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# ADVANCES IN OPTICAL AND COGNITIVE RADIO COMMUNICATION: A DUAL APPROACH

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## ABSTRACT

*This study investigates the performance of a Free-Space Optical (FSO) communication system utilizing a Distributed Switch-and-Stay Combining (DSSC) receiver that strategically selects the path with the highest Signal-to-Noise Ratio (SNR) while discarding paths with unfavorable fading. The analysis employs Moment Generating Functions (MGF) to calculate cumulative distribution functions for M-distributed path-A and applies the DSSC technique to discern the superior path between A and B, considering M'alaga (M) and Gamma-Gamma (GG) fading. Novel expressions for outage probability, ergodic capacity, and outage capacity are introduced under various policies (CIFR, OPRA, and TIFR), with simulation results validating their accuracy. The proposed joint overlay-underlay approach efficiently utilizes frequency resources, optimizing power allocation for both underlay and overlay modes. Notably, significant data rate improvements, particularly in underlay mode, are demonstrated where signal strength is influenced by concurrent power usage on the same frequency. The study emphasizes the proposed model's objective to maximize channel resource utilization, allowing each frequency to operate optimally in both overlay and underlay scenarios. The importance of this research lies in advancing the understanding of efficient power allocation and resource utilization strategies in FSO communication, with implications for enhancing the reliability and data rates of such systems.*

***Keywords:*** *Free-Space Optical Communication; Distributed Switch-and-Stay Combining; Cognitive Radio Networks; Ergodic Capacity; Overlay-Underlay Power Allocation*

## 1. INTRODUCTION

In an era defined by an insatiable demand for higher data rates and the efficient utilization of the radio frequency spectrum, this paper embarks on a comprehensive exploration of two transformative chapters: "Distributed Switch-and-Stay Combining in FSO System" and "Cognitive Radio Network Joint Overlay-Underlay Power Allocation Scheme"[1, 2]. At the forefront of contemporary communication technology, these chapters delve into Free-Space Optical (FSO) communication and Cognitive Radio (CR) networks [3], addressing the formidable challenges posed by dynamic atmospheric conditions and the ever-growing demand for seamless connectivity.

The study of Free-Space Optical (FSO) communication assumes paramount importance in the face of the intricate interplay between optical signals and the atmospheric environment. Atmospheric turbulence and diverse weather conditions introduce variability and uncertainty into FSO links, necessitating innovative solutions. Multi-hop relaying emerges as a key strategy, enabling expansive coverage, and studies based on the Gamma-Gamma (GG) and Ma'laga (M) distributions become pivotal in understanding the complexities of multi-hop FSO systems [4-6]. The Ma'laga distribution, in particular, offers a versatile modeling approach encompassing various turbulence models. In an era defined by an insatiable demand for higher data rates and the efficient utilization of the radio frequency spectrum, this paper embarks on a comprehensive exploration of two transformative chapters: "Distributed Switch-and-Stay Combining in FSO System" and "Cognitive Radio Network Joint Overlay-Underlay Power Allocation Scheme." At the forefront of contemporary communication technology, these chapters delve into Free-Space Optical (FSO) communication and Cognitive Radio (CR) networks, addressing the formidable challenges posed by dynamic atmospheric conditions and the ever-growing demand for seamless connectivity.

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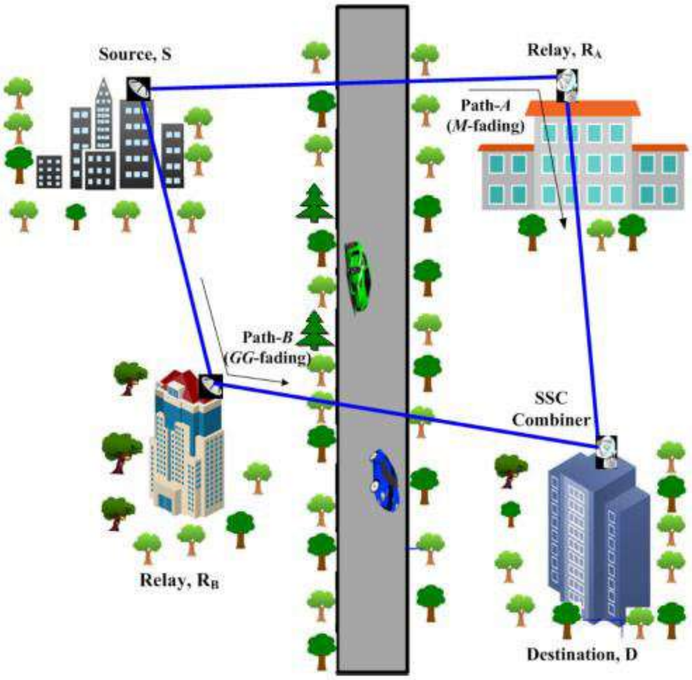


**Fig. 1:** Model of a distributed switch and stay system based on FSO

In parallel, Cognitive Radio (CR) networks emerge as a crucial player in the broader landscape of modern communication. The conventional radio frequency spectrum, already extensively allocated to licensed users, presents a scarcity of available frequencies. This scarcity is compounded by dynamic changes in frequency spectrum usage over time and across locations, as highlighted in a recent FCC report [7]. The relevance of this study lies in its strategic exploration of spectrum sensing algorithms [8, 9] and power allocation strategies, addressing the critical need to optimize resource usage in Cognitive Radio networks. Spectrum sensing becomes a key mechanism to identify unoccupied frequencies, paving the way for dynamic power allocation based on sensed data [10, 11]. The introduction of the joint overlay-underlay model not only addresses the scarcity of frequencies but also anticipates future communication needs. This model advocates for simultaneous transmission in both overlay and underlay modes, dynamically adapting to the availability of spectrum resources. The study provides a nuanced understanding of how power is allocated in scenarios where secondary users (SUs) operate concurrently with primary users (PUs) or other CR transmissions.

