# Triple-Play Services Using Different Detection Techniques for SAC-OCDMA Systems

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***Abstract-*** **The development of many high bit-rate multimedia applications has emphasized the demand for service differentiation or prioritization techniques to ensure end-user quality-of-service (QoS) necessities. This paper focuses on utilizing different detection schemes in spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems to support 'triple-play' services (voice, video, and data) with diverse QoS requirements. The used subtraction detection techniques are complementary, AND, as well as modified-AND. Modified double-weight (MDW) codes are used as the signature codes for SAC-OCDMA systems. The simulation results show that modified-AND subtraction detection demonstrates better performance over other detection approaches.**

## I. INTRODUCTION

The concurrent provision of video or TV content, voice, and fast Internet via the same network and subscriber equipment, known as 'triple-play' services, constitutes one of the main interests in modern telecommunications due to the latest developments in the areas of video and audio encoding which strain the capacity of content delivery systems. The combination of the above technologies has raised important QoS related issues. The inability to fully exploit available bandwidth, the inadequate QoS to users, and the unfulfilled requirements of all three supported services (voice, video, and data) are problems that must be addressed [1–3].

In particular, optical code-division multiple-access (OCDMA) techniques are receiving substantial attention because of the ability to operate asynchronously, enhanced privacy, increased capacity in bursty traffic, and differentiated QoS [4,5]. Conversely, the main disadvantages of conventional OCDMA systems are that the performance and capacity are limited by multiple-access interference (MAI) [6,7]. Of all OCDMA systems, SAC is the most attractive solution in terms of cost effectiveness. Also, it has the advantage of eliminating the first order MAI (in the mean) via subtraction detection techniques at the receiver side [8]. Moreover, these systems can use economical incoherent light sources such as light-emitting diodes (LEDs) owing to their broad bandwidth, which is essential in SAC encoding [9]. Intensity noise originating from the incoherency of the broad-band light sources is considered the primary reason for performance depreciation in SAC-OCDMA systems [10,11]. Recently, the authors have proposed the modified-AND subtraction detection technique to overcome the impacts of the phase-induced intensity noise (PIIN) and MAI in incoherent SAC-OCDMA systems by dividing the spectrum of the used code sequence [12,13].

Over the last decade, many unity cross-correlation codes have been suggested for SAC-OCDMA systems. One of them is MDW introduced in [14] with variable weights greater than two. For example, for a weight of four ($w$ = 4), the code length is given by:

$$L = 3K + \frac{8}{3}\left[\sin\left(\frac{K\pi}{3}\right)\right]^2 \tag{1}$$

where $L$ is the code length and $K$ is the number of users. Table 1 presents an example for 6 users of MDW code.

Table 1 MDW code words with $w$ = 4, $L$ = 18 for 6 users.

| User | | Code words |
|---|---|---|
| $K_1$ | = | { 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 } |
| $K_2$ | = | { 0 1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 } |
| $K_3$ | = | { 0 0 0 0 1 1 0 1 1 0 0 0 0 0 0 0 0 0 } |
| $K_4$ | = | { 0 0 0 0 0 0 0 0 0 1 1 0 1 1 0 0 0 0 } |
| $K_5$ | = | { 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 1 1 0 } |
| $K_6$ | = | { 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 1 } |

In this paper, the ability of supporting variable bit rates multimedia traffic by using different detection approaches is tested so as to implement service differentiation in the optical domain. This study has been carried out through simulation by using (OptiSystem, Version 9.0), which permits to consider all practical effects of fiber nonlinearities, dispersion, attenuation, receiver thermal noise and dark current shot noise. The paper proceeds as follows. Section II briefly skims the SAC-OCDMA receiver structures based on the mentioned detection techniques. Next, in Section III, the description of the simulation experiments and the discussion of the results are given. Finally, Section IV concludes the paper.

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## II. DETECTION TECHNIQUES

In OCDMA systems, the detection process affects the design of transmitters and receivers. In this paper, we focus on an incoherent detection approaches because they do not require phase synchronization. This reduces the hardware complexity of the system. In an incoherent SAC-OCDMA system, each user is assigned a distinct codeword as its address signature is based on the spectral amplitude only. When a user wants to transmit data bit one, it sends out a codeword corresponding to the address signature of the intended receiver. At the receiver, all the codewords from different users are correlated. If a correct codeword arrives, an autocorrelation function with a high peak results. For an incorrect codeword, cross-correlation functions are generated, and they create MAI, where MAI can be suppressed by using subtraction detection techniques. In this section, we present the SAC-OCDMA receiver structures based on complementary, AND, as well as modified-AND detection schemes.

