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光突发交换网络中基于 LDPC 码的丢包恢复机制

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摘　要:基于前向纠错编码理论,在光突发交换网络中提出一种丢包恢复机制来降低突发丢失率.构造了一种能对突发包进行在线编解码的低密度奇偶校验码.入口边缘节点通过对信息突发包进行在线编码产生冗余突发包,出口边缘节点利用译码算法从接收到的突发包中恢复出丢失的突发数据.另外,为信息突发包增加一个额外的偏置时间以减少冗余突发与信息突发竞争信道资源.通过 OPNET 仿真软件对不同丢包恢复机制的性能进行仿真,结果表明,与奇偶校验码提出的丢包恢复机制相比,具有更低的突发丢失率和良好的丢包恢复能力.

关键词:光突发交换;低密度奇偶校验码;丢包恢复;在线;额外偏置时间

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Research on Burst Loss Recovery Based on LDPC Codes in Optical Burst Switching Networks

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Abstract: A burst loss recovery mechanism based on forward frror correction was proposed to reduce burst loss probability in optical burst switching networks. A new low-density parity-check code was designed to encode and decode bursts online. In the ingress node, encoder generated redundant bursts by encoding information bursts, and in egress node, decoding algorithm was used for recovering lost bursts. For redundant bursts contended with information bursts for wavelength resource and that may result in large information bursts loss, extra-offset time was added for information burst. The performance of different burst loss recovery mechanism was investigated by OPNET simulation software, the results show that the burst loss recovery mechanism can reduce burst loss probability more efficiently compared with pairty-check codes. Therefore, the mechanism is provided with good capability of burst loss recovery.

Key words: Optical burst switching; Low-density parity-check codes; Burst loss recovery; Online; Extra offset-time

OCIS Codes: 060.2330; 060.4250; 060.4265; 060.6719

0 Introduction

The capacity of optical transmission systems should be rapidly increased in the near future. The ability to simply upgrading low bit-rate systems to higher rates up to 1 Tb/s will be a key to achieve this evolution. Optical Burst Switching (OBS) is developed as one of the most promising optical switching technologies for the next generation Wavelength Division Multiplexing (WDM) networks, which combines the advantages of both Optical Packet Switching (OPS) and Optical Circuit Switching (OCS)

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and avoids their disadvantages[1].

OBS network adopts the Just Enough Time (JET) protocol to reserve channel resource. In a core node, when a plurality of Data Bursts (DBs) request the same wavelength resource of the same output port, the DBs competition occurs and some DBs will be discarded. So the major concern in OBS networks is high burst contention result in DB loss. Many contention resolution policies such as optical buffering deflection and wavelength conversion were proposed[2]. To reduce Burst Loss Probability (BLP) more effectively, a DB loss recovery mechanism for OBS networks that uses Forward Error Correction (FEC) scheme[3] and Reed-Solomon (RS) erasure codes was proposed to recover the lost DBs by redundant DBs at the destination[4]. But RS code has rather high complexity of encoding and decoding. Parity-check codes which is quite simply are used for encoding information bursts to generate a redundant burst[5]. However, the capability of correcting errors for parity-check code is limited. So there is no single technique that offers flexibility to support both delay-sensitive and loss-sensitive traffic in the same OBS network.

In this paper, a latest research of Low-Density Parity-Check (LDPC) codes is considered based on Balanced Incomplete Block Designs (BIBD)[6] and Repeat Accumulate (RA)[7] codes. A systematic online BIBD-RA (OBIBD-RA) code which is easy to be implemented is constructed. The OBIBD-RA code provides a burst encoding mechanism that can encode and decode bursts online in OBS networks.

1 OBIBD-RA codes

Due to the lack of optical random access memory and the resource reservation of JET, the high BLP is intolerable in OBS network. FEC mechanism is an effective approach to reduce BLP by recovering the lost DBs from redundant DBs. In this section, as a kind of systematic LDPC code, OBIBD-RA code is constructed to reduce BLP in OBS network.