### 1.1. Importance of the Study

The profound importance of this study lies in its potential to redefine the landscape of contemporary communication systems. As we navigate an era where seamless connectivity is not just a convenience but a fundamental necessity, the insights garnered from the research presented here offer a transformative roadmap. The proposed techniques, ranging from the innovative Distributed Switch-and-Stay Combining in FSO systems to the forward-looking joint overlay-underlay model in Cognitive Radio networks, represent pioneering contributions to addressing longstanding challenges in communication systems. The significance of this research extends beyond theoretical advancements to practical implications for designing communication systems that dynamically adapt to environmental conditions and spectrum availability. In a world where connectivity is the lifeblood of diverse applications, from smart cities to autonomous vehicles, the proposed advancements hold the promise of improving reliability, efficiency, and adaptability in communication networks. The importance of these advancements reverberates across academia, industry, and the broader spectrum of interconnected technologies, paving the way for a future where communication systems seamlessly meet the evolving demands of our interconnected world.

## 2. SYSTEM MODELING AND METHODOLOGY

### 2.1. System Modeling of FSO

To enable long-distance communication, a proposed two-path Free-Space Optical (FSO) system incorporates two hops on each path. At the destination (D), the Switch-and-Stay Combining (SSC) diversity scheme combines optical signals. The Dual Switch-and-Stay Combining (DSSC) scheme selects the best path from the two, switching to the other if Signal-to-Noise Ratio (SNR) falls below a set threshold (see Fig. 3.1). Both relay paths (RA and RB) operate in Amplify and Forward (AF) mode, assuming non-identical distributions. The Ma'laga (M) distribution models S-RA-D link hops for mild to strong turbulence, while the Gamma-Gamma (GG) distribution models S-RB-D link hops, widely used for FSO channels. Relays RA and RB act as non-regenerative nodes along paths A and B, respectively, amplifying the signal before forwarding. Each FSO path employs Intensity Modulation/Direct Detection (IM/DD) and On-Off Keying (OOK) modulation schemes. It is assumed that both relays (RA and RB) and the destination node have complete Channel State Information (CSI). The equivalent Signal-to-Noise Ratio (SNR) for Path A is determined by:

$$\gamma_{eq} = \frac{\gamma_{1A}\gamma_{2A}}{\gamma_{1A}+\gamma_{2A}} \qquad 1$$

Where $\gamma_{eq}^{A}$ depends on the instantaneous SNRs $\gamma_{1A}$ and $\gamma_{2A}$ of the $S-R_A$ and $R_A-D$ links, respectively. Similarly. We define $\gamma_{eq}^{B}$ as the equivalent SNR of path *B,* stated as:

$$\gamma_{eq}^{B} = \frac{\gamma_{1B}\gamma_{2B}}{\gamma_{1B}+\gamma_{2B}} \qquad 2$$

Where $\gamma_{1B}$ is instantaneous SNR of the $S-R_B$ link, while $\gamma_{2B}$ represent instantaneous SNR of $R_B-D$ link.

Statistical path analysis for the Path A involves following equations:

$$f_1(I) = A\sum_{m=1}^{\beta} a_m I^{\left(\frac{\alpha+m}{2}\right)-1} K_{\propto-3}\left(\sqrt{\frac{\propto\beta I}{g\beta+\Omega}}\right) \qquad 3$$

$$a_m\binom{\beta-1}{m-1}\frac{1}{(m-1)!}\left(\frac{\Omega}{g}\right)^{m-1}\left(\frac{\propto}{\beta}\right)^{\frac{3}{2}}(g\beta+\Omega)^{1-\frac{m}{2}} \qquad 4$$

$$A = \frac{2(\propto)^{\frac{\propto}{2}}}{g^{\left(1\frac{\propto}{2}\right)}\Gamma(\propto)}\left(\frac{g\beta}{g\beta+\Omega}\right)^{\frac{\propto}{2}+\beta} \qquad 5$$

$$g = 2b_0(1-p) \qquad 6$$

The average power of total scattering components, $(U_S^C)+(U_S^G)$ is denoted by $2b_0$ and the factor $p$ denotes the scattering power coupled to LOS component, where $0 \le p \le 1$.

$$\Omega = \Omega + 2b_0p + 2\sqrt{2b_0\,p\Omega\cos}(\Phi_A-\Phi_B) \qquad 7$$

where $\Omega = \mathrm{E}\,[\,|U_L|^2]$ and $\Phi_A$ and $\Phi_B$ denote deterministic phases corresponding to LOS and coupled – to – LOS scattering components, respectively. $\propto$ and $\beta$ are the effective number of large-scale and small-scale cells respectively, describing fading corresponding to atmospheric turbulence. The PDF of Malaga distributed path is given by:

$$f_{\gamma}^{A}(\gamma) = \frac{\xi^2 A}{4\gamma} \sum_{m=1}^{\beta} b_m G^{3,0}_{1,3}\left(B\sqrt{\frac{\gamma}{\mu}} \Big| \frac{\xi^2+1}{\xi^2, \alpha, m}\right) \quad 8$$

The AF based MGF of dual-hop path A is stated as:

$$M_{\frac{1}{\gamma}}^{A}(S) = \sum_{m=1}^{\beta}\left(\frac{\xi^4 A^2}{32\pi^2}\right) b_m^2 4^{(\alpha+m-2)} G_{4,13}^{13,0}\left(\frac{B^4 s}{256\mu^2}\right) \Big|_{\Psi_{13}}^{\Psi_4} \quad 9$$

In statistical analysis of Path B, It is assumed that pointing errors caused by misalignment have an effect on the turbulence in the air along GG's path B. When S sends a signal to relay R, that signal is first amplified and then sent to D. The PDF of the dual-hop Gamma-Gamma (GG) distributed path B is:

$$f_{\gamma}^{b}(\gamma) = \frac{\xi^2}{2_{\gamma}\Gamma(\beta)} G_{1,3}^{3,0}\left(\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}} \Big|_{\xi^2, \alpha, \beta}^{\xi^2+1}\right) \quad 10$$

Also, the CDF of path B can be written down as:

$$F_{\gamma}^{B}(\gamma) = \left(\frac{\xi^2}{\Gamma(\alpha)\Gamma(\beta)}\right)^2 G_{3,7}^{6,1}\left(\frac{2\alpha^2\beta^2}{\bar{\gamma}}\gamma \Big|_{\Phi_7}^{\Phi_3}\right) \quad 11$$

