the first cell is received, then the probability that the next will be lost is given by P_n. The probability that a cell is lost is always P_n, unless the previous cell was also lost in which case the relevant probability is P_l.

For an average cell loss rate of 1 in 1000 and a mean burst length of 10, $P_l = 9/10$ and $P_n = 1/9999$. These probabilities indicate that long periods without cell loss occur, typically 9999 consecutively received cells, but when cell lost does occur, a burst of consecutive cells will be lost, typically a burst of 10.

A simulation of cell loss only needs a random number generator, the values of P_n and P_l and the knowledge of whether the previous cell was lost or not. Pseudo-Pascal code to perform cell loss is given below. Random is a function that returns a random number between zero and one; its implementation is given below.

```
PreviousCellLost := FALSE;
Write('Enter mean cell loss rate and burst length');
Readln(P,B);
PL := 1 - 1/B
PN := P / (B * (1-P) )

For CellCount := 1 To NumberOfCells DO
  BEGIN
    CASE PreviousCellLost OF
      TRUE  :  IF Random < PL THEN CellLost := TRUE
                              ELSE CellLost := FALSE;
      FALSE :  IF Random < PN THEN CellLost := TRUE
                              ELSE CellLost := FALSE;
      END;
    Write(CellLost);
    PreviousCellLost := CellLost;
    END;
END.
```

2.5. Random number generation

To ensure the consistent simulation of cell loss, it is necessary to ensure that the same sequence of random numbers is generated by all simulations regardless of the machine or programming language used. This section describes a method for the generation of such random numbers.

Random numbers are generated by use of a 31 bit shift register which cycles pseudo-randomly through (2^31 - 1) states (the value of zero is never achieved). The shift operation is defined by the pseudo-Pascal code below.

```
Bit30  := (ShiftRegister & 2^30) DIV 2^30
Bit25  := (ShiftRegister & 2^25) DIV 2^25
ShiftRegister := (2*ShiftRegister MOD 2^31) + (Bit30 XOR Bit25);
```

To generate a random number, the shift register is first shifted as above and then divided by (2^31 - 1). It may be easier to use it as it is, and multiply the probabilities in the program above by (2^31 - 1).

2.6. Proposal for parameters
This section suggests specific values of the parameters to allow consistent simulation of the effects of cell loss on video coding.

It is suggested that low priority cells have a mean cell loss rate of 1 in 1000 and a mean burst length of 3. It is suggested that high priority cells have a mean cell loss rate of 1 in 10^8 and a mean burst length of 3.

A separate random number generator is used for low and high priority cell loss. For each, the shift register is initialised to a value of 1 and is then shifted 100 times. If this is not done, the first few random numbers will be small, leading to the loss of the first cells in the bitstream.

3. Conclusion
A specification for a packetized bitstream has been defined. This allows cells to be marked as low or high priority and as lost or not lost. All coded data is present even when cells are marked as lost.

Assuming that cell loss is random with the probability of any given cell being lost dependent only on whether the previous cell was lost, analysis has been performed to determine the probabilities of cell loss in terms of the mean cell loss rate and the mean cell loss burst length.

This document forms a framework for the proposal from this experts group for a cell loss experiment specification.

4. Acknowledgement
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