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Performance Analysis of Interference Constrained NOMA in 5G Communication

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***Abstract*—The aim of this paper is to analyze the achievable rate in the power domain non-orthogonal multiple access (NOMA) technique for communication between six devices through an Internet-of-Things (IoT) gateway device. In this study, we first derive the expressions for the Signal-to-Noise Ratio (SNR) and Signal-to-interference-plus-noise ratio (SINR) for the transmission between the devices, which are crucial to determine the overall system performance. The analysis also takes into account the impact of co-channel interference (CCI) at the relay node, a significant factor that affects communication reliability in NOMA systems. Furthermore, we investigate how various system parameters such as distance, transmit power, and path loss exponent influence the achievable rate, considering the dynamic nature of wireless environments. By optimizing power allocation and addressing the challenges of interference, the system can achieve higher throughput and improved reliability. This paper aims to provide a comprehensive understanding of the performance of NOMA in the context of IoT system framework, offering insights into the trade-offs involved in achieving high data rates while ensuring energy efficiency. The results are discussed in terms of the systems' response to changes in key parameters, with the goal of optimizing performance for practical IoT deployments.**

***Index Terms*—non-orthogonal multiple access, signal-to-noise ratio/signal-to-interference and noise ratio, co-channel interference, successive interference cancellation, achievable rate.**

I. Introduction

The rapid evolution of wireless communication technologies has led to advanced network architectures capable of meeting the growing demands for higher data rates, improved reliability, and wider coverage [1]. Among these advancements, cooperative communication networks have emerged as a key innovation, enabling efficient information exchange through the use of multiple relay nodes. These networks capitalize on spatial diversity to overcome the limitations of traditional point-to-point communication systems [2], resulting in enhanced spectral efficiency, expanded coverage areas, and improved end-to-end reliability.

In a cooperative communication network, the exchange of information occurs with the assistance of two or more relay nodes. These nodes act as intermediaries, processing and forwarding data between the source and destination. This framework is particularly beneficial in scenarios where direct communication is hindered by distance, obstacles, or adverse channel conditions. The relay nodes employ one of two primary signal processing protocols: Amplify and Forward (AF) or Decode and Forward (DF) [3].

The AF protocol involves the relay node amplifying the received signal and retransmitting it without altering its structure. Although this approach is simple and computationally efficient, it also amplifies any noise present in the signal. Conversely, the DF protocol requires the relay node to decode the received signal, re-encode it, and then forward it to the destination. Although computationally more intensive, this method improves signal quality by eliminating noise during the decoding process. The choice of protocol depends on the specific requirements and constraints of the network.

A key feature of cooperative communication networks is their ability to connect relay nodes to multiple users through advanced multiplexing techniques. These techniques can be realized in the time-frequency domain or the power domain. Power domain non-orthogonal multiple access (NOMA) [4], [5] has gained significant traction in recent years due to its superior spectral efficiency [6]. Unlike traditional orthogonal multiple access (OMA), which assigns separate resources to individual users, NOMA allows multiple users to share the same resources by differentiating them based on power levels [7]. Users with weaker channel conditions receive higher power allocations to ensure equitable access and reliability.

By implementing proper power allocation strategies in power domain NOMA, cooperative communication networks [8], [9] can achieve greater efficiency in transmitting signals from multiple users to a central node. This approach not only maximizes resource utilization but also enhances network reliability, making it an attractive solution for modern wireless systems [10].

However, the integration of power domain NOMA [11], [12] in cooperative communication networks introduces challenges that require careful consideration. At the central node, multiple signals often converge from various relay nodes, as well as nearby devices or sensors. This convergence can lead to co-channel Interference (CCI) or Inter-Channel Interference, which significantly impacts the network's performance [13]. CCI reduces the Signal-to-Interference-plus-Noise Ratio (SINR), a critical metric that determines the quality of the received signal. A low SINR can hinder the system's ability to achieve the desired throughput, thereby compromising the

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data rate targets of contemporary wireless communication standards.

