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Original Article

Performance of Cooperative Relaying Aided mMTC System With Interference Temperature Constraints

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Abstract - *Fifth Generation (5G) and beyond communication systems are envisaged to handle reliable connections, endorsing the multiple connectivity use case scenarios. Massive machine-type communication (mMTC), one of the salient features of 5G, provides reliability among the various users of such networks. Integrating cooperative communication with mMTC enables reliable communication by providing enhanced diversity gain and extending network coverage to multiple users. Moreover, interference associated with the users due to the utilization of device-to-device communication, cognitive radio systems, etc., causes inevitable degradation to the system's performance. The effect of such constraints must be considered to examine the system's performance thoroughly. In this paper, we showed the error rate performance of the cooperative relaying Decode-and-Forward (DF) and Selective Decode-and-Forward (Selective DF) protocols with the efficacy of interference temperature constraints. Also, Monte Carlo simulations are shown for distinct interfering powers over such a cooperative relaying scheme.*

Keywords - *Massive Machine-Type Communication (mMTC), Device-to-Device (D2D), Cognitive Radio (CR), Cooperative Relaying Scheme, Interference Temperature Constraints (ITC), Sustainable Cities and Communities.*

1. Introduction

Fifth-generation and beyond wireless communication systems, referred to as 5.5G, aim to provide 10Gbps speed and connect 10 million high-speed devices per square kilometer with better Quality of Service (QoS) [1]. Further, cooperative communication is a promising technique for long-haul communication, allowing nodes or User Equipment (UE) to transfer information in Massive Machine-Type Communication (mMTC) scenarios of future communication [2, 3]. Also, cooperative relaying exploits the wireless channel's broadcast nature, forming a virtual Multiple-Input Multiple-Output (MIMO) system and increasing diversity at the destination node [4]. It results in an improvement of the system's reliability, network connectivity, capacity, and diversity gain. Such a technique has potential for applications in ad-hoc, sensor, and cellular networks [5].

The cooperative relaying scheme connects Intermediate Nodes (relay) via independent links between the Base Station (BS) and the destination/UE. The received signal at the relay node from the BS is processed and re-transmitted to the destination node. Based on the signal processing applied at the relay, different relaying schemes are used, such as Amplify-and-Forward (AF), Decode-and-Forward (DF), selective DF, etc. [6]. AF relaying has a low decoding complexity but suffers from high noise amplification. The signal received at the relay in DF is decoded before being forwarded to the UE, and the signal, regardless of the decoded information's correctness, results in error propagation [7]. On the other hand, selective DF relaying sends the received signal from the relay to the UE only once proper decoding has occurred at the relay. Additionally, it improves system performance by facilitating direct communication between the UE and the BS. The destination receives the signal via both direct and relayed paths in this relaying. The received copies of the data are merged and decoded using the maximal-ratio combining technique, which maximizes the overall Signal-to-Noise Ratio (SNR) at the UE's [8]. Further, the benefits of diversity gain and increased network coverage are provided using such relayed links [9].

Moreover, wireless communication has rapidly expanded over the last decades, and UE has increased exponentially. The limited radio spectrum and increased network users bring a challenge of crowded channels [10]. It causes congested traffic to one BS, degrading the QoS and system capacity. Device-to-Device (D2D) communication allows users to connect without involving the core network parts or BS [11]. It has the primary benefit of offloading the BS as data traffic is transmitted directly between devices. Cognitive Radio (CR) systems consist of Primary Users (PUs) and Secondary Users (SUs). If PU interference is not very disruptive, users broadcast throughout the primary spectrum bands [12].

Hence, they improve the performance of cellular networks in terms of transmission delay, throughput, and power consumption. However, it can cause severe degradation of the performance of primary cellular users by causing interference due to spectrum sharing. Hence, it is crucial to analyze the system's performance of cellular users with the impact of impairment from interference-causing systems such as D2D and CR networks.

1.1. Related Works

The author in [13] shows the pricing framework for the BS and cellular users to manage cross-tier interference from D2D users. In [14], the author showed a dual-hop Full-Duplex (FD) relayed D2D uplink transmission and presented the Outage Probability (OP) of the D2D under the aggregate power constraint of the relay and the D2D transmitter. In [15], the author investigates the cooperative FD-D2D communication underlaying a cellular network, where the cellular user assists the D2D communication by acting as a full-duplex relay.

