CHAPTER 4

SIMULTANEOUS MULTI-PATH TRANSMISSION
FOR BURST LOSS RECOVERY

4.1 INTRODUCTION

The next generation Internet considers the OBS as a major standard network to carry heavy traffic (Battestilli&Perros 2004). In OBS networks, issues related to burst losses are of major concern for real time Internet applications. Burst contention recovery techniques are needed in the OBS layer in order to reduce random burst-contention losses, thereby improving the transmission reliability of OBS networks. The existing works rarely consider the burst loss and loss of control packets which may lead to contention, burst failures, and shrinking of the congestion window.

This work proposed a simultaneous multi-path transmission along with path interleaving for consecutive lost burst recovery with load balanced deflection routing protocol. Initially, in the FEC technique, the data blocks containing redundant bursts are gathered together and the bursts are separated. When burst loss occurs continuously, this technique is combined with path interleaving which can be used to recover the continuous lost bursts. The path interleaving mechanism determines the block length, the number of source packets, and redundant packets are fixed. Based upon the redundant blocks, the continuous lost bursts can be recovered at the receiver.
With the support of simulation results, the proposed scheme decreases the processing time of FEC encoding/decoding with the improved recovery of blocks which provides high delivery ratio.

4.2 SCHEDULING IN OBS NETWORKS

The ingress OBS node in the network gathers the data into bursts and the resultant control packets are transmitted for each burst (Xu et al 2003). A wavelength channel scheduling algorithm has been used to determine the wavelength channel for a control packet which arrives at a core node and also the wavelength channel for a corresponding data burst on an outgoing link. The control packet provides the information about scheduler with an expected arrival time of the data burst and its duration. The scheduler maintains the time accessibility for each wavelength channel. Among several idle channels, the channel which reduces the burst loss is selected efficiently. The routing nodes function well in high speed environment which manage large amounts of burst traffic and so the design of scheduler needs to be simple (Nandi et al 2009).

4.3 BURST LOSS ISSUES

Packet losses may occur in OBS networks since they are connectionless and disputation may arise in the core network. The lost data need to be retransmitted at higher layers of OBS later, when the dropped burst is not able to recover at the OBS layer (Vokkarane&Zhang 2006).

The number of successive packets having lost burst indicates about the occurrence of burst loss to the TCP sender. The data present in the received acknowledgement (ACKs) is used by the duplicate/partial ACKs to indicate the burst loss (Yu et al 2004).
Triple Duplicate (TD) and Timeout (TO) retransmissions may occur during consecutive packet losses in a burst which is capable of shrinking the congestion window for the successive number of times (Shihada & Ho 2008). Few wavelength reservations for bursts may fail in the wavelength reservation method. Thus, burst loss recovery technique is required to overcome the drawbacks of consecutive burst transmission (Arima et al 2007).

4.4 PROPOSED LOSS RECOVERY TECHNIQUE

In chapter 3, a LBDR algorithm has been proposed to minimize the congestion in OBS networks. To recover from the continuous burst loss caused by random contentions, this chapter introduces the novel burst recovery method.

From the literature, it is observed that the FEC technique is one of the loss recovery schemes that use redundant bursts. If the FEC technique is implemented along with single path transmissions require additional bandwidth. Hence, this thesis aimed to utilize the same bandwidth by means of Simultaneous Multi-path Transmission with interleaving for burst loss recovery (SMT) and compared with the existing FEC method for Reliable Transmission (FECRT) algorithm.

In FEC technique, the data blocks containing redundant bursts are gathered together and the redundant bursts are separated. Using a path interleaving mechanism, all the FEC blocks send one packet to each path. However, the transmission rate cannot be higher than the original transmission rate. Then, the packet of FEC blocks selects an alternative path, if the first path’s transmission rate exceeds original transmission rate, until all packets are transmitted.
Then at the receiver, the average packet loss rate, and the number of continuous lost packets is calculated; also a feedback is sent to the sender. The sender performs the block length control by fixing the number of source packets and redundant packets, and hence does not need to increase the FEC redundant information. Using this block length, the data packet containing continuous lost bursts is divided into two Reed-Solomon (RS) codes. During packet transmission, the continuous lost bursts can be recovered using the redundant data blocks in each path.