Addressing the issue of CCI is a major focus for researchers and engineers working to optimize the performance of cooperative communication networks [14]. Effective interference mitigation strategies are essential for maintaining high SINR levels and ensuring reliable communication. Furthermore, these strategies must account for the dynamic and heterogeneous nature of modern networks, which often include a mix of devices, sensors, and relay nodes with varying capabilities and requirements.

Another important factor influencing the performance of cooperative communication networks is the impact of channel conditions, particularly in environments characterized by Rayleigh fading [15]. Rayleigh fading occurs due to multipath propagation, where the transmitted signal reaches the receiver through multiple paths with varying delays and attenuations. This phenomenon, common in urban and densely populated areas, results in rapid fluctuations in signal amplitude, posing significant challenges for reliable communication.

Designing robust communication protocols that can mitigate the effects of Rayleigh fading is crucial for ensuring consistent performance in real-world scenarios. These protocols must be capable of adapting to changing channel conditions, optimizing resource allocation, and maintaining high SINR levels.

To address these challenges, this study investigates the interplay between cooperative communication and power domain NOMA under realistic conditions, including the presence of Rayleigh fading and CCI. The analysis is based on a system model that incorporates key components of contemporary communication networks, such as IoT gateways, relay nodes, and devices.

IoT gateways play a vital role in aggregating data from numerous devices and forwarding it to a central node for processing. Relay nodes, strategically positioned within the network, extend coverage and enhance the quality of service for edge devices. These components form the backbone of modern communication networks, enabling efficient data transmission and supporting a wide range of applications.

The study focuses on evaluating key performance metrics, such as SINR and Signal-to-Noise Ratio (SNR), for various signal transmissions within the system. SINR measures the quality of a received signal in the presence of interference and noise, serving as a critical indicator of network performance. SNR, on the other hand, quantifies the strength of the signal relative to the noise level, providing insights into transmission reliability.

By analyzing these metrics across different network configurations and channel conditions, the study identifies strategies for enhancing network performance and optimizing resource allocation. These strategies include advanced power allocation schemes, interference mitigation techniques, and adaptive communication protocols that account for the dynamic nature of modern networks.

The integration of cooperative communication and power domain NOMA offers significant potential for next-generation wireless communication systems. This combination addresses the challenges posed by the exponential growth of IoT devices, high-bandwidth applications, and the increasing demand for reliable and efficient communication. By leveraging the strengths of both approaches, cooperative communication networks can achieve superior spectral efficiency, enhanced coverage, and improved reliability.

However, realizing the full potential of this integration requires overcoming several technical challenges. These include addressing the issues of CCI, mitigating the effects of Rayleigh fading, and ensuring robust performance under varying network conditions. This study provides valuable insights into these challenges and proposes solutions that contribute to the development of advanced communication systems.

In conclusion, cooperative communication networks, when combined with power domain NOMA, represent a promising solution to the challenges of modern wireless communication. By utilizing relay nodes, advanced multiplexing techniques, and effective resource allocation strategies, these networks can achieve remarkable improvements in spectral efficiency, reliability, and coverage. Despite the challenges posed by interference, fading, and dynamic network conditions, the insights gained from this study pave the way for the design of robust and scalable network architectures that meet the demands of a rapidly evolving digital landscape.

II. System Model and Signal Model

A. System Model

The system model considered for this work, is given in Figure 1. It consists of two-way and half-duplex system, where 2 devices, i.e, device$_I$ and device$_{II}$; communicate through an IoT gateway. Furthermore the device$_I$ receive signals from both device$_A$ and device$_B$ and device$_{II}$ receives signals from both device$_C$ and device$_D$. Furthermore, it is assumed that the channel between devices and IoT gateway experience Rayleigh fading. The channel conditions are considered to be fixed over the transmission. The effect of CCI is considered at the IoT gateway for more practicality. Channel gains between device$_k$ $\rightarrow$ device$_I$ $(k \in A, B)$ are h_1 and h_2, device$_l$ $\rightarrow$ device$_{II}$ $(l \in C, D)$ are h_3 and h_4 and device$_m$ $\rightarrow$ IoT gateway $(m \in I, II)$ are h_I and h_I and h_{II}. The link coefficient between CCI and IoT gateway is considered as β_c. The devices are considered to be at different distances from each other.