### 2.1.1. Analysis of distributed switch-and-stay combining, with the outrage analysis

The probability of falling of output SNR below certain threshold $\gamma_{th}$ is outage probability, $P_{out}$.The OP of DSSC based FSO system is given by:

$$P_{out}^{DSSC} = \Pr[\gamma DSSC < \gamma_{th}] = F_{DSSC}(\gamma_{th}) \quad 12$$

For optional implementation of the proposed system, we consider the switching threshold for the minimum OP, $\gamma_T$, same as $\gamma_{th}$. A "High SNR Analysis of OP" involves examining a system under conditions where the signal-to-noise ratio is significantly high. In such scenarios, the strength of the signal greatly surpasses the impact of background noise. This analysis is crucial for understanding how the system performs under optimal signal conditions, allowing insights into its efficiency and reliability. In the context of optical communication systems, it helps optimize design and explore how the system utilizes enhanced signal strength for improved performance.

### 2.2. System Modeling involved in CR network joint overlay-underlay power allocation scheme

A novel power allocation strategy applicable to both overlay and underlay schemes in cognitive radio (CR) is proposed. The functionality of a CR node is dependent on received information, allowing for overlay transmission when the channel appears open. Conversely, underlay transmission permits simultaneous transmissions on the same frequency. In the proposed cognitive radio network depicted in Fig. 2, secondary users (SU) are categorized as SUoRx for overlay mode and SURx for underlay mode. When a spectrum hole is identified, SUoRx transmits; otherwise, SUuRx seizes the opportunity. Overlay transmission involves high-power communication, enabling long-distance reach without interfering with active primary users (PUs). Before transmission, SU Tx searches for a spectrum gap, employing sensing techniques discussed in [8, 9]. The information gathered by a CR node informs the decision on whether a frequency can be used for transmission. In overlay mode, the node transmits with high power (P) when the channel is vacant, and with low power (Pu0) in the underlay mode when the channel is busy.

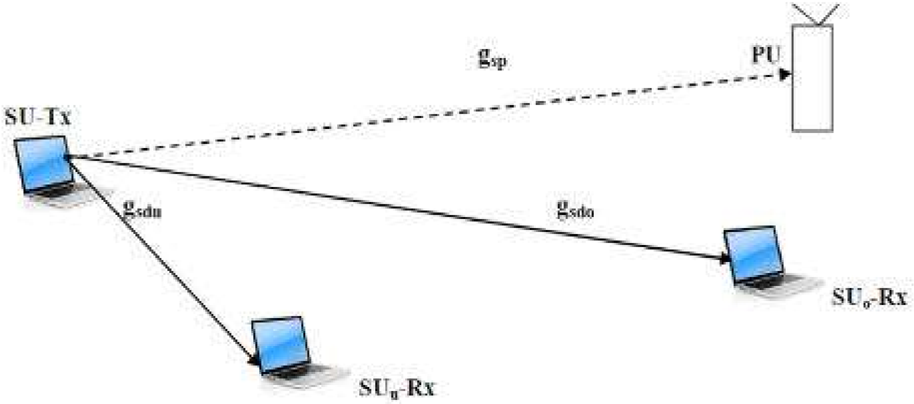


**Fig. 2:** A joint overlay and underlay system based on CR

If there is noise and a signal is found, the channel is thought to be unavailable. We used standard energy detection methods to find the hole in the spectrum.

$$H_0 : r(t) = n\,(t) \qquad 13$$

$$H_1 : r(t) = h * s(t) + n\,(t)$$

Using the information from the sensors, the probability combinations are made [71] as:

$$A_0 = p\,(H_0)(1 - p_{fa}) + p\,(H_1)(1 - p_d) \qquad 14$$

$$A_1 = p\,(H_0)(1 - p_{fa}) + p\,(H_1)(1 - p_d)$$

Where A0 is the total number of chances that the channel is open and the user can send at full power in overlay mode. The channel is used based on the set of probabilities given by A1.

### 2.2.1. Convex Optimization

Constrained optimization is a powerful approach to determining the optimal solution for maximizing or minimizing a given objective or cost function while considering various constraints. When both the objective and constraints are linear, it falls under linear programming, facilitating straightforward global optimization. However, in convex problems, different methods are employed to reach the global optimum. Gradient and Newton's methods are common for convex problems without constraints, with the former adjusting the feasible point in the direction of the gradient, and the latter offering faster convergence but requiring the calculation of the Hessian. For constrained convex problems, methods such as the interior point method, ellipsoid method, and projected gradient algorithm are utilized. The interior point method adjusts the objective function as it nears the search point's edge, while the ellipsoid method employs a series of ellipses within the feasible set, decreasing in size with each iteration to snugly encapsulate the convex function. In cases where constraints or the objective function are non-linear, the optimization problem becomes non-linear programming (NLP). Global optimization for NLP often involves methods like the interior point method, genetic algorithm, and simulated annealing. The Lagrange multiplier aids in determining whether a multi-variable function is at its maximum or minimum. The weighted sum of constraints is integrated into the objective function, contributing to the Lagrange function in this comprehensive approach to non-linear programming optimization.

$$\mathcal{L}\,(x, \lambda) = f(x) - \sum_{i=1}^{m} \lambda_i f_i(x), \qquad 15$$

To find the global maximum of the problem, KKT, there is a need to meet both the necessary and sufficient conditions.

### 2.2.2. Ergodic Capacity

Ergodic capacity represents the average data rate over all fading statistics, encompassing deep fading, in scenarios where neither the transmitter nor the receiver has Channel State Information (CSI) access. It considers the average of instantaneous capacities over the Additive White Gaussian Noise (AWGN) channel. However, the conventional approach has limitations, leading to a significant reduction in capacity [12]. In the proposed model, maximizing capacity involves empowering the cognitive radio (CR) user to transmit with the highest available power. To optimize resource utilization, the power is allocated between two modes: overlay and underlay. This innovative approach aims to enhance overall capacity by strategically managing power distribution across these operational modes.