1.1 Balanced incomplete block designs

This part gives a brief description of BIBD. At first, Let t be a positive integer so that $m=12t+1$ is a prime number. Then consider the finite field GF$(12t+1)=\{0,1,\cdots,12t\}$ and design a set of BIBD χ in GF$(12t+1)$, Suppose GF$(12t+1)$ has a primitive element α of that GF$(12t+1)$ satisfy the condition

$$\alpha^{4t}-1=\alpha^{c} \tag{1}$$

where c is an odd positive integer less than $12t+1$. So we can design an $(m,n,\gamma,\rho,\lambda)$ BIBD, where $m=12t+1$, $n=t(12t+1)$, $\gamma=4$, $\rho=4t$, $\lambda=1$. There are t base blocks, which are given as follows

$$B_i=\{0,\alpha^{2i},\alpha^{2i+4t},\alpha^{2i+8t}\},0\leqslant i\leqslant t \tag{2}$$

For each base block B_i, each element of GF$(12t+1)$ is added to the B_i and $t(12t+1)$ blocks can be got. Each element appears in exactly γ of the n blocks and every two elements appear together in exactly λ of the n blocks. Then an $(12t+1)\times t(12t+1)$ matrix $\boldsymbol{H}$ over GF(2) can be got as

$$\boldsymbol{H}=[\boldsymbol{M}_0,\boldsymbol{M}_1...\boldsymbol{M}_{t-1}] \tag{3}$$

where $\boldsymbol{M}_i$ is a $(12t+1)\times(12t+1)$ circulant. So matrix $\boldsymbol{H}$ consists of a row of t circulants and has column and row weights 4 and $4t$, respectively, and a binary-regular BIBD-LDPC code can be constructed by using the parity-check matrix $\boldsymbol{H}$[6].

1.2 Construction of OBIBD-RA codes

Let i be zero so we can get B_0 from Eq. (2)

$$B_0=\{0,1,\alpha^{4t},\alpha^{8t}\} \tag{4}$$

The translation of B_0 gives rise to the circulant submatrix $\boldsymbol{M}_0$ as show in Eq. (5), where every column has two consecutive 1-entries. All two consecutive ones are retained and the others are deleted to obtain the required double diagonal matrix[9]. Finally, $\boldsymbol{M}_0$ will be shown as Eq. (6).

$$\boldsymbol{M}_0=\begin{pmatrix}
1 & & & & & 1 & & & 1 & & & \\
1 & 1 & & & & & 1 & & & \cdot & & \\
 & 1 & 1 & & & & & \cdot & & & \cdot & \\
 & & 1 & 1 & & & & & \cdot & & & \cdot \\
 & & & 1 & \cdot & & & & & \cdot & & \\
1 & & & & \cdot & \cdot & & & & & 1 & \\
 & 1 & \cdot & & & \cdot & \cdot & & & & & 1 \\
 & & \cdot & & & & \cdot & 1 & & & & \\
1 & & & \cdot & & & & 1 & 1 & & & \\
 & \cdot & & & \cdot & & & & 1 & 1 & & \\
 & & \cdot & & & 1 & & & & 1 & 1 & \\
 & & & \cdot & & & 1 & & & & 1 & 1
\end{pmatrix} \tag{5}$$

$$\boldsymbol{M}_0=\begin{pmatrix}
1 & & & & & & & & & & & \\
1 & 1 & & & & & & & & & & \\
 & 1 & 1 & & & & & & & & & \\
 & & 1 & 1 & & & & & & & & \\
 & & & 1 & \cdot & & & & & & & \\
 & & & & \cdot & \cdot & & & & & & \\
 & & & & & \cdot & \cdot & & & & & \\
 & & & & & & \cdot & 1 & & & & \\
 & & & & & & & 1 & 1 & & & \\
 & & & & & & & & 1 & 1 & & \\
 & & & & & & & & & 1 & 1 & \\
 & & & & & & & & & & 1 & 1
\end{pmatrix} \tag{6}$$

Adjust the position of $\boldsymbol{M}_0$ in Eq. (3) as follows

$$\boldsymbol{H}=[\boldsymbol{M}_1,\boldsymbol{M}_2\cdots\boldsymbol{M}_{t-1},\boldsymbol{M}_0] \tag{7}$$

So the parity-check matrix $\boldsymbol{H}$ has the features of repeat accumulation codes which used for encoding without generation matrix. However, the parity-check matrix $\boldsymbol{H}$ used for producing a redundant DB at the ingress node and recovering information DBs at the destination will take a large amount of time. For example, it's not until all the bursts (except for lost bursts) in a coding sequence arrive at the destination that the decoding process started. Therefore, a particular structure of parity-check matrix is proposed to shorten the generating time of redundant DBs and the recovering time of information DBs in a coding sequence for OBS networks.