The joint OP and achievable rate region is derived to characterize the system's performance. Using a cooperative D2D communication system, the author of [16] helps users of densified cellular networks enhance transmission quality by acting as relays for D2D transmitters. The suggested solution gives D2D couples access to the spectrum while improving the efficiency of cellular users who cannot satisfy their rate needs. Moreover, authors in [13, 17, 18] presented the performance of the D2D network, cooperative communication, and MIMO system with interference management and constraints, respectively.

Recent advances have extended cooperative relaying and interference management research into 5G and 6G contexts. Sarma et al. [19] analyzed Decode-and-Forward (DF) relay-assisted D2D communication in mmWave 5G systems and quantified outage and energy performance, but did not address interference temperature constraints. Collectively, these studies expand upon cooperative and intelligent interference-management paradigms but leave open the detailed BER characterization of DF and SDF schemes under concurrent D2D and CR interference with explicit ITC consideration—precisely the focus of this work.

1.2. Motivation and Contribution

The prior literature reveals the performance of the D2D network with cooperative communication and MIMO system over the Interference Temperature Constraints (ITC) using OP and sum rate as performance metrics. Further, the literature survey reveals that no pertinent research shows the error rate performance of cooperative relaying DF and selective DF protocols incorporating the efficacy of interference, considering the D2D and CR-aided networks *(application-oriented research problem)* as mentioned above. Moreover, based on this rationale, the significant contributions of the paper are summarized as follows:

Table 1. Summary of main symbols used in the paper

Symbols	Descriptions
Di	Cellular PUs ∀ i ∈ {1, 2, 3, 4}
Dj	D2D pair ∀ j ∈ {5, 6}
Dk	Cognitive SUs ∀ k ∈ {7, 8}
z	Channel gain (Rayleigh faded)
w	Additive white Gaussian noise (AWGN)
x	Transmitted modulated data
$\hat{x}$	Decoded data at the intermediate user
Pl	Transmitted power at BS and relayed to users (l ∈ {1, 2, 3})
P_I	Interference power

The average Bit Error Rate (BER) performance of the cooperative relaying, including DF and selective DF protocols associated with interference from D2D and CR networks, is presented. Furthermore, the performance of the considered system is shown with the efficacy of ITC from nearby devices/UEs in terms of error floor due to the Signal-to-Interference Plus Noise Ratio (SINR). It is observed that the error floor increases with a decrease in the intended user's SINR, deteriorating the system's performance.

Moreover, the comparative performance of both aforesaid cooperative protocols is demonstrated. Due to the additional direct link, selective DF relaying resembles a virtual MIMO system, improving the diversity gain and performing better than the DF relaying system.

Furthermore, the rest of the paper* is organized as follows: Section II presents the system model of the considered system, incorporating the effectiveness of the ITC on cooperative relaying systems owing to D2D and CR networks. Section III shows the numerical results and their enlightening discussion, and the paper is concluded in Section IV.