The primary objective of the proposed model is to enable Cognitive Radio (CR) users to transmit data in both modes, maximizing the potential data rate. The operational mode is determined based on the acquired information.

$$max \left(E \left[A_0 log_2 \left(1+\frac{g_{sd0}P_0}{\sigma^2}\right)+ A_1 log_2\left(1+\frac{g_{sdu}P_u}{\sigma^2}\right)\right]\right) \quad 16$$

### 2.2.3. Overlay and Underlay Transmissions

In overlay transmission mode, CR sends over the channel that is not being used by licenced users [13]. The main goal of CR users is to maximise the data rate without affecting the other PUs. The most interference should not be more than the SNR threshold. Convex optimization is employed to determine the optimal power level. The objective function is referred to as the "primal objective," and the minimum value of the Lagrangian over variable "x" is termed the "dual objective" [13].

To determine the optimal power, the Lagrangian multipliers l and n are utilized to identify the point where d is minimized (l; n). Once the subgradient of the dual function d is determined, the Newton method [14] is applied to find the optimal solution (l; n). The subgradient method is employed for solving non-differentiable functions due to its simplicity and minimal memory requirements. In this method, the gap between the current solution, x(t), and the optimal solution, x, is progressively reduced. Additionally, the subgradient method is effective when the step size is sufficiently small [15].

$$L\left(P_{0,}\lambda_{1,}\lambda_2\right)=E\left[A_0 log_2\left(1+\frac{g_{sd0}P_0}{\sigma^2}\right)\right]+\lambda_1(\gamma_{thu}-E[A_0 g_{sd0}P_0] \quad 17$$

$$+\lambda_2(E\left[A_0 g_{sp}P_0\right]-\gamma_{tho}).$$

For the A1 set of probabilities, the node operates in "underlay mode." The objective of the proposed method is to maximize the data rate by enabling the node to operate in both overlay and underlay modes. This approach optimally utilizes the power of Cognitive Radio (CR) in underlay mode.

Outage probability, denoted as Pout, serves as a crucial design metric, providing insights into the likelihood of successfully decoding the transmitted signal [12]. The expression Pout = P(g < gmin) represents the outage probability, where 'g' is the received Signal-to-Noise Ratio (SNR). If the received SNR is less than the minimum required threshold 'gmin', it signifies that the data cannot be recovered, leading to the announcement of an outage.

## 3. RESULTS AND DISCUSSIONS

This paper delves into two pivotal realms of contemporary communication technology: "Distributed Switch-and-Stay Combining in FSO System" and "Cognitive Radio Network Joint Overlay-Underlay Power Allocation Scheme." The former focuses on Free-Space Optical (FSO) communication, addressing challenges posed by atmospheric conditions through strategies like multi-hop relaying and insightful modeling with Gamma-Gamma (GG) and Ma'laga (M) distributions. Meanwhile, the latter explores the significance of Cognitive Radio (CR) networks in optimizing resource usage within the constrained radio frequency spectrum. Spectrum sensing algorithms are examined to identify available frequencies, facilitating dynamic power allocation. The joint overlay-underlay model introduces a novel approach, advocating for simultaneous transmission in both modes, thereby adapting to spectrum resource availability. This study provides valuable insights into power allocation scenarios involving secondary users alongside primary users or other CR transmissions.

### 3.1. Consequences of Distributed Switch-and-stay Combining in FSO Systems

In this section, graphical representations of outage probability, ergodic capacity, and outage capacity are provided. The analysis considers hops on paths A and B utilizing the IM/DD detection technique, assuming i.n.i.d Ma'laga (M) and GG distributions for paths A and B, respectively. To maintain generality, parameters for SRA; RAD and SRB; R D links are considered identical in the analysis of various performance parameters. The study examines performance under both moderate (10^13 m^2 = 3 B) and strong (10^11 m^2 = 3j48yy513) turbulence conditions. The turbulence parameters investigated are (a = 4.2; b = 3) and (a = 2.296; b = 2), determined using the Rytov variance.