Let $\boldsymbol{H}_1=[\boldsymbol{M}_1, \boldsymbol{M}_2 \cdots \boldsymbol{M}_{t-1}]$, $\boldsymbol{H}_1$ is an $m\times(n-m)$ matrix. The modification required in $\boldsymbol{H}_1$ is to interchange every column with each other such that satisfy as follows

$$\varepsilon_{i+1}=\varepsilon_i+\rho(i);\varepsilon_0=0 \tag{8}$$

$$\boldsymbol{H}_1(i,k)=\begin{cases}1, \varepsilon_i\leqslant k\leqslant\varepsilon_i+\rho(i)\\ 0, \varepsilon_i+\rho(i)<k<n\end{cases} \tag{9}$$

where $0\leqslant i<m$, $\Gamma_i=\{\varepsilon_i, \varepsilon_i+1, \cdots, \varepsilon_i+\rho(i)\}$ is a position set of consecutive 1-entries of the ith row in matrix $\boldsymbol{H}_1$, $\rho(i)$ is the number of consecutive 1-entries in the ith row and k is a positive integer. Parity-check matrix $\boldsymbol{H}$ adjusted the following structure in Fig. 1. The code with particular structure is called OBIBD-RA code.

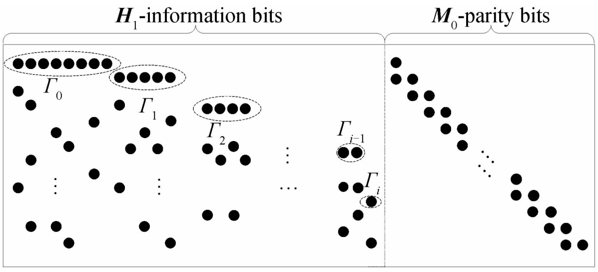

Fig. 1 The structure of parity-check matrix $\boldsymbol{H}$

Fig. 2 shows the bipartite graph of parity-check matrix $\boldsymbol{H}$ with $n-m$ information bits and m parity bits, where Γ_i represents a set of consecutive 1-entries of the ith row in $\boldsymbol{H}_1$, $0\leqslant i<m$. Each of the information bits is corresponding to one of the information nodes; and each of the parity bits is corresponding to one of the parity nodes. The value of a parity bit is computed by the condition that the mod-2 sum of the values of the variable nodes (information nodes and parity nodes) connected to each of the check nodes is zero[10].

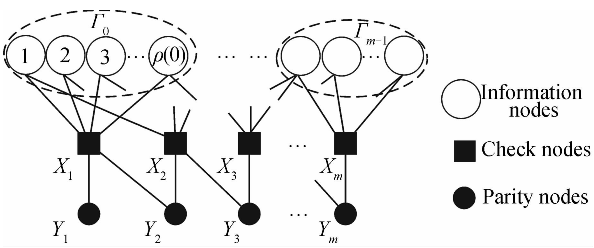

Fig. 2 The bipartite graph of OBIBD-RA codes

Obviously, the OBIBD-RA systematic codes avoid girth-4 successfully, and the particular structure of parity-check matrix will provide the requirement for encoding online in the next part.

