FSO-CDMA Systems Supporting end-to-end Network Slicing

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Abstract: A new flexible, secure FSO-CDMA system supporting end-to-end network resource slicing is proposed and investigated. New mathematical formalisms considering distinct turbulence conditions are derived. The system supports different applications, use cases, and traffic requirements.

1. Introduction

The digital market transformation of different industries will require support to several applications and use cases, but each with distinct and specific needs. To address this new demand, innovative technologies are required to meet the needs of each application by supporting end-to-end network resource slicing in a flexible way [1]. Optical code-division multiple-access (OCDMA or Optical CDMA) technology has built-in flexibility and scalability by encoding users' data to be sent over the end-to-end network [2]. OCDMA can multiplex several channels simultaneously via code sequences, with the latter granting a higher level of security at the physical (PHY) layer of the end-to-end network. Despite its inherent benefits, optical fiber deployments in remote geographical areas are still cumbersome due to different reasons such as geographical difficulties, site access rights, and high costs. Alternatively, wireless networks based on free-space optics (FSO) are a prospective solution to provide high capacity where only fiber deployment is impractical or deficient [2]. Accordingly, the potential leverage of both technologies, optical CDMA and FSO [2], can render a flexible fiber wireless network-as-a-service with resource slicing capabilities while supporting flexibility and optimal resource management. In fact, flexible FSO-CDMA networks offer additional levels of security at the PHY layer and full support to bandwidth and QoS allocation according to different traffic requirements. In turn, this grants the system the ability to support mission-critical and network-performance-sensitive use cases for new verticals. In this paper, we propose a new flexible free-space optical CDMA system with end-to-end network resource slicing capabilities for supporting different use cases, applications, and traffic scenarios. The users transmit data with enhanced secure levels at the PHY layer in a fully asynchronous manner by means of assigned optical codes. The network resource slicing (bandwidth and QoS) is achieved according to different class traffic requirements. The network employs an FSO receiver with equal gain-combining (EGC) and intensity demodulation and direct detection technique. New mathematical formalisms for three distinct turbulence conditions, namely, totally and partially correlated channels, and no correlated channels, are derived. The FSO link is accounted for by using gamma-gamma (GG) scintillation turbulence channels. Numerical results shown all class-1 traffic users are within the FEC limit, remarkably achieving error-free transmissions (average bit error rate (BER) $\leq 10^{-12}$) under the investigated scenarios for an irradiance variance ($\sigma_I^2 \leq 1.25$) and an additive white Gaussian noise power ($\sigma_N^2 = 0.1$); and for nearly any noise power when $\sigma_I^2 = 0.12$ (i.e., for 2.67 km range and a refractive-index structure $C_N^2 = 10^{-15}$ m$^{-2/3}$).

2. Flexible Optical CDMA-FSO system description and average BER evaluation

The flexible Optical CDMA-FSO system with support to end-to-end network resource slicing is arranged in a star topology connecting all users to the multiple access channel via optical fibers as illustrated in Fig. 1. The network consists of J-class user traffic sharing the same optical medium, where users are divided into classes according to a given data traffic requirement (bandwidth and QoS). The total number of users is $U=\sum_{j=1}^{J} U_j$, where U_j is the number of class-$\boldsymbol{j}$ users. The user data bits are OOK modulated using a broadband optical source. The optical signal is encoded by the OCDMA encoder, then the star coupler combines the signals of all transmitters and provides access to the optical channel. Next, the combined signal is transmitted through the FSO link, where signal fading might occur due