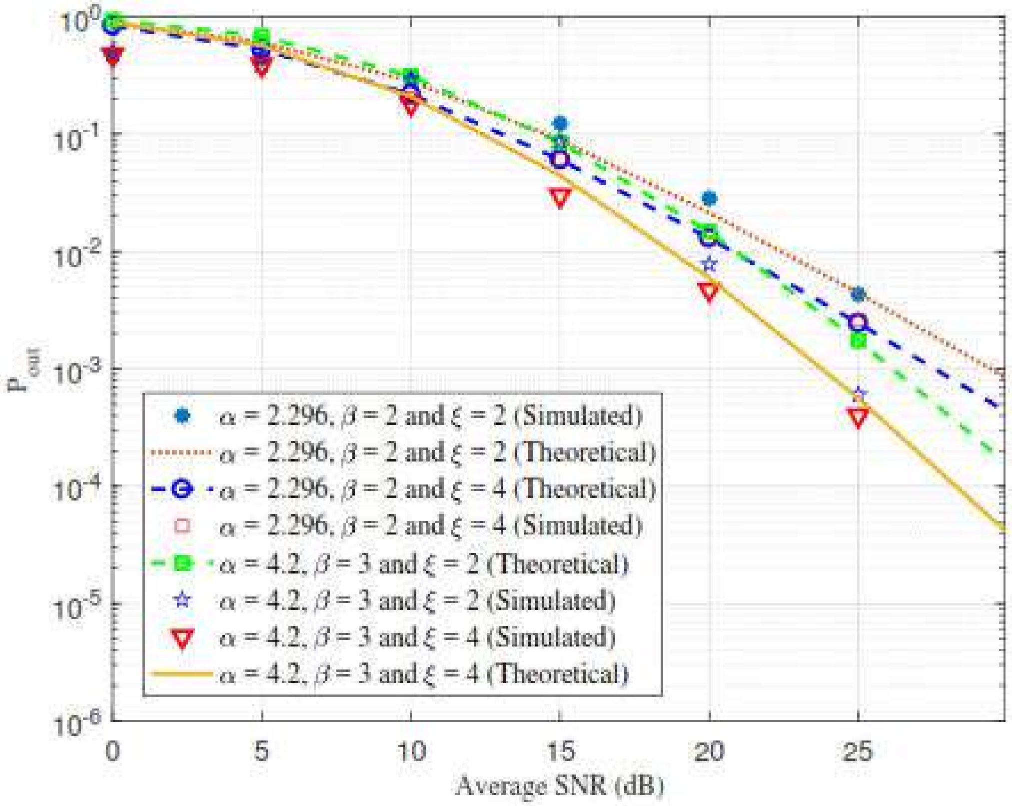


**Fig. 3:** OP of proposed DSSC model plotted against average SNR

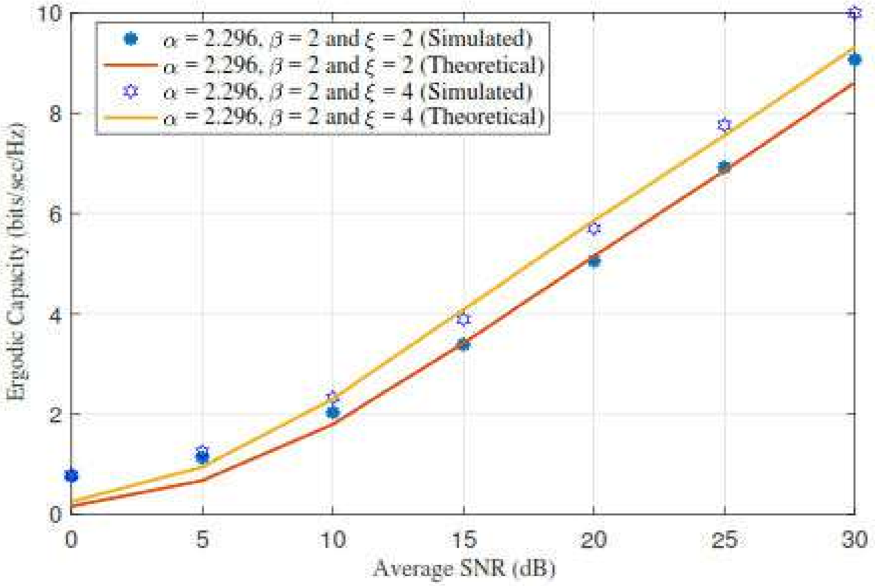


**Fig. 4:** Average SNR vs. Ergodic Capacity of DSSC FSO system

The graph Fig. 4 illustrates the relationship between the average Signal-to-Noise Ratio (SNR) and the ergodic capacity at the Distributed Switch-and-Stay Combining (DSSC) combiner. The analysis sets 0 dB as the threshold SNR. Remarkably, the plot indicates a positive correlation, revealing that the capacity increases as the pointing error decreases. In Fig.5. the theoretical expression of Cognitive Interference-Free Relay (CIFR) capacity, considering pointing errors according to previous equations, is depicted against the average Signal-to-Noise Ratio (SNR) with three distinct sets. Notably, as the severity of pointing errors increases, there is a corresponding decrease in CIFR's capacity, signified by a reduction in the value of 'x.'

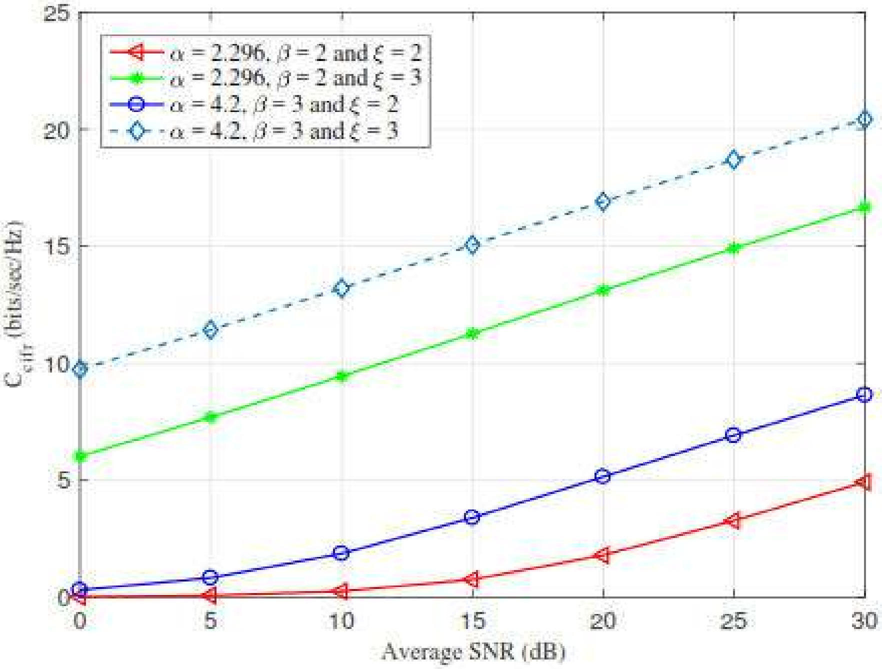


**Fig. 5:** Channel Inversion with Fixed Rate of DSSC based FSO system vs. Average SNR

In Fig. 5, the capacity of the Optical Power Ratio Allocation (OPRA) system is graphed against the cut-off Signal-to-Noise Ratio (SNR), incorporating various pointing errors and atmospheric turbulence parameters. For instance, when g = 5 dB, a = 2.296, and b = 2, the OPRA capacity is visually represented for different pointing errors, specifically x = 2, 4, and 8. Moving on to Fig. 6, it provides a visual representation of the mathematical expression of the Temporal Interference-Free Relay (TIFR) capacity as a function of average SNR for x = 2, 4, and 10. The cut-off SNR for this analysis is set at 0 dB. Notably, the plot reveals an increase in TIFR capacity as x increases. Furthermore, Fig. 7 presents a graphical comparison of TIFR capacity, Ergodic capacity, and Cognitive Interference-Free Relay (CIFR) capacity against the parameter g (Signal-to-Noise Ratio).