2 Burst encoding mechanism

2.1 Online encoding

In the ingress node, as shown in Fig. 3 (a), the information burst will be transmitted immediately after the bits of redundant bursts are updated by the encoder. So the redundant bursts are temporarily stored in the edge buffer until the bits of redundant bursts are updated fully, after an offset time, the redundant bursts will be transmitted through the optical core network. Consider the bipartite graph as show in Fig. 2, suppose the output of check nodes is $[X_1, X_2, \cdots X_m]$, and output of the parity nodes $[Y_1, Y_2, \cdots Y_m]$ are related as

$$\begin{cases}Y_1=X_1\\ Y_2=Y_1+X_2\\ \quad\vdots\\ Y_m=Y_{m-1}+X_m\end{cases} \tag{10}$$

So the accumulator of encoder generates redundant bursts consequently from Y_1 to Y_m. The OBIBD-RA encoder produces the first redundant DB immediately after the first $\rho(0)$ information DBs are formed in a coding sequence, after the next $\rho(1)$ information DBs being completely assembled, the encoder will produce the second redundant DB, therefore all redundant DBs may be produced in this way. Such way of online encoding reduces the delay of burst loss recovery.

If information DBs are encoded by ordinary LDPC codes (without online encoding mechanism), producing a redundant DB need up to m information DBs. However, with online encoding mechanism, generating a redundant DB need only a few information DBs assembling completely in a coding sequence in the encoder, e. g. $\rho(0), \rho(1), \cdots \rho(m)$. So the redundant DB′s generating time is shortened compared with all bursts formed completely in a coding sequence. Thus, the probability of multiple redundant bursts that would be transmitted to core nodes are reduced at a given time, the delay of online encoding in ingress edge node is decreased. Furthermore, online encoding provides the requirement for online decoding in egress edge node.

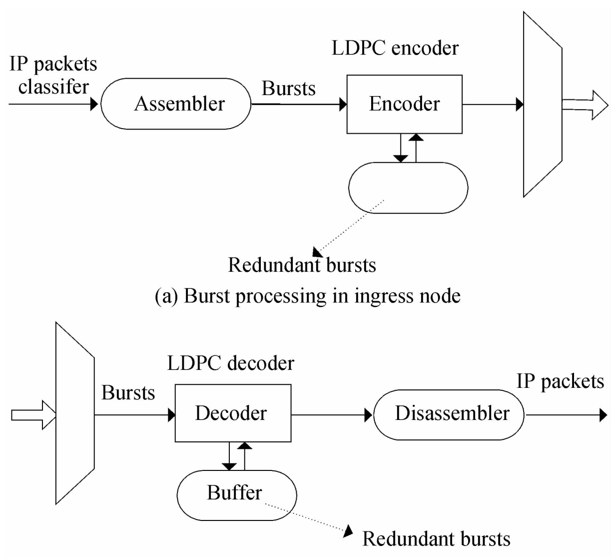

Fig. 3 Structure of edge node

2.2 Online decoding

In the egress node, as shown in Fig. 3 (b), if a burst among the bursts is lost, the lost bursts will be recovered with the redundant DBs by the encoder. Propose an online decoding algorithm to reduce delay while recovering lost bursts.

In the decoding bipartite (Fig. 4), let V_i and C_j represents the bits-value of variable nodes $\{v_0, v_{1,} \cdots, v_{n-1}\}$ and check nodes $\{c_0, c_1, \ldots, c_{m-1}\}$, respectively, for $0 \leqslant i < n$, $0 \leqslant j < m$. The decoding process is shown as follows.

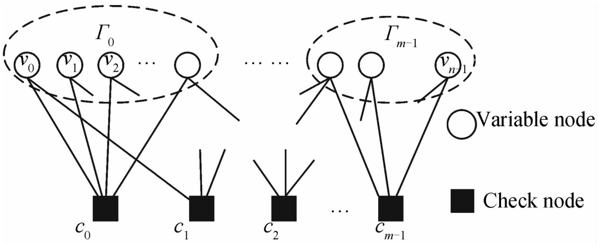

Fig. 4 The decoding bipartite

1) $C_j = 0$, where $j = 0, 1, \cdots m-1$.

2) When ith burst in a coding sequence arrive at the destination, the bits-value V_i received correctly, then $C_j = C_j \oplus V_i$, if the variable node v_i connected with check node c_j where $0 \leqslant i < n$, $0 \leqslant j < m$, then remove the variable node v_i from the graph together with the associated edges.

3) If the remaining graph exits a check of node one, the bits-value of variable node v_i connected to the check nodewill be recovered, $V_i = C_j$, where $0 \leqslant i < n$, $0 \leqslant j < m$, then remove v_i and c_j from the graph together with the associated edge.