4.5 FEC BASED BURST RECOVERY TECHNIQUE

Initially, FECRT algorithm considers RS codes for the FEC processing. The \((n, k)\) RS codes includes \(n\)-byte length code words, with \(k\) out of \(n\) bytes as the original data and the remaining \((n-k)\) byte as the redundant data. Equation (4.1) denotes the \((n, k)\) RS code which can correct \(t\) errors and \(e\) errors occurring in one \(n\) byte codeword.

\[
2t + e \leq (n - k) \quad (4.1)
\]

Here, \((n-k)\) byte data loss can be recovered when no errors occur.

Also, an application data is split into \(\eta\) blocks with the same size. Each data block generates a burst \(\eta\) which are transmitted to the destination node. The size of the data blocks is \(S\) bytes. The parameters of RS code are chosen as specified in Equations (4.2) and (4.3).

\[
n = (\eta + 1)\lambda \quad (4.2)
\]

and

\[
k = \eta\lambda \quad (4.3)
\]

where \(\lambda\) is a constant.
Using this, a new burst is constructed that consists of a redundant data of the other ‘η’ bursts. When one of the ‘η+1’ bursts is lost during transmission, it can be recovered until the destination node receives the remaining ‘η’ bursts successfully.

Figure 4.1 Redundant Burst Generation

Figure 4.1 shows three data blocks D₁, D₂ and D₃ with redundant data in it. The redundant blocks in D₁ and D₂ are separated to form a redundant burst. FEC encoding is done with (η+1)λ, ηλ) RS code is performed at the source node. The encoding scheme collects ‘λ’ byte data blocks from each of the ‘η’ bursts. The ‘ηλ’ byte data are collected from the ‘λ’ byte data blocks. By combining these redundant blocks, a redundant burst is constructed.

(S/λ) encoding operations need to be performed for each data burst which has ‘S’ bytes and it generates ‘λ’ redundant data. Original burst ‘η’ and the generated redundant burst are transmitted to their destination node. At an intermediate node, when one of the ‘η+1’ bursts is lost, FEC decoding
algorithm recovers the lost burst at the destination node. Since the lost original burst can be recovered from the other original burst and redundant one, the transmission of the two original bursts succeeds (Arima et al 2007).

The FEC decoding time can be calculated using ‘P’ number of FEC processors, and ‘W’ bps FEC processing speeds for each FEC processor. The FEC decoding time ($\delta$) is given by Equation (4.4) as

$$\delta = \frac{8(n+1)S}{PW}$$ (4.4)

The burst $D_3$ has continuous lost data blocks and thus it has to be recovered using a FEC encoding technique combined with path interleaving.

4.6 CONTINUOUS LOST BURSTS RECOVERY USING SMT

FECRT algorithm failed to recover the continuous lost data block using FEC technique. Hence, the introduction of redundant burst in the single path transmission increases the transmission bandwidth. Generally, the network cost lies on the transmission power and bandwidth. Therefore, this technique may not be compatible with high traffic load balanced deflection routing. Considering this scenario, this thesis proposes a novel burst recovery algorithm, known as simultaneous multi-path transmission with path interleaving. The main objective of SMT is to recover the continuous lost bursts and BHPs without additional bandwidth requirement.

This section concentrates the concept of path interleaving mechanism, block length adoption, and interleaving controller for developing SMT algorithm.
4.6.1 Path Interleaving Mechanism

Initially, when the sender transmits data through different paths, it ensures that the different FEC blocks can interleave with each other. When the continuous lost packets occur, these continuous lost packets disperse to different blocks and improve the FEC recovery efficiency. There is a chance for the blocks getting interrupted when the sender transmits the data through different paths.

The several different FEC blocks are transmitted to the receiver in different paths, after encoding process performed by the FEC encoder. The path interleaving mechanism is used to transmit data through different paths.

- First, all FEC blocks send one packet to each path. However, the transmission rate cannot be higher than the original transmission rate.

