Performance Analysis of Packet Loss Concealment in Mobile Environments with a Two-State Loss Model

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Introduction

- VoIP and other real-time packet-based applications will traverse wireless networks that are suffer from fading, network (node) losses or both.
- Typical outages are non-uniform but can be modeled by a two-state loss model: High Loss and Low Loss states.
- RFC 2198 packet loss concealment algorithm will enhance speech quality in harsh channel conditions.
- Effect of packet replication delay and packet concealment method (resulting in different bandwidth expansion rates) is a very important design factor.
In Scheme 1, voice samples of a packet are copied and retransmitted D packet times later with voice samples of the new packet, resulting in 100% information bandwidth expansion

- (A) Loss of either packet (1 out of 2) will not result in loss of data

In Scheme 2, voice samples from adjacent packets are XORed together and are transmitted D packet times later, resulting in 50% information bandwidth expansion

- (B) Loss of 1 out of 3 packets will not result in loss of data

(A) and (B) ➔ Scheme 1 performs better at the cost of more bandwidth expansion ➔ We need to quantify the cost/benefit

D has a profound effect on performance in a two-state loss environment ➔ We need to quantify the effect of this parameter since unnecessary large D results in extra delay in a real-time application
Two-State Model

- Low Loss and High Loss sojourn time and transition parameters are defined as follows:
  - $p$, the transition probability from Low Loss to High Loss state
  - $\alpha$, the probability that when the channel is in High Loss state it stays in the High Loss state (i.e., the transition probability from High Loss to Low Loss state is $1 - \alpha$)
  - $\beta$, the probability of a packet being dropped (i.e., lost) while the channel is in Low Loss state
  - $\gamma$, the probability of a packet being dropped (i.e., lost) while the channel is in High Loss state

- Traditional two-state loss models do not apply due to the time correlation of original and replicated packet transmissions. This introduces memory effects that are essential to take into account in the analyses.
Probability of Success for Scheme 1

For Scheme 1:

\[
P_s = \frac{1 - \alpha}{1 - \alpha + p} \left[ (1 - \beta) + \beta \left( (1 - \beta) \eta_{L,D} + (1 - \gamma) \omega_{L,D} \right) \right] + \frac{p}{1 - \alpha + p} \left[ (1 - \gamma) + \gamma \left( (1 - \beta) \eta_{H,D} + (1 - \gamma) \omega_{H,D} \right) \right]
\]

where

\[
\begin{align*}
\eta_{L,1} &= 1 - p \\
\eta_{H,1} &= 1 - \alpha \\
\eta_{L,i} &= (1 - p) \eta_{L,i-1} + p \eta_{H,i-1} & \text{for } i > 1 \\
\eta_{H,i} &= \alpha \eta_{H,i-1} + (1 - \alpha) \eta_{L,i-1} & \text{for } i > 1 \\
\omega_{L,1} &= p \\
\omega_{H,1} &= \alpha \\
\omega_{L,i} &= (1 - p) \omega_{L,i-1} + p \omega_{H,i-1} & \text{for } i > 1 \\
\omega_{H,i} &= \alpha \omega_{H,i-1} + (1 - \alpha) \omega_{L,i-1} & \text{for } i > 1
\end{align*}
\]
For Scheme 2, the probability of successfully receiving a packet is:

\[
P_S = \frac{(1-\alpha)(1-\beta)}{1-\alpha+p} + \frac{p(1-\gamma)}{1-\alpha+p} + \frac{1}{2(1-\alpha+p)}(1-\beta)(1-p) + (1-\gamma)p)\left((1-\beta)(\eta_{L,D+1} + \eta_{L,D}) + (1-\gamma)(\omega_{L,D+1} + \omega_{L,D})\right) + \\
\frac{1}{2(1-\alpha+p)}((1-\beta)(1-\alpha) + (1-\gamma)\alpha)\left((1-\beta)(\eta_{H,D+1} + \eta_{H,D}) + (1-\gamma)(\omega_{H,D+1} + \omega_{H,D})\right).
\]

Simulation results over 100000 packet times corroborated both Scheme 1 and Scheme 2 analyses.
Example 1 for Scheme 1

- Take \( \beta = 0 \) (no loss in Low Loss state), \( \gamma = 1 \) (100% loss in High Loss state) and \( p = 0.1 \)
Example 2 for Scheme 1

Take $p = \beta = 0.1$ and $\alpha = 0.5$
PLR before & after Concealment

- Input PLR vs. Output PLR for Scheme 1 with $\beta = 0$, $\gamma = 1$ and $p = 0.1$, for various values of $D$
What if $p$ is relatively large?

Take $p = 0.5$ with $\beta = 0$ and $\gamma = 1$

Take $p = 1$ (!!) with $\beta = 0$ and $\gamma = 1$

Then $D = 1$ gives the most reasonable performance.
Scheme 2 Example

- Take $\beta = 0$ (no loss in Low Loss state), $\gamma = 1$ (100% loss in High Loss state) and $p = 0.1$
Comparing Schemes 1 and 2

- Take $\beta = 0$ (no loss in Low Loss state), $\gamma = 1$ (100% loss in High Loss state), $p = 0.1$ and $D = 3$