# 行政院國家科學委員會專題研究計畫　期中進度報告

## 子計畫二：智慧型光網路研究與模擬測試平台之建立(2/3)

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計畫編號：NSC92-2213-E-032-003-
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# 行政院國家科學委員會專題研究計畫成果報告

# 高速光通信系統及元件之研究－

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## 一、　中文摘要

在此研究當中，我們將光分碼多工處理 (OCDMA) 網路系統中的 on-off-keying (OOK) 編碼方式改用平衡式編碼 (balanced encoding)方式。配合本研究中所提出的時槽和封包格式，每個時槽中的干擾量即可維持定。由於接收機只需在每個時槽的開端利用極少數的位元估測一次干擾量即可，新系統中的接收機架構比其他使用干擾偵測器的 OOK-OCDMA 接收器簡單了很多。而且由於不再需要針對每一位元進行干擾量的估測，新系統的資料傳輸率不再嚴重受限於干擾估測電路所需的電子處理時間。

本研究中導入了最佳化和次佳化兩種臨界值設定方式。分析結果顯示，新系統具有比 OOK 系統更小的 BER (bit error rate)，而且藉由增加少許的訓練位元，新系統的 BER 還能更低。此外，分析結果也顯示，簡單的次佳化臨界值設定法，其成效僅略差於最佳化設定法，因此是一種值得採用的方式。

關鍵詞：光分碼多工處理(OCDMA)，on-off-keying (OOK)，平衡式編碼 (balance encoder)，多重存取干擾 (MAI)。

**Abstract**

In this research, the balanced encoding scheme is used instead of OOK for OCDMA systems[1]-[12]. The slotted timing and the packet format to maintain constant interference in a time slot are discussed. The receiver in the proposed OCDMA system needs only to estimate the MUI [9][13]-[28] at the beginning of a time slot instead of estimating bit by bit; therefore, the data rate is no longer severely limited by the electronic processing time in estimating the MUI and tuning the threshold device.

The maximal number of users in the proposed system is the same as that in the OOK system with interference estimator. Although the balance encoder is more complex than the OOK encoder, the receiver in the proposed system is simpler than that in the OOK system. In the receiver, two kinds of threshold estimator are introduced. Numerical results show that the proposed OCDMA systems have smaller BER than OOK systems. The BER of the proposed system can be further reduced by slightly increasing the number of training bits. Numerical results also show that the system with sub-optimal estimator, which is much simpler than the optimal estimator, has good performance, especially when the number of simultaneous users is large.

**Keywords:** optical CDMA (OCDMA), optical code-division multiplexing (OCDM), on-off-keying (OOK), balance encoder, multiple–access interference (MAI).

## 二、 緣由與目的

The fixed optical code-division multiplexing (OCDM) system is a simplified version of the optical code-division multiple access (OCDMA) system. In OCDM systems, the number of active simultaneous users can be fixed as long as the idle code-channels are keeping transmitting idle data. However, in OCDMA networks, the number of simultaneous users is no longer constant. As a result, the receivers in the OCDMA network have to dynamically estimate the MUI and the threshold should be adaptively tuned.

In [22], the receiver shown in Fig. 1 with interference estimator for the OOK-OCDMA system that uses modified prime codes as spreading codes is proposed. In the receiver, half of the received power is split to the MUI estimator while the other is split to the decoder. The MUI estimator estimates the power of interference and then tunes the threshold of the threshold circuit. However, since the MUI in the OOK-CDMA system is changed bit by bit, the receiver has to estimate the MUI and tune the threshold for every bit. Consequently, the main disadvantage of the receiver is the limited transmission rate due to the electronic processing time in estimating the interference and determining the threshold. To overcome this problem, we try to maintain the MUI constant during a time slot by using the balanced encoding scheme. In such systems, the interference estimation is needed only at the beginning of each time slot instead of at every bit. Moreover, since the parallel processes in estimating the MUI and detecting data are no longer needed in the proposed system, it is possible to simplify the hardware of the receiver.

## 三、 結果與討論

### 1.系統架構

### 1.1 The transmitter

The transmitter with balanced encoding is shown Fig. 2. The data bits $b=0$ and $b=1$ are encoded by the upper branch and lower branch respectively. In each group of EPCs, $(p-1)$ EPCs are allotted to transmit $b=1$ to $(p-1)$ users respectively, and the remaining EPC is reserved as the common code to transmit $b=0$ to the $(p-1)$ users. Based on the balanced encoding, the MUI contributed by any user is independent of the transmitting data.

### 1.2 The receiver

The structure of the receiver is shown in Fig. 3. Let $I$ be the number of simultaneous users whose EPCs are outside the group to which the receiving EPC belongs, the received power can be expressed as

$$P_{CR} = \begin{cases} (p+I)P_R / p, & \text{for } b=1 \\ IP_R / p, & \text{for } b=0 \end{cases}$$

where $P_R$ is the received power per chip and the optical correlator is assume the delay-line correlator [2][28]. As long as all of the beginning bits in each time slot are 0s, each decoder can get the interference power ($IP_R/p$). Therefore, at the beginning of each time slot, the decoder estimates the MUI and determines the threshold $\theta$. After the estimation, the receiver begins to detect the received data. Since the MUI estimation is done at the beginning of each time slot only, the data rate of the system is no longer limited by the electronic processing time in estimating the MUI. Moreover, since the MUI estimation and data detection are now performed sequentially, the hardware of the new decoder is much simpler than that shown in Figure 1.