### *A. Complementary Subtraction Technique*

The conventional complementary subtraction technique is presented in Fig. 1 where the received signal is divided into two branches. In the upper branch, a decoder, which is spectrally identical to an encoder (i.e., the desired user code), is used to extract the information encoded on the transmitter side. The lower branch contains a complementary decoder which is the logical complement of the decoder. The complementary decoder's spectral signature is orthogonal to that of the encoder (or equivalently, the decoder). To eliminate the MAI from undesired users, the attenuation factor is set to ensure a zero-mean signal is generated by the interferer at the output of the balanced detector. The two branches of spectral signals are sent to a balanced detector that computes the difference between both decoded signals [15].

Let $X$ and $Y$ be the two OCMA code sequences. The complementary of sequence ($X$) is given by $(\overline{X})$ whose elements are obtained from ($X$) by $\overline{x}_i = 1 - x_i$. Let $X$ = 1100 and $Y$ = 0110 and therefore $\overline{X}$ = 0011. The periodic cross-correlation sequence between ($X$) and ($Y$) is expressed as :

$$\theta_{XY}(k) = \sum_{i=0}^{N-1} x_i y_{i+k} \quad (2)$$

Similarly, the cross-correlation sequence between $(\overline{X})$ and ($Y$) given by:

$$\theta_{\overline{X}Y}(k) = \sum_{i=0}^{N-1} \overline{x}_i y_{i+k} \quad (3)$$

We look for sequences for which is given in (4):

$$\theta_{XY}(k) = \theta_{\overline{X}Y}(k) \quad (4)$$

At the receiver, the photo detectors will detect the two complementary inputs which will be fed to the subtraction whose cross-correlation output, $Z$ can be expressed as given in (5):

$$Z_{Complemenary} = \theta_{XY}(k) - \theta_{\overline{X}Y}(k) = 0 \quad (5)$$

By the end the answer is 0, which means that, at the output of the subtractor, there will be no more cross-correlation terms indicating that there is no more signal from other users in the intended channel.

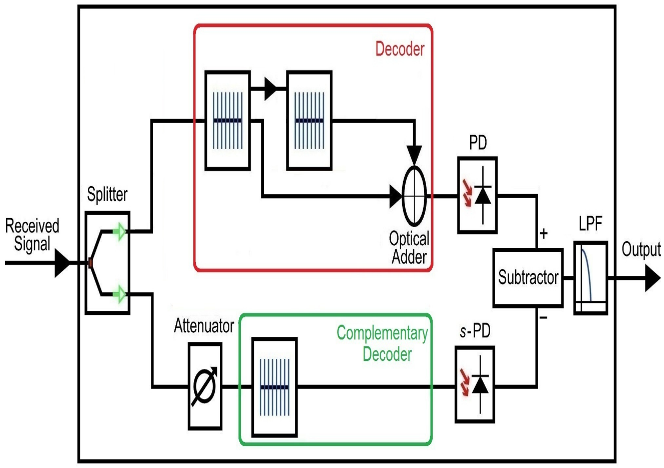



Figure 1. Implementation of Complementary subtraction detection.

### *B. AND Subtraction Technique*

The AND subtraction technique is presented in Fig. 2 where the incoming signal splits into two parts, one to the decoder that has an identical filter structure with the encoder and the other to the decoder that has the AND filter structures (called AND decoder) [16]. A subtractor is then used to subtract the overlapping data from the intended code. The cross-correlation $\theta_{(X\&Y)Y}$ where $\theta_{(X\&Y)}$ represents the AND operation between sequences $X$ and $Y$. For example, let $X$ = 1100 and $Y$ = 0110 and therefore ($X$ AND $Y$) = 0100.