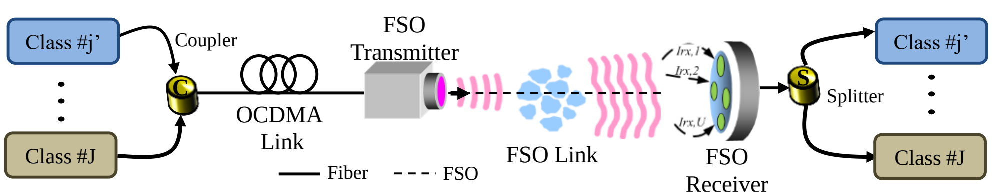
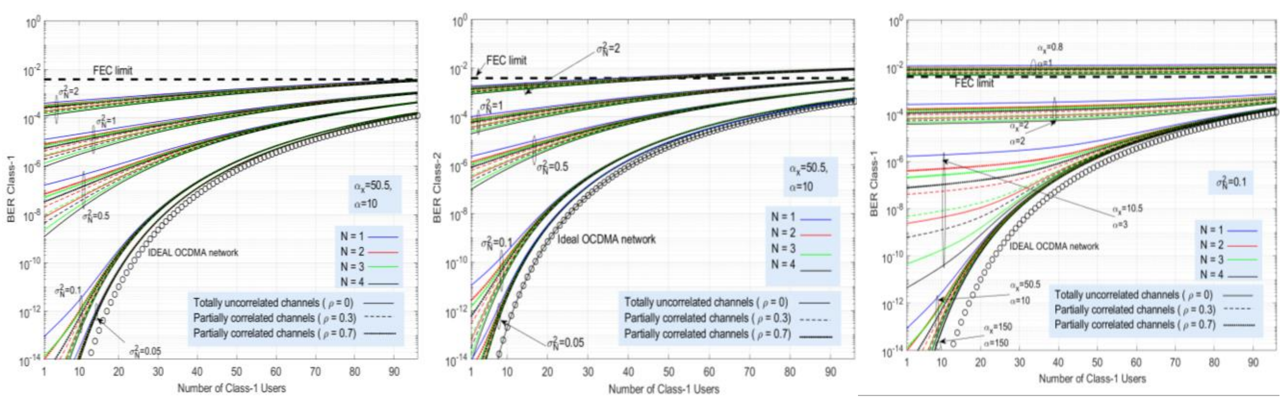


Fig. 1. Architecture of the proposed OCDMA-FSO system connecting all data traffic J classes in a star topology.

to atmospheric turbulence scintillation. Finally, the FSO receiver, which employs an EGC spatial diversity technique to mitigate scintillation degrading effects using four aperture collecting lenses, collects the transmitted signal and a star splitter delivers the signals to each user receiver, where the OCDMA decoder retrieves the data bit based on IM/DD technique. Accordingly, the decoded signal is sent to a photodetector and then to an OOK demodulator, where the output signal is integrated and compared to a threshold. The turbulence-induced fading (scintillation) degrades the performance of FSO channels. The system performance is investigated via the GG probability density function (PDF) of the irradiance [2, 3]. The irradiance GG PDF consists of a doubly stochastic theory of scintillation governed by independent gamma distributions. The PDF of the combined received irradiance with the effective number of small-scale turbulent eddies for each receiving channel is modified and derived from [2]. This PDF is averaged over the error probability of the OCDMA link to obtaining the new average (ABER) expressions of the OCDMA-FSO system that are used in the analysis of several distinct scenarios. Full derivation and analysis will be published elsewhere.

3. Numerical results

A flexible FSO-CDMA system with two-class of data traffic with different requirements is considered. To satisfy the traffic requirements, the users employ 2-D codes with code length and weight, respectively, by $L_1 = 150$, $W_1 = 12$, $U_1 = 96$, $L_2 = 300$, $W_2 = 10$, $U_2 = 32$, where U_j is the number of class-j users. The total number of wavelengths used in the 2-D code generation is 19. Class-1 traffic has high-QoS and -rate whereas class-2 data traffic has low-QoS and -rate. The ABER of both classes versus the number of simultaneous class-1 users is plot in Figs. 2(a) and (b). The ABER worsens as the number of simultaneous users increases, which is due to the increased interference variance and, consequently, to the signal-to-interference ratio reduction. Note that the ABER increases drastically when $\alpha = 10$, but remarkably it is still within the FEC limit (ABER $\leq 3.8\times10^{-3}$, see horizontal dashed line in Fig. 2(a)). Hence, even under the worst fading intensity case, all users can simultaneously transmit without errors as their ABER levels are within the FEC limit. Additionally, the overall performance of class-2 (Fig. 2(b)) is more penalized as compared to class-1 (Fig. 2(a)). Finally, Fig. 2(c) shows the adverse effect of the turbulence for a fixed AWGN variance.



(a) (b) (c)

Fig. 2. Average BER performance of the OCDMA-FSO system for different noise and turbulence conditions (receiver with a single aperture lens with total correlation (solid lines), uncorrelated (dashed lines) and partially correlated (dotted lines)). (a) and (c) Class-1 results, (b) Class-2 results.

5. Conclusions

A new optical CDMA wireless FSO system with network resource slicing capabilities and enhanced secure levels at the PHY layer was proposed and analytically investigated. Numerical results shown users can remarkably transmit error-free data (employing FEC), even when the maximum number of class-1 users is simultaneously active in the system for the three turbulence scenarios including the worst fading intensity scenario.

Acknowledgment

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6. References

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