- Then, the packet of FEC blocks may select alternative path, if the first paths transmission rate exceeds original transmission rate until all packets are transmitted.

The data block containing continuous lost bursts is divided based upon the block length adaptation scheme. The RS(n, k) bursts are partitioned into $RS_A(n/2, k/2)$ and $RS_B(n/2, k/2)$. By doing so, parts of losses are easily recovered with smaller FEC blocks when the number of continuous redundant bursts is larger.

When sending the bursts of FEC blocks over multiple paths, the scheme changes the transmission order of FEC blocks and sends them using path interleaving. The receiver has a packet buffer to absorb the impact of packet disordering. Path interleaving distributes two or more FEC block bursts over multiple paths to share the number of continuous redundant bursts among different blocks.
In Figure 4.2, the burst D₃ has continuous lost data blocks. Before encoding and decoding process, the data blocks are split into two categories according to the block length. The RS (n, k) code is splitted into RSₐ(n, k) and RS₉(n, k), and are encoded. Then, the lost bursts are recovered.

![Diagram](image)

**Figure 4.2 Partitions of RS (n, k) for Encoding**

### 4.6.2 Block Length Adaptation

In the FEC control scheme, the sender determines RS (n, k) and the receiver returns the number of continuous redundant bursts and the average burst loss rate to the sender for each path. The number of continuous redundant burst is dispersed over FEC blocks with an interleaving depth of ‘m’. After the interleaving depth ‘m’ is determined, the sender partitions RS (n, k) into RSₐ(n, k) & RS₉(n, k). Moreover, to send the FEC blocks to the receiver through different paths, the sender sends data along multiple paths using path interleaving.
In the FEC mechanism, there are ‘n’ packets consisting of ‘k’ source packets and ‘h’ redundant packets in one FEC block. Thus, the total number of packets for transmission within one block is ‘(k+h)’ packets. If any ‘k’ or more packets are successively received, the block can be completely reconstructed.

To analyze the effect of FEC protection on every block, the transmission of packets is regarded as a series of independent Bernoulli trials ($V^n_i$). When the packet error rate ‘$E_R$’ in the network is known, the probability of a block ‘$B_p$’ that cannot be recovered is given by Equation (4.5),

$$B_p = \sum_{i=0}^{k-1} V^n_i \times (1 - E_R)^i \times E_R^{n-i}$$

Since the file is comprised of approximately ‘n/k’ blocks, the expected number of successfully recovered blocks ‘$S_R$’ can be estimated from the following Equation (4.6),

$$S_R = \frac{n}{k} \times (1 - B_p)$$

Thus, the expected total number of source packets ‘$T$’ received from the successfully recovered blocks can be estimated from the following Equation (4.7),

$$T = \frac{n}{k} \times (1 - B_p) \times k = n \times (1 - B_p)$$

A block is deemed to be unrecoverable if more than ‘h’ packets are lost. Hence, the expected number of source packets received from each unrecovered block ‘$T_u$’ is given by Equation (4.8),

$$T_u = \frac{k}{k+h} \times \left( \sum_{i=0}^{k-1} V^n_i \times (1 - E_R)^i \times E_R^{n-i} \times i \right)$$
The expected total number of source packets received from all the unrecovered blocks ‘$S_{R_u}$’ can be estimated from the following Equation (4.9),

$$S_{R_u} = \frac{n}{k+h} \times \left( \sum_{i=0}^{k-1} V^i \times (1 - E_R)^i \times E_R^{n-i} \times i \right) \quad (4.9)$$

However, the receiver can still receive ‘(k -1)’ or fewer source data packets from the FEC blocks that could not be recovered. Hence, the unsuccessfully recovered rate does not necessarily provide a true indication of the average packet loss rate following the FEC decoding operation at the receiver. The effective packet loss rate needs to be subtracted from the remaining source data packets after an unsuccessful recovery.

The effective packet loss rate ‘$L_E$’ following the packet-level FEC decoding process can be estimated from the Equation (4.10),

$$L_E = B_p - \frac{\left( \sum_{h=0}^{k-1} V^i \times (1 - E_R)^i \times E_R^{n-i} \times i \right)}{k+h} \quad (4.10)$$

The effective packet loss rate for FEC block length ‘m’ has to be calculated. The decision making process is employed to choose the most suitable block length ‘m’. After determining the value of ‘m’, the sender transmits data by utilizing path interleaving mechanism.