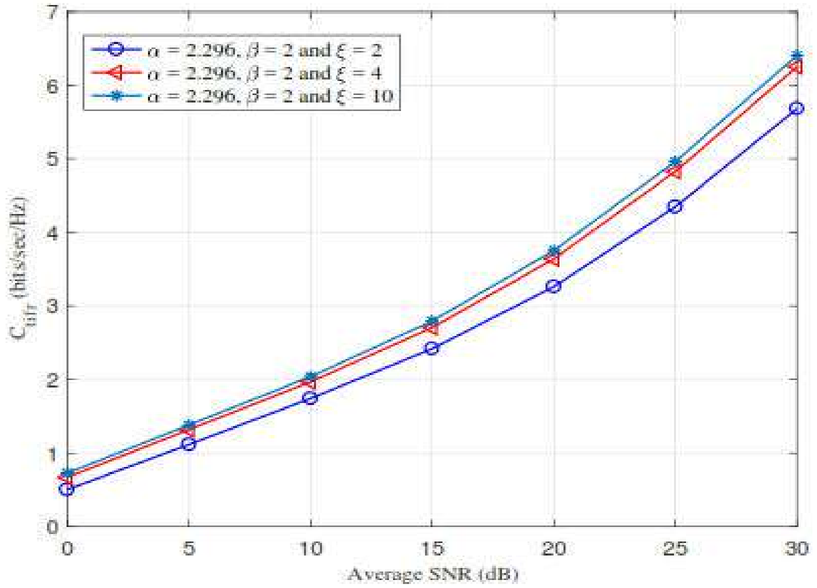


**Fig. 6:** Average SNR vs. TIFR Capacity for Different Values of Pointing Error

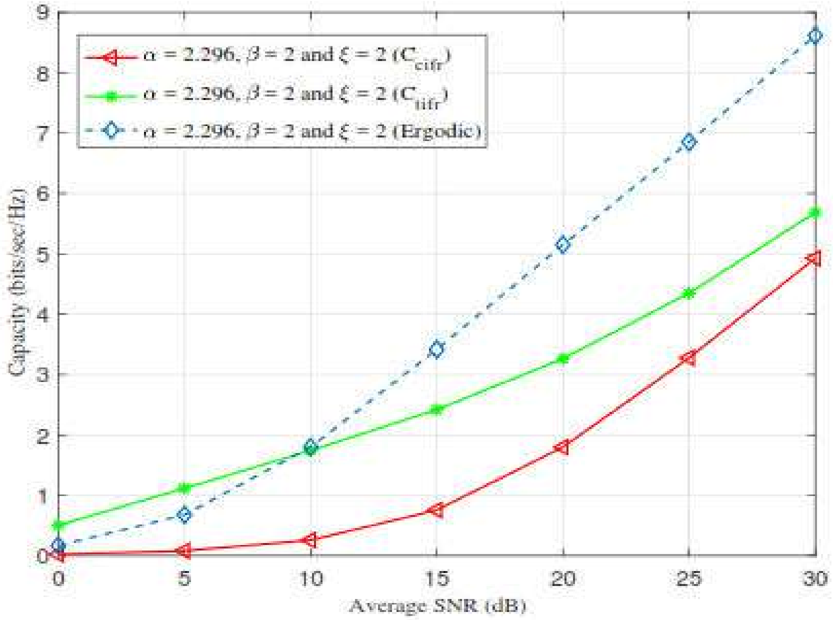


**Fig. 7:** CIFR, TIFR, and Ergodic Capacity in (bits/sec/Hz) vs. Average SNR (g) in (dB)

### 3.2. Consequences of CR Network Joint Overlay-Underlay Power Allocation Scheme

A novel and optimal power allocation approach is proposed, designed to seamlessly accommodate both overlay and underlay schemes in Cognitive Radio (CR) networks. The operation of a CR node is contingent upon the information it receives. In the overlay transmission mode, the CR node transmits data when the channel appears to be available. Conversely, underlay transmission permits simultaneous transmissions on the same frequency, allowing both Primary and CR users to transmit concurrently. The overarching objective of the proposed model is to enable CR users to transmit data in both modes, thereby maximizing the data rate to its fullest potential. This section provides a summary of the simulation results for the proposed joint overlay-underlay scheme in a cognitive radio system. The scheme optimally utilizes the frequency spectrum by employing both overlay and underlay modes. The average maximum interference power at the Primary User (PU) is denoted by the variable 'g,' assigned a value of 2 dB. The numerical analysis is conducted using probabilities: p (Hth > 0) = 0.6, p(H1) = 0.4, pfa = 0.05, and pd = 0.09, which play a crucial role in evaluating the system's performance.