*The symbol notations used in this paper are tabulated in Table I

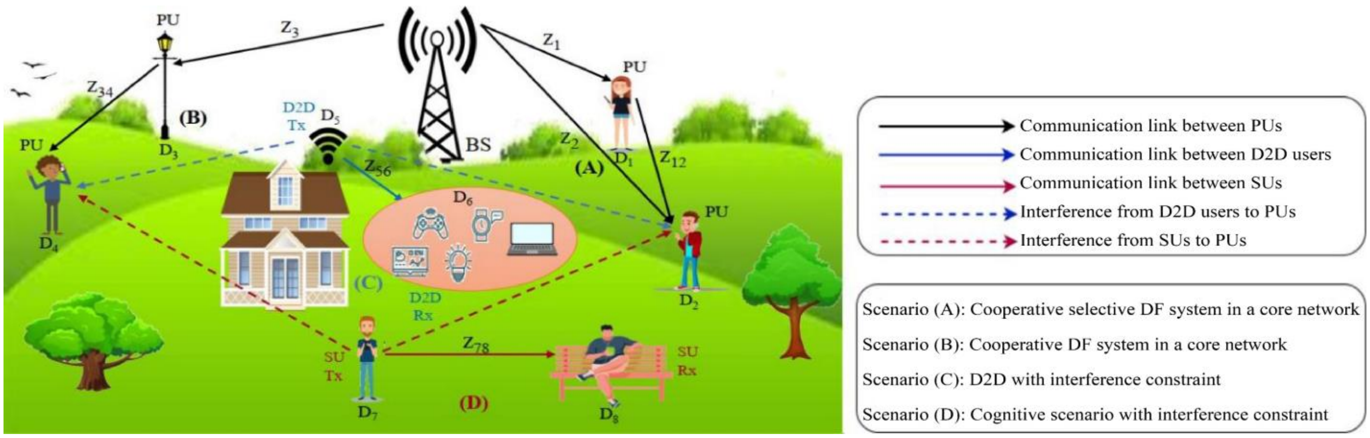

Fig. 1 An Application-Oriented Illustration of mMTC Scenario with Interference Links for Various Use Cases: (A) Cooperative Relaying DF, (B) Cooperative Relaying Selective DF Protocols, (C) D2D Communication, and (D) Cognitive Radio.

2. System Model

A scenario having a single cell, a BS, cellular PUs, one D2D user pair, and cognitive SUs is considered, as shown in Figure 1. Each node is presumed to have a single antenna. Also, all the users are assumed to be stationary or slow-moving with substantially low Doppler spread. Note that the cellular users operating in cooperative relaying mode are named D_1, D_2, D_3, and D_4, the users working in D2D pair are labelled D_5 and D_6, and cognitive users are denoted as D_7 and D_8. Also, the users D_1 and D_2 are assumed to be communicated with the BS in a selective DF scenario, and the users D_3 and D_4 are communicated with the BS using a DF scenario.

The channel gains corresponding to links between the users are denoted by z_1, z_2, z_3, z_{12}, and z_{34}, as referred in Figure 1. These channel gains are assumed to be independent and identically distributed zero-mean complex Gaussian random variables $\sim CN(0,\sigma_h^2)$ whose amplitude pursues the *Rayleigh* fading model.

2.1. Cooperative Selective DF Scenario

The end-to-end transmission between the BS and the end users happens in two phases in this cooperative relaying protocol *(refer to system A in Figure. 1)*. In the first phase, the BS transmits the signal to users D_1 (relayed user) and D_2 (end user influenced by the interference); thus, the received signal at the intended users is given as

$$y_{BS\rightarrow D1} = z_1\sqrt{P_1}x + w_1 \quad (1)$$

$$y_{BS\rightarrow D2} = z_2\sqrt{P_1 x} + \sqrt{P_I x} + w_2 \quad (2)$$

Where x is the broadcasted transmitting modulated information from the BS to the UEs, P_1 is the transmitted power to users D_1 and D_2 from the BS. P_I is the interference power coming from user D_5 to user D_2. w_1 and w_2 are the Additive White Gaussian Noise (AWGN) $\sim CN(0, N_0)$ associated with D_1 and D_2 users, respectively.

In the second phase, the intermediate user D_1 uses the selective DF protocol, which decodes the signal and re-transmits it if only the correct information is decoded.

Further, if the signal is correctly decoded at the user D_1, the multiple copies of the received signal are combined and decoded using the maximum-ratio combiner at user D_2. The received signal at D_2 user is given as

$$y_{BS\rightarrow D2} = z_2\sqrt{P_1}x + \sqrt{P_I} + w_2 \quad (3)$$

$$y_{D1\rightarrow D2} = z_{12}\sqrt{P_2}x + \sqrt{P_I} + w_{12} \quad (4)$$

Where P_2 is the transmitted power from the intermediate user D_1, and w_{12} is the AWGN$\sim CN(0, N_0)$ associated with user D_2.

Furthermore, if the received signal at D_1 is decoded erroneously, the received signal at D_2

The user is given as

$$y_{D2} = z_2\sqrt{P_1}x + \sqrt{P_I} + w_2 \quad (5)$$

Where the symbols used in (5) have general notations.

2.2. Cooperative DF scenario

The end-to-end transmission between the BS and the end users (D_3 and D_4) happens in two stages in this cooperative DF scenario *(refer to system B in Figure 1)*. In the first stage, the user D_3 receives the signal transmitted from the BS, and the received signal at D_3 is given as

$$y_{BS\rightarrow D3} = z_3\sqrt{P_1}x + w_3 \quad (6)$$

Furthermore, in the second stage, the received signal y_{D3} at the intermediate user D_3 is decoded and re-transmitted to the user D_4; thus, the received signal at user D_4 is given as

$$y_{BS\rightarrow D4} = z_{34}\sqrt{P_3} + \sqrt{P_I}\hat{x} + w_{34} \quad (7)$$

Where P_3 is the power transmitted from user D_3 to user D_4. $\hat{x}$ is the decoded information at D_3. Note that the remaining symbols have general notations.