For different block lengths of ‘m’, there are different corresponding FEC effective packet loss rates. Using Equations (4.5) and (4.10), Blocking probability and loss rate can be given for different values of ‘m’ as shown in Equations (4.11) and (4.12) respectively,

$$B_P(m) = \sum_{i=0}^{k-1} V^i/m \times (1 - E_R)^i \times E_R^{n-i} \quad (4.11)$$
\[ L_E(m) = B_p(m) - \frac{\sum_{i=0}^{k \cdot m} V_i^m \times (1 - L_R)^{i} \times L_R^{\frac{n}{k+h} + i}}{m} \]  

(4.12)

Tsai et al (2011) formulated the Equations (4.5) to (4.12) for video streaming in next generation networks. In this work, the path interleaving mechanism along with FEC is used for OBS networks where the recovery of burst is more stringent for the reduction of burst loss.

4.6.3 Interleaving Depth Controller

The suitable interleaving depth can be calculated using the following steps:

1. Initially, the number of common factors \( A \) of \( (n, k) \) is determined.
2. Select \( 'Z_j' \) as common factors of \( (n, k) \) where \( 1 \leq j \leq A \).
3. Select the available \( 'Z_j' \) to meet the constraint that \( Z_j > U_h \), where \( U_h \) is the number of continuous lost packets.
4. If \( 'U_h' \) is larger than the maximum \( 'Z_j' \), then \( 'Z' \) is the maximum \( 'Z_j' \).
5. \( (n/Z, k/Z) \) is given as input to the FEC encoder.

In Figure 4.3, the simultaneous multi-path FEC control scheme with path interleaving is described. The FEC control scheme divides the burst into two segments and encodes the redundancy. This scheme can reduce the packet losses on all multiple paths because the receiver is able to observe the average losses on multiple paths.

Here, the six source packets along with four FEC packets are transmitted from the sender. The FEC control scheme sends source data to different paths and encodes the redundancy for each path. After receiving the
acknowledgement from the receiver, the number of source packets and the redundant bursts are fixed by the sender.

The sender splits RS codes into two; $RS_A(n, k)$ includes source 1, 2, and 3 along with ‘FEC A’ and ‘FEC B’. $RS_B(n, k)$ includes source 4, 5, and 6 along with ‘FEC C’ and ‘FEC D’ packets. Three paths are established between the sender and receiver. Path 1 transmits source 1, 3, 5 and 6. Path 2 transmits FEC A and path 3 transmits FEC D. Since the bursts are divided and transmitted in three various paths, all the bursts can be transmitted simultaneously. The source 2 can be recovered using FEC A present in $RS_A(n, k)$ along the path 2 and source 4 can be recovered using FEC D present in $RS_B(n, k)$ with path 3. Thus this scheme helps in recovering all the lost packets successfully.

Figure 4.3 Multi-path Transmission with Path Interleaving
4.6.4 Proposed Algorithm

The proposed SMT algorithm is simulated and compared with FECRT. This algorithm considers three bursts $D_1$, $D_2$, and $D_3$ with redundant data. $D_3$ has continuous lost data blocks.

1. Bursts $D_1$ and $D_2$ are considered initially and the lost data blocks in the bursts are separated to form a redundant data burst.

2. $(s/\lambda)$ encoding operations need to be performed for each data burst which has ‘$S$’ bytes and it generates ‘$\lambda$’ redundant data.

3. Original burst and the generated redundant burst are transmitted to their destination node.

4. At an intermediate node, when one of the burst is lost, FEC decoding algorithm recovers the lost burst at the destination node.

5. The burst $D_3$ has continuous lost data blocks, so one data block is sent through each path.

6. When the receiver receives these blocks, it calculates the blocking probability and the effective loss rate using Equations (4.5) & (4.10).

7. Using this information, the sender performs block length control by fixing the number of source packets and redundant packets from Equation (4.9).

