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Power allocation scheme for mitigation of fiber temperature fluctuations in OCDMA networks based on firefly algorithm

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A R T I C L E I N F O

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A B S T R A C T

In this paper, a power allocation scheme based on an evolutionary heuristic approach, namely Firefly Algorithm (FA) is proposed for the mitigation of fiber temperature fluctuations effects in the optical code division multiplexing access (OCDMA) networks. The temperature fluctuations degrade the 2-D wavelength-hopping time spreading optical codes by inducing a distortion on the autocorrelation of the received signal. The fiber temperature fluctuations are ordinarily hard to accurately determine and compensate due to the dynamic nature of the environmental temperature variation. In this context, power allocation (PA) policies constitute an efficient way to dynamically mitigate the effects of temperature variation with low cost and complexity of implementation. In this work, an FA input parameter optimization procedure has been conducted aiming to guarantee an efficient FA-based OCDMA power allocation algorithm regarding convergence velocity and quality of the solutions trade-off. The numerical results have demonstrated the effectiveness of the proposed FA power allocation scheme in mitigating the effects of fiber temperature fluctuations, as well as balancing the near–far effect (NFE) and multiple access interference (MAI). Moreover, the influence of the code parameters and the number of the nodes on the FA-based OCDMA power allocation scheme has been investigated. The comparison from both evolutionary heuristics FA and particle swarm optimization (PSO) power allocation schemes has indicated the faster convergence of FA-based scheme when the number of nodes $\boldsymbol{K}$ increases, while for both the complexity is similar, resulting in polynomial order $\mathscr{O}(\boldsymbol{K}^2)$. Moreover, the FA-based power allocation approach presents a smoother and monotonic convergence when compared with the more oscillatory behavior of the PSO-based power allocation procedure.

1. Introduction

Passive optical network (PON) is a promising architecture for broadband access network and backhauling of mobile networks [1]. In addition, the increase of traffic from content-delivery networks, data centers interconnections and Internet of things (IoT) has motivated the consolidation of the PONs [1,2]. The new stages of next generation-PON (NG-PON) will be based on the use of technologies such as wavelength-division multiplexing (WDM), orthogonal frequency-division multiplexing (OFDM) and optical code division multiple access (OCDMA), which can be used individually or jointly [3–9]. These technologies present limitations and advantages to be explored [4]. The PON architecture based on the OCDMA technology is attractive considering characteristics such as asynchronous operation, high network flexibility, protocol transparency, simplified network control and security at physical layer [5]. In this context, recent technological developments of the OCDMA [4,6] and new schemes employing OCDMA-WDM jointly [7] or OCDMA-OFDM [8,9] aiming at increasing the system performance and capacity have motivated recent research on the hybrid and adaptive OCDMA systems [3,4]. For example, in the hybrid OCDMA-OFDM optical systems context, the OFDM-based transmitter and receiver schemes are deployed to multiply the code on frequency domain while takes advantage of the dense subcarrier spacing. Such composite system can support asynchronous bandwidth sharing, which is the main benefit of OCDMA while presents superior performance regarding pure OFDM schemes [8,9]. In addition, there are OCDMA-WDM architectures wherein the downstream from optical line terminal (OLT) to optical network unit (ONU) utilizes time and wavelength division multiplexed (TWDM). On the other hand, motivated by the asynchronous traffic from the ONU user to the OLT, the OCDMA technique is deployed in the upstream, with no need to protocol network management [7]. However, TWDM suffers from periodic

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resynchronization of each ONU, and a high cost of the optical components [3,7].

In OCDMA networks, each different code identifies a user and the code parameters can be adjusted to the traffic variations and quality of service (QoS) requirements. Therefore, the development of on-demand and adaptive resource allocation algorithms with low-complexity resource management is an exciting challenge of OCDMA-based NG-PONs [4]. The different codes sharing simultaneously a common channel results in the multiple access interference (MAI) [5,10]. Besides, the increase of the number of users implies in the gradual performance degradation. The use of wavelength-hopping time spreading optical coded (2-D) in OCDMA networks has improved substantially the network performance related with the MAI mitigation. Herein, the challenge of OCDMA resource allocation investigation is related to the network performance of the OCDMA technology, which can be individually or jointly associated to other techniques directly associated with the linear and nonlinear impairments of the physical layer [4]. The physical impairments are related to several elements in the optical network, such as the transmitted power, link length, bit rate and the optical code parameters [4–6]. In OCDMA networks based on 2-D codes, there is another important physical impairment, which are the effects of environmental temperature variation [13,14]. This variation results in the fiber temperature fluctuations and became a relevant issue in to the signal degradation as demonstrated experimentally [15]. The fiber temperature fluctuations is ordinarily hard to accurately determine and compensate due to the dynamic nature of the environmental temperature variation [16]. The effects of fiber temperature fluctuations include the time skewing, pulse broadening and peak power reduction. The time skewing is the effect of the temporal spreading of multi-wavelengths pulses and relative delays occur between chips at different wavelengths [13]. Furthermore, pulse broadening, peak power reduction and time skewing caused by fiber temperature fluctuations results in incorrect decoding and then errors in bit detection [14]. Moreover, the effects from fiber temperature fluctuations will affect the full compensation for dispersion fibers [13–15,17]. The compensation of fiber temperature fluctuations is based on the adjustment of the code parameters [13,18], the deployment of a semiconductor optical amplifier (SOA) at the receiver [15], and on the optimal allocation of the transmitted powers [17]. In Ref. [13], the adjusting of the code spectral spacing reduction and the spectral spacing between the individual wavelengths were investigated in the code formation aiming to reduce the temporal skewing. In Ref. [18], an intelligent fuzzy system can *a priori* choose the better code weight, at the encoder, according to estimations of environmental temperature variations provided by external sensors networks. In Ref. [15], the change in the SOA bias current is utilized to mitigate the pulse broadening caused by the temperature-induced dispersion. In Ref. [17], the intensity of the transmitted optical signal was directly adjusted from the laser source with respect to the target signal-to-noise-plus-interference ratio (SNIR) by two different bio-inspired meta-heuristic algorithms, namely particle swarm optimization (PSO) and ant colony optimization (ACO) algorithm, aiming to mitigate the power penalty for fiber temperature fluctuations.