3. Results and Discussion

This section presents the simulation results and discusses cooperative relaying, DF, and selective DF protocols over the *Rayleigh* fading channels. For simulations, we considered the Binary Phase-Shift Keying (BPSK) modulation scheme for data transmission. Also, the transmitted powers from the BS and the relayed node, i.e., users D_1 and D_3, are assumed to be equal.

Furthermore, Monte Carlo simulations of the average BER are demonstrated for various values of the interfering power of nearby devices and cooperative relaying protocols.

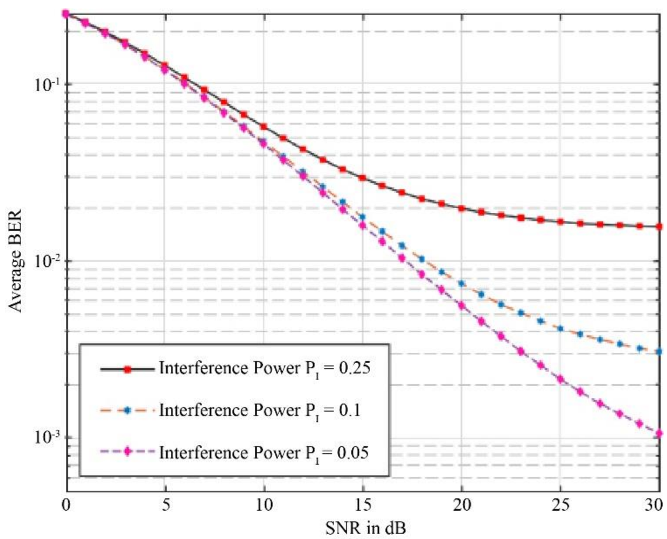

Fig. 2 Average BER Performance of Cooperative DF Relaying Scheme with Interfering Power P_I = {0.05, 0.1, 0.25}

Figure 2 presents the average BER performance of the dual-hop cooperative DF relaying system. For simulations, the following fixed interference power values (in linear scale) of other nearby devices are considered, i.e., {0.05, 0.1, 0.25}. It is observed that increasing the interference power values from 0.05 to 0.25 decreases the SINR. It occurs due to the less dominant interference-to-noise power compared to the signal power from the D2D and CR networks, resulting in degradation of the system's performance and justifying the result.

Figure 3 demonstrates the average BER performance of a cooperative selective DF system with interfering power values {0.01, 0.1, 0.5}. It is observed that the error floor increases as the interference values increase from 0.01 to 0.5 due to the dominance term, rather than

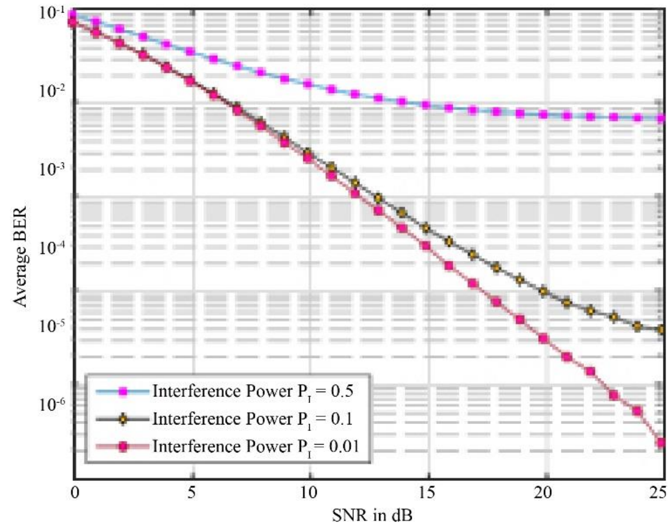

Fig. 3 Average BER Performance of Cooperative Selective DF Relaying Scheme with Various Interfering Powers, P_I = {0.01, 0.1, 0.5}