B. Signal Model and SINR/SNR Analysis

1) Signal Model: Received signal from A and B at I is expressed as,

$$y_k = \frac{\sqrt{P_1} h_1 x_1}{\sqrt{d_1^{\nu}}} + \frac{\sqrt{P_2} h_2 x_2}{\sqrt{d_2^{\nu}}} + n, \ \ (k \in 1, 2) \tag{1}$$

where P_1 and P_2 is used to indicate the transmit power for transmission of signal from devices A and B respectively. x_1 and x_2 are the transmitted signal from A and B respectively. d_1 and d_2 are the distances of A and B from I. n is the additive white gaussian noise (AWGN).

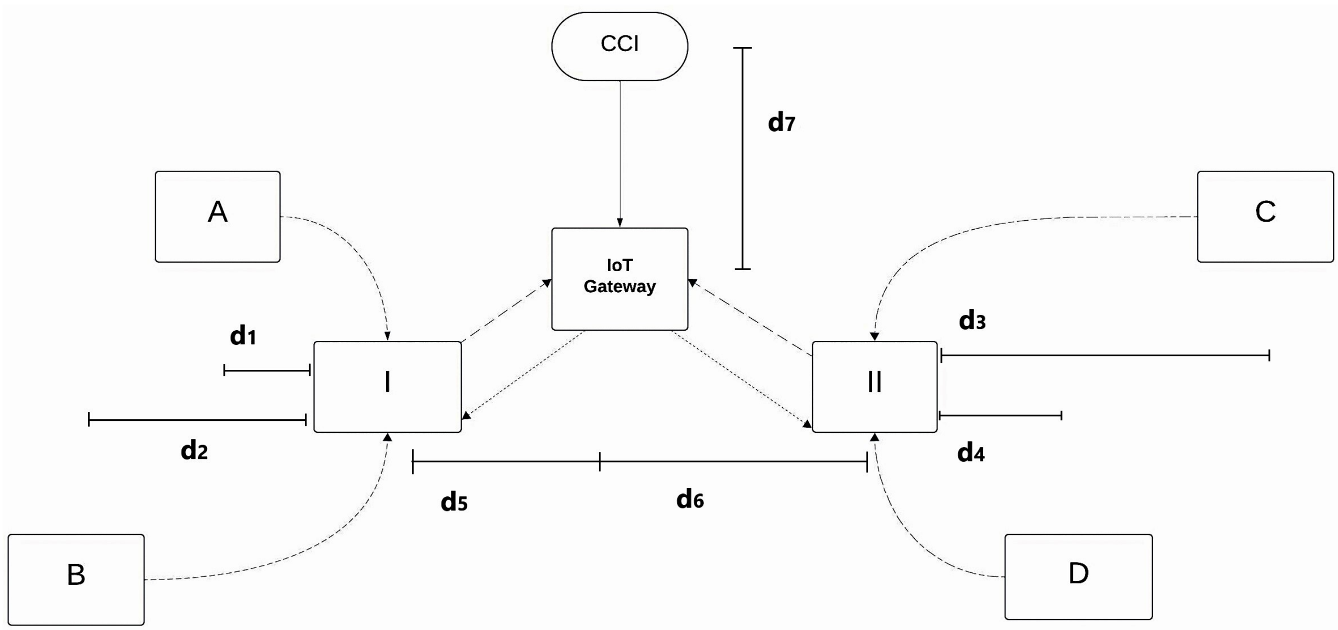

Fig. 1: System Model

Received signal from C and D at II is expressed as,

$$y_k = \frac{\sqrt{P_3} h_3 x_3}{\sqrt{d_3^{\nu}}} + \frac{\sqrt{P_4} h_4 x_4}{\sqrt{d_4^{\nu}}} + n, \ \ (k \in 3, 4) \tag{2}$$

where P_3 and P_4 is used to indicate the transmit power for transmission of signal from devices C and D respectively. x_3 and x_4 are the transmitted signal from A and B respectively. d_3 and d_4 are the distances of C and D from II. n is the additive white gaussian noise (AWGN).