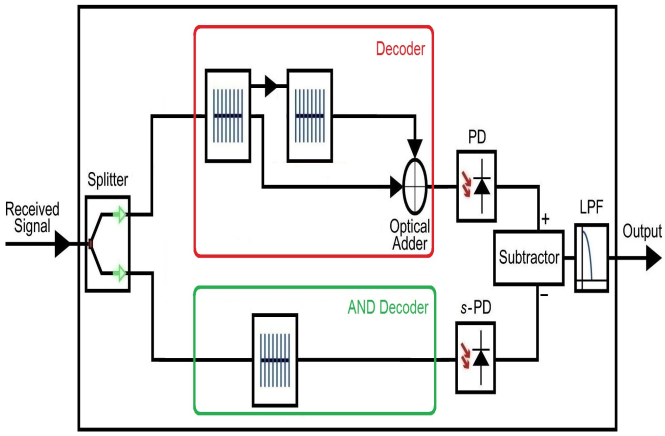



Figure 2. Implementation of AND subtraction detection.

At the receiver,

$$Z_{AND} = \theta_{XY}(k) - \theta_{(X\&Y)Y}(k) = 0 \quad (6)$$

Equation (6) shows that, with AND subtraction technique, the multiple access interference or interference from other channels can also be cancelled out. This subtraction technique can be implemented with any OCDMA code, but for comparison purposes, the double-weight (DW) code is used as an example. Comparison between AND and complementary subtraction technique using DW code is shown in Table 2.

Table 2 Example of Complementary and AND Subtraction Techniques.

| | **AND Detection** | | | | **Complementary Detection** | | | |
|---|---|---|---|---|---|---|---|---|
| | λ1 | λ2 | λ3 | λ4 | λ1 | λ2 | λ3 | λ4 |
| X | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| Y | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| | $\theta_{XY} = 1$ | | | | $\theta_{XY} = 1$ | | | |
| | X&Y = 0100 | | | | $\overline{X} = 0011$ | | | |
| | $\theta_{(X\&Y)Y} = 1$ | | | | $\theta_{\overline{X}Y} = 1$ | | | |
| | $Z_{AND} = \theta_{XY} - \theta_{(X\&Y)Y} = 0$ | | | | $Z_{Complementary} = \theta_{XY} - \theta_{\overline{X}Y} = 0$ | | | |

The complete subtraction (result is zero) shows that the MAI can be eliminated (in the mean) by using both techniques. In terms of construction, AND subtraction needs less number of filters in the AND decoder (Fig. 2) as compared to complementary decoder (Fig. 1). The filter is only needed at the position of overlapping spectra occurring in the code sequences (refer to Table 2 example of AND operation, (*X* AND *Y* = 0100). In the complementary technique, the number of filters required depends on the value of the weight and the cross-correlation in the utilized code sequences [17]. The overall system cost and complexity can be reduced by using fewer number of filters in the AND subtraction. At the same time, the performance of the OCDMA system is improved significantly because with less number of filters in the decoder, the total power loss can be reduced and this can be clearly seen in the simulation result.

### C. *Modified-AND Subtraction Technique*

The modified-AND subtraction technique provides a significantly better performance in terms of allowing longer transmission distance or higher data rate or a larger number of users [12,13]. It has the advantage of suppressing the impacts of the PIIN and MAI in incoherent SAC-OCDMA systems by dividing the spectrum of the used code sequence. Moreover, the number of filters are the same as compared to AND detection.

The SAC-OCDMA receiver diagram of this technique is shown in Fig. 3. The received optical signal is split by splitter 1 into two parts: one to the upper decoding branches and the other to the AND decoder through an attenuator. The attenuator ensures that the interference signal has an equivalent power incident on each photo-detector in the case of inactive user. The filters are placed in a parallel configuration. This structure divides the weight of the used code sequence. Take note that the both splitters (splitter 1 and splitter 2) and the attenuator could be replaced by a single coupler with appropriate coupling ratio to get a more cost effective system. The decoder has a spectral response matched with the active user, while AND decoder has the overlapped bins from different interferers. These overlapped bins can be represented mathematically by AND operation between the active user and interferers as explained in AND detection. The photo-detector is composed of two photodiodes (PD and *s*-PD), connected electrically in opposition to provide a differential signal between both decoded signals. The corresponding passband resulting from the filtering is taken to be 75% of the date rate $R_B$.