8. A suitable interleaving depth is calculated using the interleaving depth controller.

9. The determined source packets and the redundant packets are split into according to the interleaving depth and transmitted through multiple paths.
10. During transmission, the lost data blocks in a path can be recovered at the receiver using their corresponding redundant blocks.

The simulated SMT algorithm is compared with FECRT in terms of Delay, Burst received, Bytes received, and Delivery Ratio. The performance metrics considered above are analyzed quantitatively & depicted the performance of the proposed algorithm. These metrics are studied by varying several parameters that include network traffic rate, different time interval, and increase in traffic flow.

4.7 SIMULATION

4.7.1 Simulation Setup

The performance of the proposed SMT burst loss recovery with an extensive simulation study is carried out using Network Simulator – ns-2 for OBS networks (Gurel et al 2007). FECRT algorithm is also simulated and compared. The corresponding simulation settings are tabulated in the Table 4.1.

<table>
<thead>
<tr>
<th>Topology Center</th>
<th>Mesh center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of Nodes</td>
<td>28</td>
</tr>
<tr>
<td>Edge Nodes</td>
<td>14</td>
</tr>
<tr>
<td>Core Nodes</td>
<td>14</td>
</tr>
<tr>
<td>Maximum channels per link</td>
<td>10</td>
</tr>
<tr>
<td>Number of control channels per link</td>
<td>2</td>
</tr>
<tr>
<td>Number of data channels per link</td>
<td>8</td>
</tr>
<tr>
<td>Total channel Bandwidth</td>
<td>100 Mb</td>
</tr>
<tr>
<td>Link Delay</td>
<td>1 ms</td>
</tr>
<tr>
<td>Maximum Burst Size</td>
<td>4 Mb</td>
</tr>
<tr>
<td>Traffic Type</td>
<td>CBR</td>
</tr>
<tr>
<td>Packet Size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>Time</td>
<td>3, 5, 7, 9, 11 seconds</td>
</tr>
<tr>
<td>Transmission Rate</td>
<td>10 to 50 Mbps</td>
</tr>
<tr>
<td>Flows</td>
<td>1 to 5</td>
</tr>
</tbody>
</table>
In this simulation, a CBR traffic model is used to generate bursty traffic in which 5 traffic flows are set up between two edge routers. In all the simulation models, the results of the proposed SMT technique are compared with FECRT.

4.7.2 Results and Performance Analysis

The performance metrics measured through simulation studies are plotted, analyzed and compared with the existing method.

A. Variation on Traffic Rate

In this work, the OBS network performance is observed by varying the network traffic rate from 10 Mbps to 50 Mbps.

![Figure 4.4 Rate vs Burst Delay](image)

Figure 4.4 Rate vs Burst Delay

Figure 4.4 shows that the proposed SMT algorithm introduced less delay in transmission of bursts to the receiver than FECRT when the transmission rate is increased.
Figures 4.5 and 4.6 show the performance of the burst received and bytes received respectively when the transmission rate is increased from 10 Mbps to 50 Mbps. SMT performs the best when the transmission rate is even high. Both techniques perform good at low rate, while at very high rate SMT fares better than FECRT. It is observed that, at very high rate, SMT recovers the lost burst compared to FECRT by applying simultaneous multi-path recovery.
Figure 4.7 Rate vs CBR Delay

Figure 4.7 shows that CBR delay increases with the increasing of the network traffic rate. As the rate increased, the transmission system introduces more transmission delay. CBR delay is reduced by 50% in SMT compared to FECRT since it employs interleaving process.

Figure 4.8 Rate vs Delivery Ratio

Figure 4.8 portrays rate versus delivery ratio and it is noted that the proposed SMT algorithm provides 100% delivery ratio compared to FECRT method when the transmission rate is increased. In both the algorithms, the delivery ratio is constant for the change in rate. But in SMT algorithm, burst losses are observed even in multi-path environment and recovered which improves the delivery of packets.
B. Variation on Time

This simulation also includes the evaluation of the network performance with all simultaneous multi-path flows with different time intervals. The throughput of the network in terms of bytes, delay and delivery ratio for concurrent flows are also determined.