The total signal received at IoT gateway due to A, B, C, D and the interference is expressed as,

$$\begin{aligned} y = & \frac{\sqrt{P_I P_1}}{\sqrt{(d_5 d_1)^{\nu}}} |h_I h_1| x_1 + \frac{\sqrt{P_I P_2}}{\sqrt{(d_5 d_2)^{\nu}}} |h_I h_2| x_2 \\ & + \frac{\sqrt{P_{II} P_3}}{\sqrt{(d_6 d_3)^{\nu}}} |h_{II} h_3| x_3 + \frac{\sqrt{P_{II} P_4}}{\sqrt{(d_6 d_4)^{\nu}}} |h_{II} h_4| x_4 \\ & + \frac{\sqrt{P_c}}{\sqrt{d_7^{\nu}}} |\beta_c| x_C \end{aligned} \tag{3}$$

where P_I, P_{II} and P_c is used to indicate the transmit power for transmission of signal from nodes I, II and CCI respectively to IoT gateway. x_c is the interference signal from the CCI. d_5, d_6 and d_7 are the distances of I, II and CCI from the IoT gateway. n is the additive white gaussian noise (AWGN).

2) SINR/SNR Analysis: SINR at I due to A is expressed as,

$$\text{SINR}_A = \frac{h_1^2 P_1}{d_1^{\nu} \big(\frac{h_2^2 P_2}{d_2^{\nu}} + \sigma^2 \big)} \tag{4}$$

SINR at I due to B is expressed as,

$$\text{SINR}_B = \frac{h_2^2 P_2}{d_2^{\nu} \big(\frac{h_1^2 P_1}{d_1^{\nu}} + \sigma^2 \big)} \tag{5}$$

SINR at II due to C is expressed as,

$$\text{SINR}_C = \frac{h_3^2 P_3}{d_3^{\nu} \big(\frac{h_4^2 P_4}{d_4^{\nu}} + \sigma^2 \big)} \tag{6}$$

SINR at II due to D is expressed as,

$$\text{SINR}_D = \frac{h_4^2 P_4}{d_4^{\nu} \big(\frac{h_3^2 P_3}{d_3^{\nu}} + \sigma^2 \big)} \tag{7}$$

SINR at IoT gateway due to I is expressed as,

$$\text{SINR}_I = \frac{\frac{(h_I^2 h_1^2)(P_I P_1)}{(d_5 d_1)^{\nu}} + \frac{(h_I^2 h_2^2)(P_I P_2)}{(d_5 d_2)^{\nu}}}{\frac{(h_{II}^2 h_3^2)(P_{II} P_3)}{(d_5 d_3)^{\nu}} + \frac{(h_{II}^2 h_4^2)(P_{II} P_4)}{(d_5 d_4)^{\nu}} + \frac{P_C \beta^2}{d_7^{\nu}} + \sigma^2} \tag{8}$$

SINR at IoT gateway due to II is expressed as,

$$\text{SINR}_{II} = \frac{\frac{(h_{II}^2 h_3^2)(P_{II} P_3)}{(d_6 d_3)^{\nu}} + \frac{(h_{II}^2 h_4^2)(P_{II} P_4)}{(d_6 d_4)^{\nu}}}{\frac{P_C \beta^2}{d_7^{\nu}} + \sigma^2} \tag{9}$$

SNR at I due to IoT gateway is expressed as,

$$\text{SNR}_I = \frac{\frac{(P_{II} P_3)(h_{II} h_3)^2}{(d_6 d_3)^{\nu}} + \frac{(P_{II} P_4)(h_{II} h_4)^2}{(d_6 d_4)^{\nu}}}{\sigma^2} \tag{10}$$