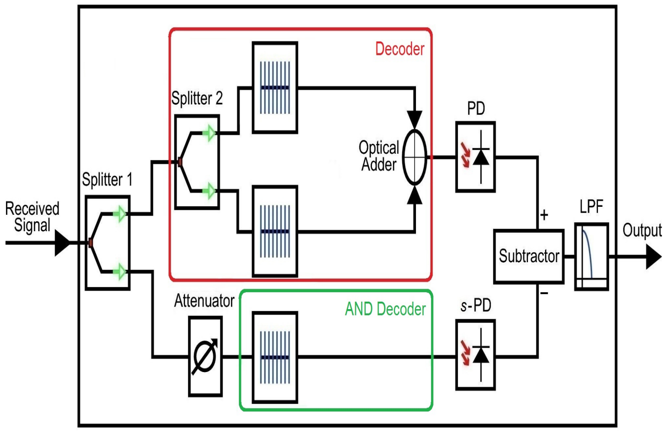



Figure 3. Modified-AND subtraction detection technique.

## III. SIMULATION SETUP AND RESULTS

Here, the simulation results of performance comparison of the mentioned detection techniques in SAC-OCDMA systems are presented. Transmission of three channels with different detection techniques is simulated using OptiSystem 9.0 over 10 km single-mode fiber (SMF) without any amplifier. Since the system designed is incoherent SAC-OCDMA, the LED is used as the optical source. Each chip has a spectral width of 0.8 nm. The attenuation coefficient and the dispersion coefficient of SMF at a wavelength of 1550 nm are 0.25 dB/km and 18 ps/km/nm respectively according to ITU-T G.652 standard. Nonlinear effects were specified as close to typical industrial values as possible for simulating the real environment. The noise generated at the receivers was set to be random and totally uncorrelated. The dark current value was set at 5 nA, and the thermal noise coefficient was $1.8\times10^{-23}$ W/H$_z$ for each of the photo-diodes at the detection part. The performance of the system is calculated using bit-error rate (BER) estimation and eye diagrams.

Fig. 4 shows the changes of the BER against the fiber length for MDW code using different detection schemes at $R_B$= 622 Mbps (STM-4). It is observed from Fig. 4 that the BER increases when the fiber length increases. It is also noticed that the modified-AND detection technique achieves superior performance than other detection approaches where the eye diagram having the large opening. Note that all these techniques used balanced detection to remove the mean of MAI. But the signal-to-noise ratio (SNR) stays poor in complementary as well as AND subtraction detections mainly because of the dominant PIIN. Due to this reason, PIIN reduction achieved by using the modified-AND detection is a solution of considerable importance.