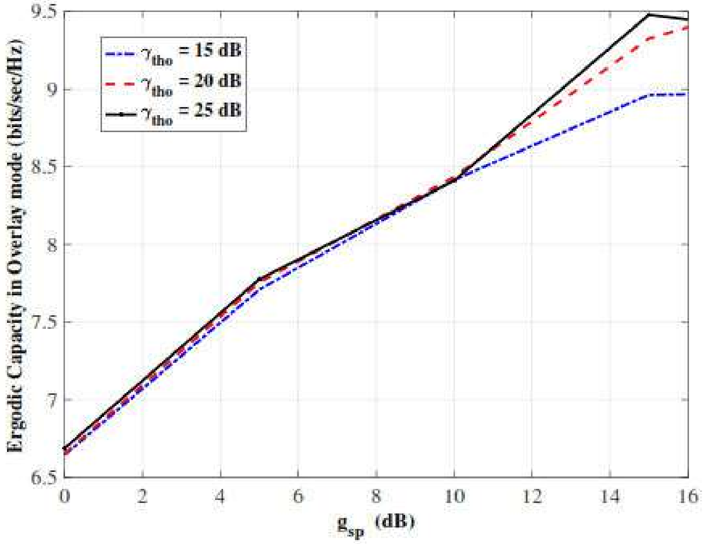


**Fig. 8:** Ergodic Capacity Achieved in Proposed Scheme (bits/sec/Hz) vs. Channel Fading Gain between SU Tx and PU

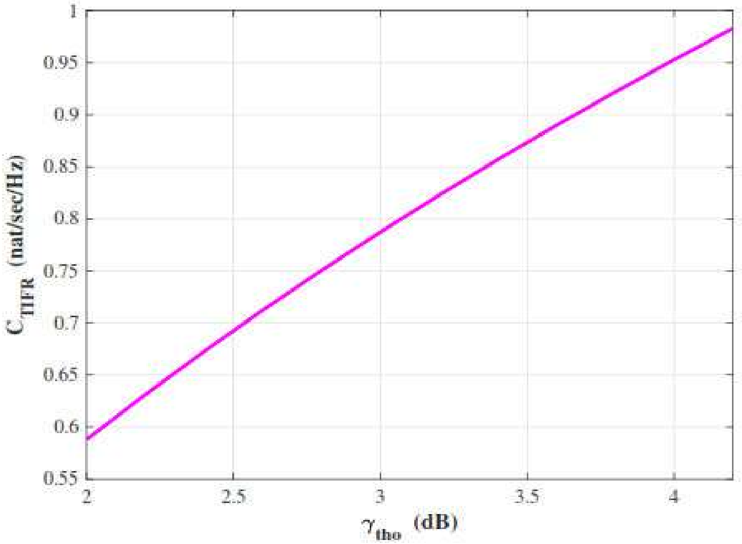


**Fig. 9:** Average SNR vs. TIFR Capacity Obtained for Overlay Transmission Scheme (dB)

Through simulations, both overlay and underlay transmission modes can have their ergodic and outage capacities calculated. Fig. 9 illustrates the relationship between the data rate of Secondary User (SU) transmission and the channel fading gain from SU transmission to the Primary User (PU) in dB. Notably, the capacity increases as the interference threshold at the PU rises. The proposed model allows concurrent use of the available frequency by both overlay and underlay modes, showcasing more efficient resource utilization compared to the model discussed in [16]. Additionally, the data rate experiences an enhancement of 6 to 10 bits/s/Hz. In the presence of channel issues, transmission is halted, with 'gu' and 'g' representing the Signal-to-Noise Ratio (SNR) thresholds for underlay and overlay modes, respectively.

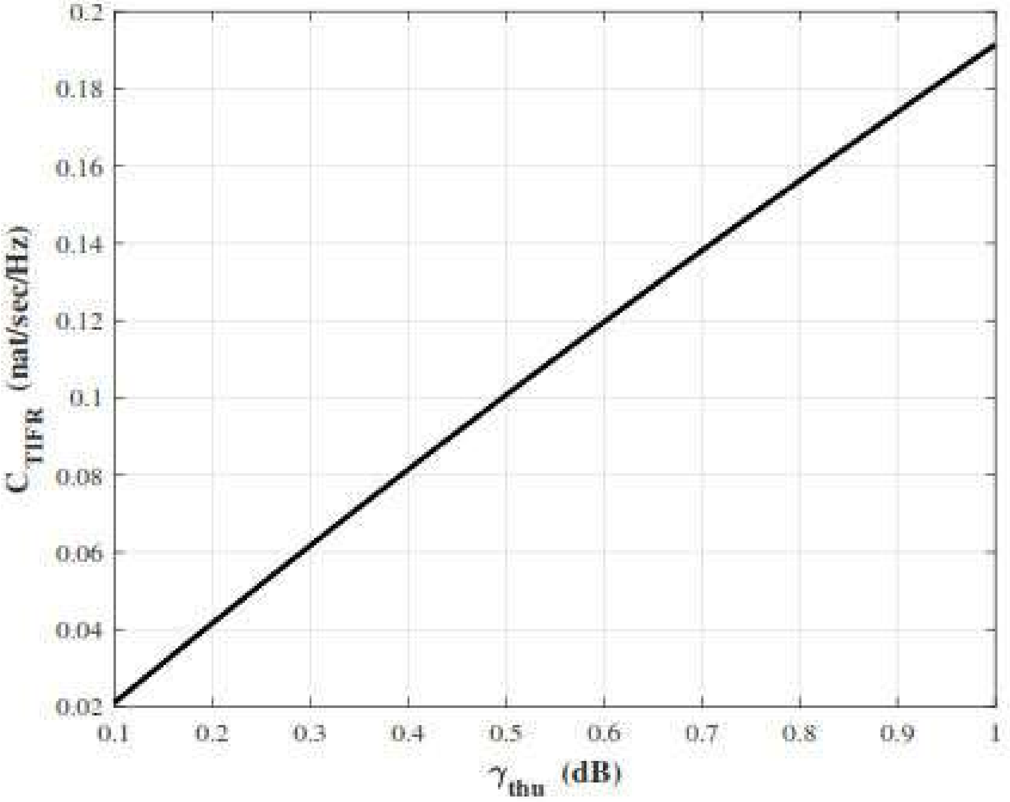


**Fig. 10:** Average SNR vs. TIFR Capacity for Underlay scheme (bits/sec/Hz)

Fig. 9 and Fig. 10 display the Temporal Interference-Free Relay (TIFR) capacity for both overlay and underlay modes. In Fig. 11, the highest achievable data rates in underlay mode are depicted across various Signal-to-Noise Ratio (SNR) thresholds. If the received power is below the threshold 'gthu,' it is assumed that the Receiver of Secondary User in Overlay (SUo Rx) is encountering noise. This mechanism is particularly effective for low-power transmissions, such as Wi-Fi and Bluetooth, where the power levels are below the noise floor of users operating on higher frequencies.