SNR at II due to IoT gateway is expressed as,

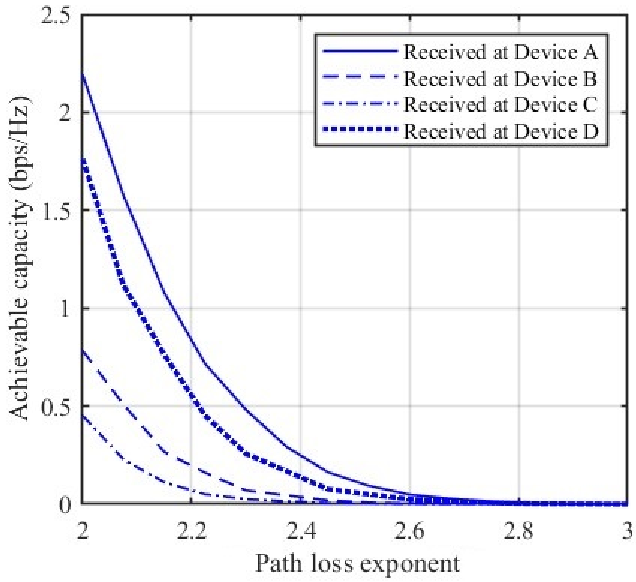

Fig. 2: Achievable Capacity vs ν

$$\text{SNR}_{II} = \frac{\frac{(P_I P_1)(h_I h_1)^2}{(d_5 d_1)^{\nu}} + \frac{(P_I P_2)(h_I h_2)^2}{(d_5 d_2)^{\nu}}}{\sigma^2} \tag{11}$$

III. Numerical Results

In this section, we present the results to validate the analytical results obtained in the last section. The principle behind the results is Shannon-Hartley capacity theorem expressed as,

$$C = BW \times \left(1 + \log_2^{SNR}\right) \tag{12}$$

where C indicates channel capacity, BW symbolizes Bandwidth and SNR is Signal-to-noise-ratio.

Fig 2. shows the variation of the achievable rate versus the path loss exponent (ν) in the 5G communication architecture in the various devices considered in the system. As shown in the figure, at lower values of path loss exponent the achievable rate at the devices is high. The closer the device, the lesser the effect of path loss exponent on it and this results in higher information rate at the nearer nodes. With an increase in the value of ν, the achievable rate gradually decreases and this leads to loss of information.

Fig 3. shows the variation of achievable rate versus transmitted power. From the figure, it is clear that the minimum transmit power requirement for the transmission of the signal is 15 dBm. The achievable rate increases with increasing transmit power.

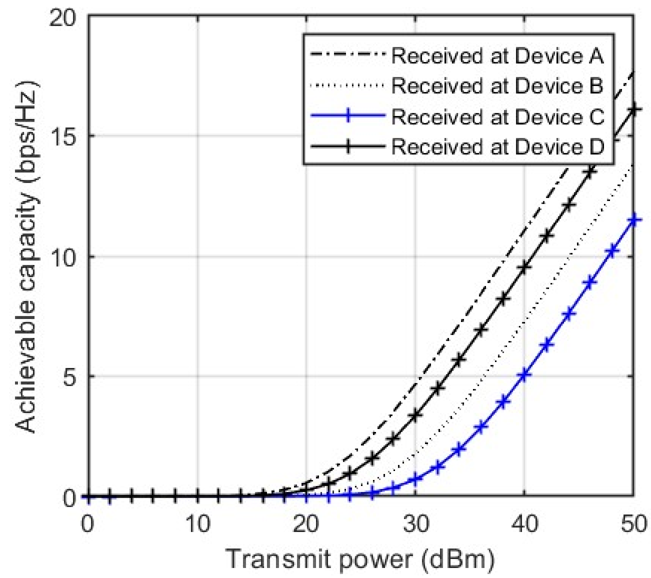

Fig. 3: Achievable Capacity vs Transmit Power

TABLE I: Parameter Settings

Parameter	Value
ν	0.8
d_1	10 m
d_2	16 m
d_3	14 m
d_4	8 m
d_5	8 m
d_6	12 m
d_7	14 m
BW	10^8

IV. Conclusion

In this work, we considered and demonstrated the use of NOMA in transmission of signal from four devices at variable distances from two different nodes which are also separated by a certain distance. Since the four devices involved in transmission of signals, during uplink NOMA, to two nodes each, the SINR due to the transmission is carefully formulated. The IoT gateway also receives signal from both nodes and interference from the CCI node. During downlink NOMA, the IoT gateway transmits signals to both the nodes for which SINR is carefully formulated. The analysis shows the effect of CCI in NOMA scheme and how the throughput is affected by the different distances at which the nodes are placed.

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