![Figure 4.9 Time vs Burst Delay](image)

**Figure 4.9 Time vs Burst Delay**

From the Figure 4.9, it is noticed that the proposed SMT algorithm has less Delay than FECRT method when the time interval is increased. The processing time taken by SMT is less than FECRT due to the path interleaving process.

![Figure 4.10 Time vs Burst Received](image)

**Figure 4.10 Time vs Burst Received**
Figure 4.11 Time vs Bytes Received

The burst received and the bytes received at the destination of the network is plotted for the different values of time interval in the Figures 4.10 and 4.11 respectively. When the simulation time interval period increases, the performance of SMT increases as a greater number of packets are recovered by FEC with interleaving. During long time intervals, the results show that SMT is better than the standard FECRT.

Figure 4.12 Time vs CBR Delay

Figure 4.12 shows that the proposed SMT algorithm has less CBR delay than the FECRT method when the time interval is increased.
Figure 4.13  Time vs Delivery Ratio

From Figure 4.13, it is indicated that the proposed SMT algorithm has more delivery ratio than FECRT method when the time interval is increased. It is noted that the performance improvement in delivery ratio is possible by the increase in processing speed obtained in SMT algorithm.

C. Variation on Flows

The performance of the OBS network for real time Internet applications is measured by varying the number of flows from 1 to 5 and the impact on the network parameters is observed if the number of flows increases.

Figure 4.14  Flows vs Burst Delay
Figure 4.14 shows the burst delay appeared in both the techniques. The delay appears marginally less for SMT technique when compared to FECRT, since it abruptly reduces the burst contention, thereby minimizing the re-transmission delay.

Figure 4.15  Flows vs Burst Received

Figure 4.16  Flows vs Bytes Received

Figure 4.15 and Figure 4.16 shows the throughput in terms of bursts and bytes received, respectively. As burst loss and contention is minimized in SMT, the bursts and bytes received in SMT method increases with increase in number of flows and becomes four times more for higher number of flows when compared with FECRT technique.
Figure 4.17 Flows vs CBR Delay

Figure 4.17 shows that the proposed SMT algorithm has better CBR Delay by at least 2% than FECRT method when the flows are increased. This is due to bursts with redundant information taking any path in SMT. Hence the receiver recovers the lost burst within its offset, the delay with respect to flows gets reduced. But in FECRT, the same data path is considered for original transmission and retransmission traverse on the same single path introduces delay.

Figure 4.18 Flows vs Delivery Ratio

Figure 4.18 depicts the performance of delivery ratio for flow 1-5. It clearly indicates that the proposed SMT algorithm has 100% delivery ratio whereas in FECRT, it is decreased when the flows are increased. But in case of SMT, the path interleaving method improves the burst loss recovery performance.
FECRT is one of the FEC derived from RS codes. RS are non-binary codes which are capable of correcting errors those appear in the bursts and are used in concatenated coding systems. RS coding algorithm calculates the error location using Newton identities which is one of the iterative techniques. During the identification of errors, the bursts are in the buffer hence reduces the delivery ratio. At the same time, the flow varies from 4 to 5; the number of iterations taken by the coding process is less that result a considerable increase in burst delivery ratio.

4.8 INFERENCE

Through analysis and extensive simulation experiments, the performance of the proposed SMT algorithm is compared to FECRT mentioned in the literature that uses only FEC to achieve burst loss recovery. The delivery ratio 100% implies that the lost bursts are recovered properly at the destination without the additional bandwidth requirement. The benefit of using multiple paths to send the redundancy packets is utilized for OBS networks to get packets without loss. This is very useful for the video transmission over OBS networks especially if data bursts are large and with high traffic loads.

In FECRT, there is only a single communication link does not require reassembly of bursts. So the destination node decodes simultaneously for each successful reception of packets. However, the proposed SMT, the data bursts are transmitted in multi-path, requires reassembly of packets at the destination.

Therefore, there is a need of extensive study for burst assembly and scheduling for reliable communication in OBS networks. In this work, a new assembly and scheduling technique for OBS networks is introduced and presented in the next chapter.