### 1.3 The slotted timing

In the proposed OCDMA network, the packets are transmitted in synchronous time slots. As shown in Fig. 4, every packet is transmitted at the same time $t_T$. In order to ensure that every packet has reached its destination, the receiver begins to estimate the MUI at $t_E = t_T + T_{MD}$, where $T_{MD}$ is the maximal possible delay. In the duration from $t_E$ to $t_D$, the receiver estimates the MUI and then tunes the threshold $\theta$. After that, from $t_D$ to $t_N$, the receiver detects the received bits.

### 1.4 The packet format

As shown in Fig. 4, each packet consists of the following fields.

(i) Preamble field: The preamble consists of all zero bits. The length of the preamble must ensure that every receiver can get the zero bits from all of the transmitted packets to estimate the MUI during the training period from $t_E$ to $t_D$. Let $T_{PM}$ denote the length of the preamble in seconds, we have $T_{PM} \geq t_D - t_T$.

(ii) Data field: The data field consists of header bits, the payload, and tail bits. Since all of the preamble bits are zeros, the first bit of the header must be 1 to declare the beginning of the data field. To ensure that the latest tail bit can reach the receiver before $t_N$, we have $T_{DTA} \leq t_N - t_E - T_{PM}$, where $T_{DTA}$ is the length of the data field.

(iii) Pad field: In order to maintain the constant MUI in the detecting period, the length of each packet should be padded to ($t_N - t_T$) seconds. Let $T_{PD}$ denote the length of the pad field, we have

$$T_{PD} = t_N - t_T - T_{PM} - T_{DTA}$$

## 2. Numerical Results

In this section, we calculate the numerical results according to the parameters listed in Table 1. The BERs of constant interference OCDMA systems using optimal and sub-optimal thresholds for $p$=5 and $P_R$=2 μW are shown in Fig. 5. In the figure, the determination of threshold is based on the optimal threshold that minimizes the BER or based on the sub-optimal threshold that minimizes the BER for full loaded case only. Under the same parameters, the BER of the OOK-OCDMA system shown in Fig. 1 using threshold $\tilde{\theta}_{OOK} = X + 0.45 G T_c \lambda_s p$, which is suggested in [22], is also shown in Fig. 5. By comparing the BERs of the OOK system and those of the constant interference systems with $W$=1, it is found that constant interference systems have lower BERs, though the average MUI in the OOK system is smaller. The reason of this phenomenon is that the constant interference systems use full power to estimate the MUI and to detect data while only half of the received power is used in the OOK system.

As the number of training bits $W$ increased, the estimation error is reduced since the variance in estimating the MUI is decreased. Therefore, the BERs of the proposed systems are reduced toward their ideal curves. Moreover, since the sub-optimal system is design to get the minimal BER under full load, it can be found that the difference between the BERs of the optimal and sub-optimal systems decreases with the increased $N$.

Under full load, the BER against received power $P_R$ is shown in Fig. 6. It is obvious that the BERs of constant interference OCDMA systems are smaller than that of the OOK system. Fig. 6. also shows that the BER can be obviously reduced if a few training bits are used.

## 四、 已完成之具體成果

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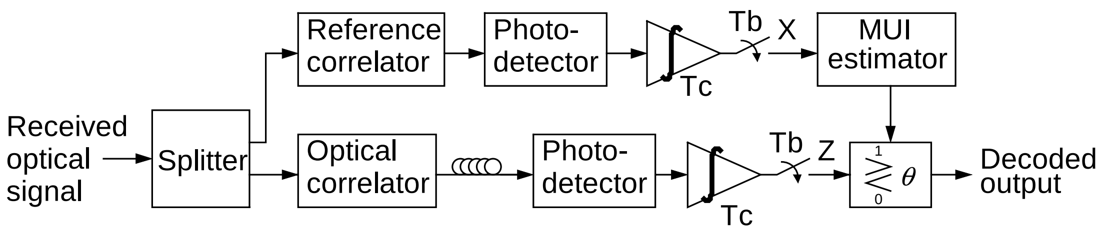