If there are remaining variable nodes in the decoding bipartite after the maximum decoding time, the decoding process will be stuck. That means there are remaining bursts unrecovered after the decoding process finished. In fact, what we really care about is whether the information DBs are lost or recovered. So when all information DBs arrive or be recovered in a coding sequence at the destination, the decoding process can be stop for the sequence.

2.3 Burst encoding scheme based on extra offset-time

In ingress edge node, IP packets which come from traditional networks form information DB by assembly algorithm. The burst level encoder of OBIBD-RA systematic code received n-m information DBs to produce m redundant DBs by online encoding. At an intermediate node, a burst may encounter contention for a wavelength channel with other bursts. In such a case, contending bursts may be lost in the core network. When the remaining bursts arrive at destination, the erased bursts can be recovered by means of redundant DBs.

Multiple information DBs and redundant DBs are transmitted to the same destination in a coding sequence. In the core nodes, redundant bursts contend with information DBs for wavelength resource and that may result in information DB loss. In order to overcome this drawback, the extra offset-time scheme is used to reduce the information burst loss probability. Adding extra-offset time for information DBs provide high priority over information DB for reserving wavelength resource forward in core nodes. Thus, the pass rate of information DBs increase.

3 Simulation and analysis

The number of bursts which involve encoding and decoding will increase in a coding sequence if code length is long. Consequently, the delay of burst loss recovery increases. Therefore, we need to construct a short length code. On the other hand, the low code rate will produce more redundant bursts, and the network load is higher. In this section, we investigate the performance of the proposed method for OBIBD-RA codes with high code rate and short code length in binary erasure channel and show the effect of OBIBD-RA codes on burst loss recovery in OBS networks.

3.1 Performance of OBIBD-RA codes over binary erasure channel

In the OBIBD-RA codes proposed in section 2, let $t=6$, and then $12t+1=73$ is a prime number. Get a set $\{0, 1 \cdots 72\}$ in finite field GF(73). The primitive element $\alpha=5$, and satisfies formula Eq. (1), where $c=73$. Using this finite field, we can construct a $(m, n, \gamma, \rho, \lambda)$ BIBD with $m=73$, $n=438$, $\gamma=4$, $\rho=24$, $=1$. The parity-check matrix $\boldsymbol{H}$ over GF(2) gives a (438, 365) OBIBD-RA code with high code rate 0.833.

$$\boldsymbol{H} = [\boldsymbol{H}_1 \boldsymbol{H}_2] \tag{11}$$

The row of column and row weight in matrix $\boldsymbol{H}_1$ is 4 and 20, respectively. $\boldsymbol{H}_2$ is a 73×73 array as show in Eq. (6).

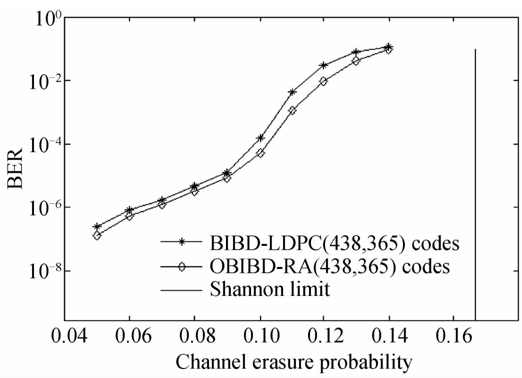

Fig. 5 Bit error rate performance of OBIBD-RA codes over the binary erasure channel

In Fig. 5, we present the error performance of OBIBD-RA (438, 365) codes over binary erasure channel. It shows that OBIBD-RA (438, 365) codes perform better compared with regular BIBD-LDPC (438,365) codes[6], it performs 0.09 from the Shannon limit.