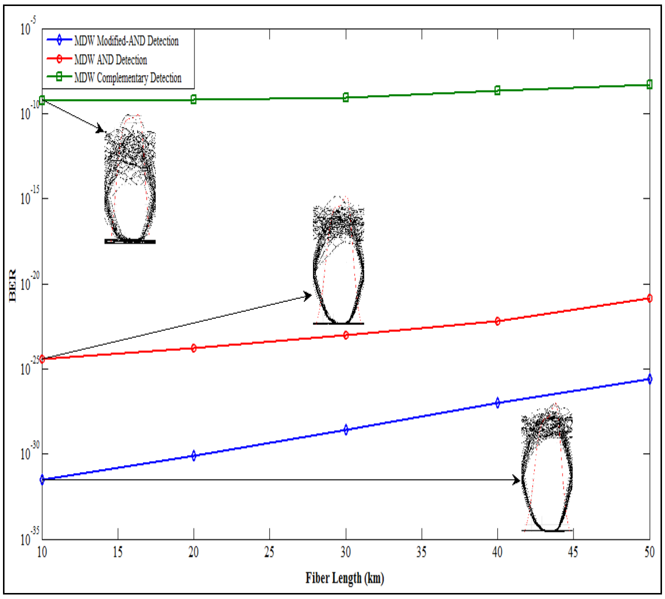
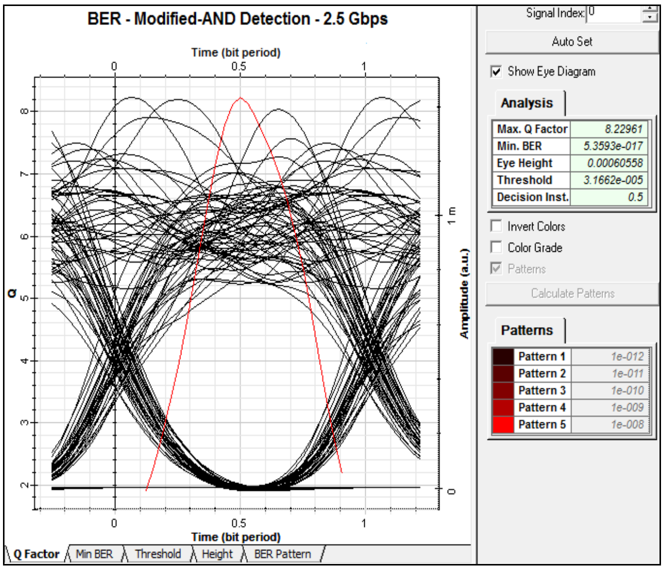
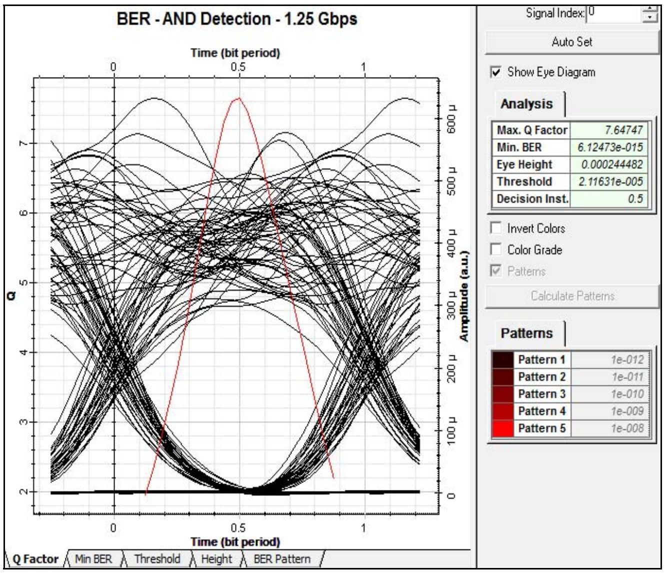



Figure 4. BER versus fiber length for different detection approaches at data rate of 622 Mbps.

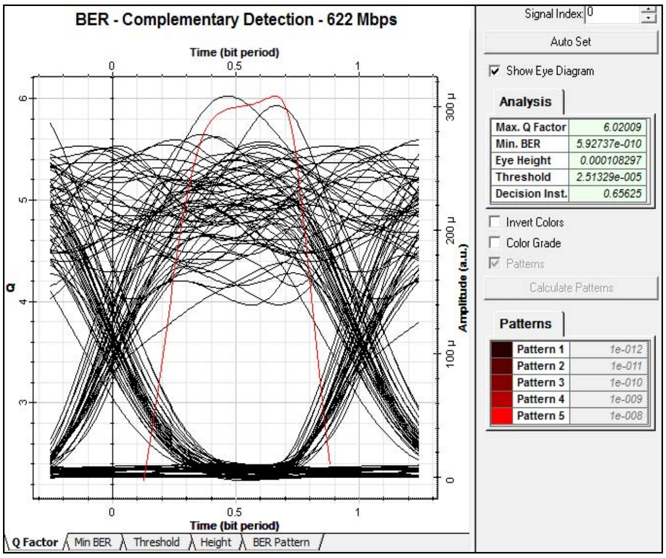
For service differentiation, the second test is carried out at 10 km fiber length with different data rates. The eye patterns are shown in Fig. 5 for each detection. It clearly shows that the modified-AND detection achieves the lowest errors with higher data rate up to 2.5 Gbps.




(a)




(b)




(c)

Figure 5. The eye diagrams of different detections after 10 km transmission; (a) Modified-AND detection at 2.5 Gbps; b) AND detection at 1.25 Gbps; c) Complementary detection at 622 Mbps.

## IV. CONCLUSIONS

Multi-rate transmission is one of the main advantages of asynchronous OCDMA systems. This paper investigates different types of subtraction detection techniques for service differentiation in SAC-OCDMA systems. According to simulation results, the modified-AND detection technique shows noticeable performance enhancement over other detection approaches mentioned in this study. Its usefulness is mainly because of its ability to suppress the PIIN and MAI. Future work will be devoted to reduce the complexity and cost of these detection techniques.

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