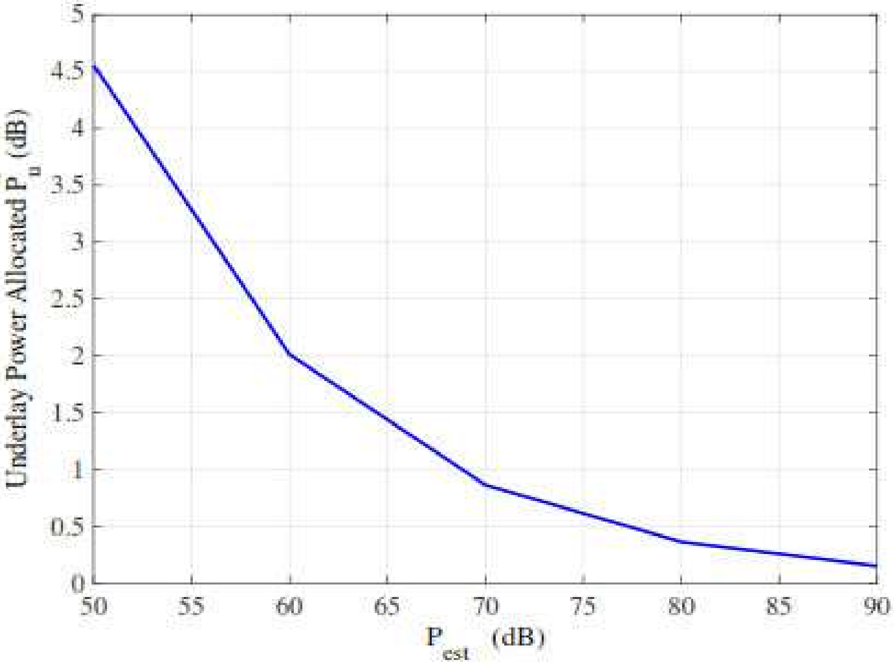
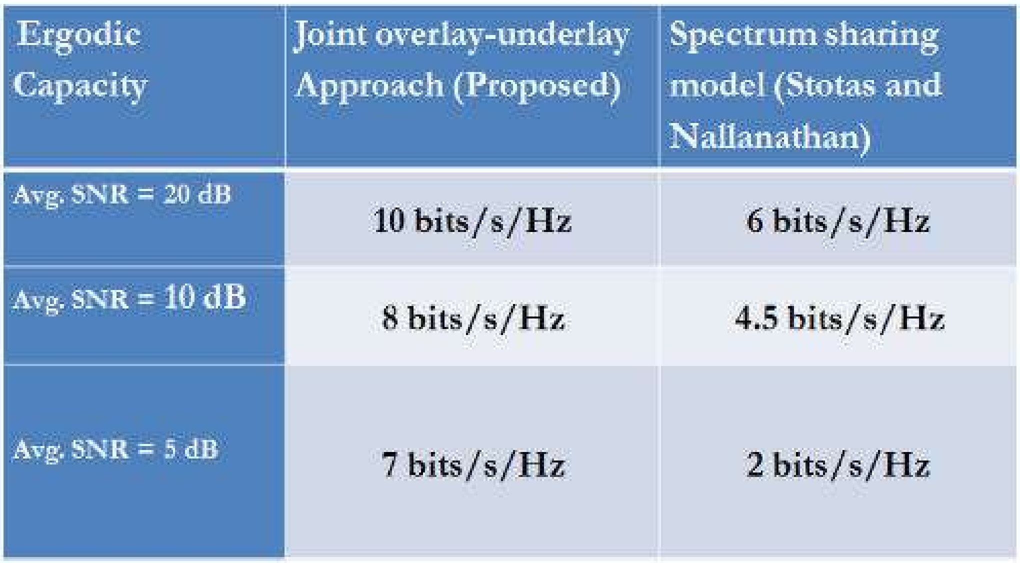


**Fig. 11:** Estimated power vs. suboptimal power allocation in underlay mode (in dB)

Fig. 11 illustrates a suboptimal approach for estimating the signal's power, taking into account both the actual transmission power and interference from other frequencies. In underlay mode, power is distributed exponentially. Consequently, if the estimated power over a given frequency is high, users receive less power. The estimates factor in interference from adjacent users as well as power contributions from users on top of each other who share the same frequencies. Here, 'g' is assumed to have a value of 10 dB. Fig. 12 provides a comparison between our proposed approaches. The results in the figures unmistakably demonstrate that the proposed scheme achieves a higher ergodic capacity compared to Stotas et al. [16] scheme as the average Signal-to-Noise Ratio (SNR) is varied.



| Ergodic Capacity | Joint overlay-underlay Approach (Proposed) | Spectrum sharing model (Stotas and Nallanathan) |
|---|---|---|
| Avg. SNR = 20 dB | 10 bits/s/Hz | 6 bits/s/Hz |
| Avg. SNR = 10 dB | 8 bits/s/Hz | 4.5 bits/s/Hz |
| Avg. SNR = 5 dB | 7 bits/s/Hz | 2 bits/s/Hz |

**Fig. 12:** Analysis of the proposed joint overlay and underlay scheme and model by

## 4. CONCLUSION

In conclusion, this study extensively examines the performance of a DSSC-based Free-Space Optical (FSO) communication system, employing a receiver that selects the path with the highest Signal-to-Noise Ratio (SNR) and discards the path with the worst fading. The analysis involves the calculation of cumulative distribution functions using Moment Generating Functions (MGF) for M-distributed path-A, along with the application of the DSSC combining technique to determine the superior path between A and B with M'alaga (M) and Gamma-Gamma (GG) fading. The study introduces novel expressions for outage probability, ergodic capacity, and outage capacity under various policies, namely CIFR, OPRA, and TIFR, and simulation plots validate the accuracy of the results. The proposed joint overlay-underlay approach efficiently utilizes frequency resources based on availability, optimizing power allocation for both underlay and overlay modes. The analysis demonstrates significant improvements in data rate, particularly in underlay mode where signal strength is influenced by concurrent power usage on the same frequency. While there are alternative power distribution schemes, the proposed model aims to maximize channel resource utilization, allowing each frequency to operate optimally in both overlay and underlay scenarios.

## 5. SCOPE FOR THE FUTURE WORK

The future scope of this research lies in enhancing the performance of DSSC-based FSO communication systems by exploring advanced path selection and fading mitigation strategies. Further optimization and refinement of policies such as CIFR, OPRA, and TIFR could be pursued to improve resource allocation efficiency in cognitive radio systems. The study's concept of adaptive power allocation based on frequency availability opens avenues for future investigations into the development of intelligent algorithms or machine learning models for dynamic adjustment to changing network conditions. Additionally, the integration of emerging technologies and communication standards, along with real-world deployment and validation, will be essential steps toward practical implementation. Exploring robust security mechanisms, energy efficiency considerations, and industry-standard adoption will ensure the applicability and sustainability of the proposed models in evolving communication environments.

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