3.2 Performance of OBIBD-RA codes in OBS networks

OBIBD-RA(438,365) codes is used to study the performance of burst loss probability in dumbbell network (see Fig. 6) by OPNET simulation software, and the proposed codes is compared with parity-check codes (PCC)(6,5). In the network, it is assumed that each link has 1 dedicated control channel and 64 data channels; transmitting speeding of a channel is 10 Gb/s. The size of each packet is fixed as 4 000 bit and arrival of packets is exponentially distributed. The delay of a link is assumed to be 10 μs. The Fixed Assembly Size Algorithm (FAS)[11] is used at the ingress nodes, and the fixed threshold is 200 kbit. LAUC-VF scheduling algorithm is used for scheduling DBs in core nodes. It is assumed that the number of wavelength converters is enough and no optical buffers.

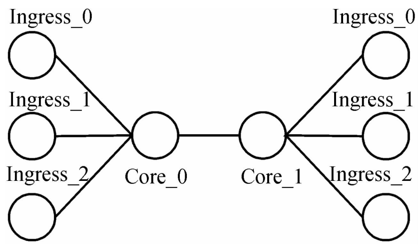

Fig. 6 Network simulation topology

We measured information burst and redundant burst loss probability for OBIBD-RA codes with and without extra offset-time scheme, parity-check codes with and without extra offset-time scheme for different network load respectively. the extra offset-time is 1.0e-4 s[8]. In each encoding mechanism, the number of hops subject to uniform distribution of 3 to 20, even in multi-hop networks, if only a small number of redundant DBs reach the destination node, some of the lost information DBs will be recovered. The data channel rate affects the network load and throughput, and the burst loss probability based on OBIBD-RA codes will increase along curves with the network load (see Fig. 7 and Fig. 8). The load showed in the figures is measured without encoding mechanism.

Fig. 7 shows the performance of OBIBD-RA (438, 365) codes we constructed perform better than parity-check codes (6,5) with the same extra offset-time. And we also observe that OBIBD-RA codes without extra offset-time perform worse than other schemes if the load is above 0.8. Actually, a large extra offset-time for information bursts has advantage in wavelength reservation.

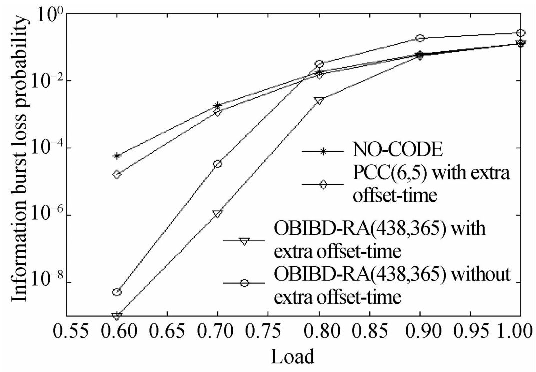

Fig. 7 Information burst loss probability

From Fig. 8, it can be observed that redundant burst loss probability with OBIBD-RA (438, 365) codes and parity-check codes (6,5) experience more loss, when compared to each other without extra offset-time scheme, respectively. In fact, what we really care about is the BLP of information bursts. In the high load, redundant DBs will compete for wavelength resource. This is likely to cause a large number of information DBs to be lost. However, the extra offset-time helps information DBs for reserving wavelength resource forward in core nodes; in contrast, it will lead to much more redundant DBs loss even though the decoding performance may be affected. Therefore, the BLP of information DBs with extra offset-time will increase in the case of high load (>0.8).

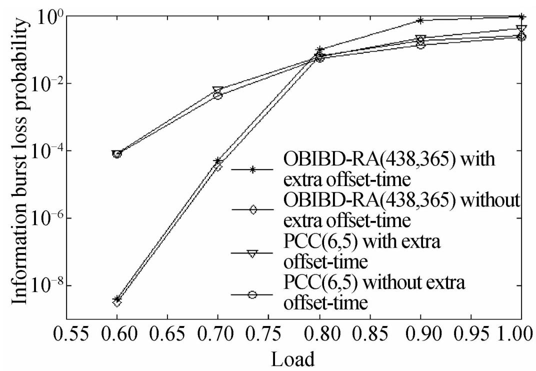

Fig. 8 Redundant burst loss probability

4 Conclusions

A new LDPC code with extra offset-time scheme is used to recover loss burst in OBS networks, and the performance of LDPC code perform very well even without extra offset-time in low load. Moreover, we propose online encoding and decoding mechanism to reduce the burst delay during recovering lost bursts period.

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