The power allocation procedure is an efficient way to mitigate dynamically the effects of fiber temperature fluctuations with low cost and complexity [17]. Moreover, the optimization method based on the evolutionary meta-heuristics such as PSO and ACO approaches are attractive due to its performance-complexity tradeoff and fairness features regarding the optimization methods that deploy matrix inversion, purely numerical procedures and other heuristic approaches [17,19,20]. More details regarding power allocation (power control) in optical scenario, please see Ref. [21].

In this context, this paper proposes and analyses a new power allocation scheme based on Firefly Algorithm (FA), in order to mitigate dynamically the effects of fiber temperature fluctuations while increase the overall energy efficiency of the OCDMA network based on 2-D non-coherent codes [5,22]. In this sense, the FA parameters optimization procedure has been conducted considering the high sensibility of meta-heuristics algorithms efficiency for different applications [17,19,20]. Hence, the focus on the FA parameters optimization developed herein was to achieve the best relation between the algorithm convergence *versus* the number of iterations. Moreover, the effectiveness of the proposed power allocation scheme able to mitigate the effects of fiber temperature fluctuations is evaluated considering the influence of the different link lengths, number of nodes and code parameters. A fair comparison between the FA and PSO power allocation schemes for the same run time and equivalent computational complexity has been carried out aiming to estimate the efficiency of the proposed resource allocation scheme.

The paper is organized as follows. In Section 2 the OCDMA network based on 2-D codes is presented. In Section 3 the effects of the fiber temperature fluctuations are described. The proposed FA-based power allocation scheme is discussed in Section 4. Numerical results are analyzed in Section 5. Section 6 offers the main conclusions and final remarks.

2. Network architecture

2.1. OCDMA network

Fig. 1 illustrates the OCDMA network utilized in this study. This is an ordinary model of OCDMA network architecture commonly deployed in PON applications and it could be adapted for other PON configurations [1,5]. This architecture is based on broadcast-and-select pattern with $K \times K$ nodes interconnected by passive star coupler. Each node is equipped with transceiver with encoders and decoders at the transmitter and receiver. The distance between the transmitting and receiving nodes is given by Ref. [21],

$$L_{ij} = L_i^{tx} + L_j^{rx} \tag{1}$$

where L_i^{tx} is the link length from the transmitting node to the star coupler and L_j^{rx} is the link length from the receiving node to the star coupler. The received power at the j-th node is given by Ref. [21],

$$P_{rj} = L_{star} p_i \exp\left(-\alpha L_{ij}\right) \tag{2}$$

where p_i is the transmitted power by i-th transmitter node, α is the fiber attenuation (km^{-1}) and L_{star} is the star coupler attenuation [21].

2.2. 2-D OCDMA codes

The 2-D codes are represented by a set of parameters ($N_\lambda \times N_T$, w, I_a, I_c), where N_λ is the number of rows, that is equal to the number of available wavelengths, and N_T is the code length, which is equal to the number of columns. In each code, there are w short pulses of different

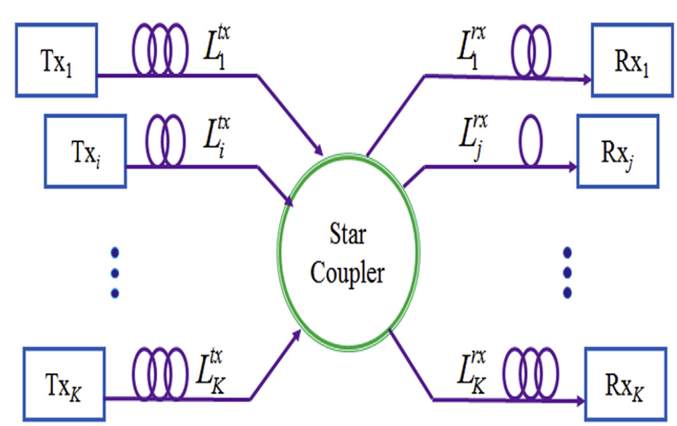

Fig. 1. OCDMA network architecture.