Fig. 1. The receiver with dynamical MUI estimator for OOK-OCDMA systems

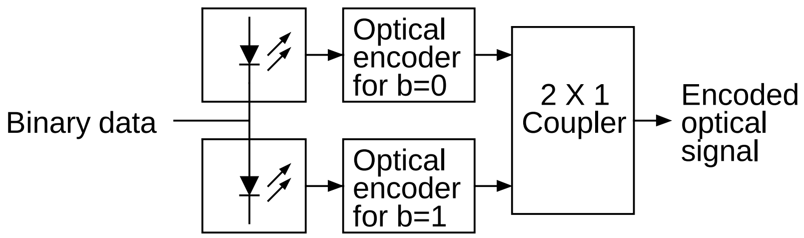


Fig. 2. The block diagram of the transmitter

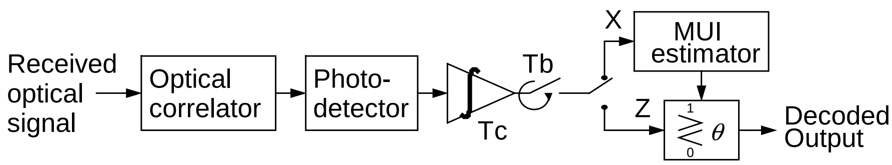


Fig. 3. The receiver of the slotted transmission OCDMA network

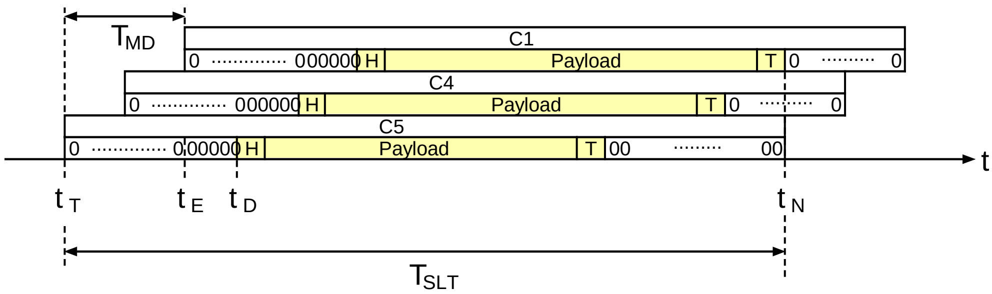


Fig. 4. The received packets with fixed preamble length at some receiver

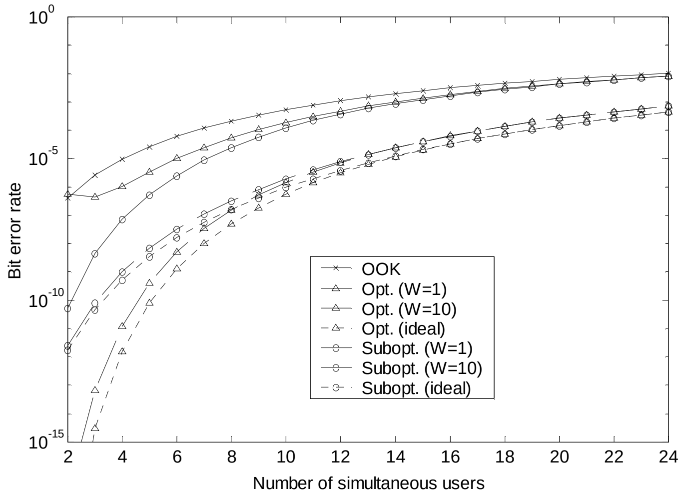


Fig. 5. The bit error rates of constant interference OCDMA systems and the OOK-OCDMA system. ($p$=5, $P_R$=2 μW)

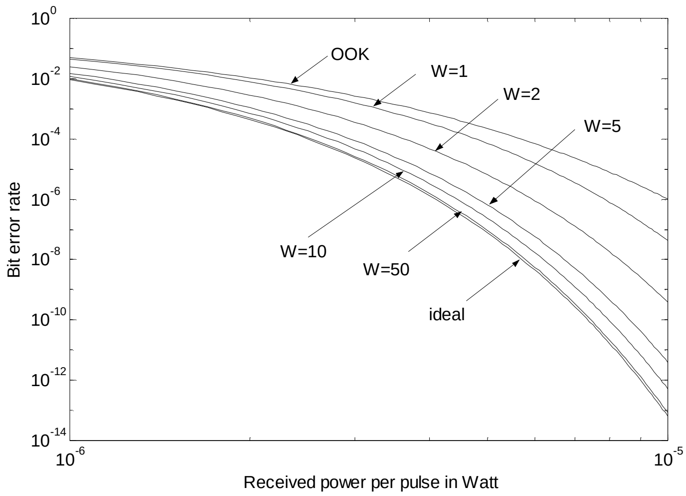


Fig 6. The full loaded BER against received power for OOK and constant interference OCDMA systems with $p$=5

| Name | Symbol | Value |
|---|---|---|
| Wavelength | $\lambda$ | 1300 nm |
| APD quantum efficiency | $\eta$ | 0.6 |
| APD gain | $G$ | 100 |
| APD bulk leakage current | $I_b$ | 0.1 nA |
| APD surface leakage current | $I_s$ | 10 nA |
| APD effective ionization ratio | $k_{eff}$ | 0.02 |
| Chip duration | $T_c$ | 0.1 ns |
| Receiver noise temperature | $T_r$ | 300 K |
| Receiver load resistance | $R_L$ | 1000 Ω |

Table 1. Link Parameters