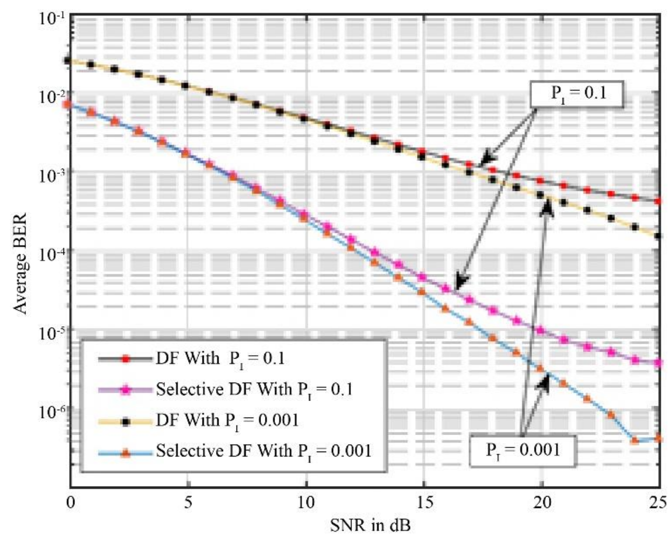

Fig. 4 Average BER Performance Comparison of Cooperative DF and Selective DF Scheme with Various Interfering Power Values

The transmitted power, and, hence, the performance of such a system, degrades. However, the efficacy of interference caused by other devices is compensated for by the availability of multiple links due to the virtual formation of MIMO in a selective DF cooperative relaying scheme. Therefore, it achieves an error floor of approximately 10^-6 at a 25 dB transmit SNR.

Figure 4 shows the average BER comparison of cooperative DF and selective DF relaying protocols for different interfering powers, i.e., {0.1, 0.001}. It causes degradation in the system's performance, as the same trend is observed in prior results and validated. In addition to the interference, the selective DF outperforms the DF system. An additional link in the selective DF scenario resembles a virtual

MIMO system, introduces diversity, and enhances the system's performance, resulting in a 15 dB gain at an error floor of 10^{-3}.

4. Conclusion

This paper presents a single-cell cooperative DF and selective DF protocols-aided system, including D2D and CR networks as interfering devices. The average BER performance for such scenarios with the ITC is from D2D users and cognitive SUs to primary cellular users. The performance of end users in both cooperative relaying systems degrades due to interference from other nearby devices. In addition, Monte Carlo simulations also show the outperformance of the selective DF over the DF scheme due to diversity gain. Increasing the links in Selective DF over DF achieves a gain of 15 dB at an error floor of 10^-3, thereby suppressing the effect of interference with virtual MIMO.

References

[1] Pengfei Sun, *Evolution to 5.5G and 6G and Key Applications*, Unleashing the Power of 5GtoB in Industries, Springer, pp. 281-287, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] Qians Li et al., "Cooperative Communications for Wireless Networks: Techniques and Applications in LTE-Advanced Systems," *IEEE Wireless Communications*, vol. 19, no. 2, pp. 22-29, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[3] Sandhya Soni et al., "Link-Level Assessment of NOMA Aided Multi-hop DECT-2020 New Radio for mMTC Applications," *2023 International Conference on Information Networking (ICOIN*), Bangkok, Thailand, pp. 478-482, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[4] Salama Ikki, and Mohamed H. Ahmed, "Performance Analysis of Cooperative Diversity Wireless Networks Over Nakagami-m Fading Channel," *IEEE Communications Letters*, vol. 11, no. 4, pp. 334-336, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[5] Himanshu Katiyar, Ashutosh Rastogi, and Rupali Agarwal, "Cooperative Communication: A Review," *IETE Technical Review*, vol. 28, no. 5, pp. 409-417, 2011. [Google Scholar] [Publisher Link]

[6] K.J. Ray Liu et al., *Cooperative Communications and Networking*, Cambridge University Press, pp. 1-13, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[7] A. Goldsmith, *Wireless Communications*, Cambridge University Press, pp. 1-664, 2005. [Google Scholar] [Publisher Link]

[8] T. Eng, Ning Kong, and L.B. Milstein, "Comparison of Diversity Combining Techniques for Rayleigh-Fading Channels," *IEEE Transactions on Communications*, vol. 44, no. 9, pp. 1117-1129, 1996. [CrossRef] [Google Scholar] [Publisher Link]

[9] Neeraj Varshney, Amalladinne Vamsi Krishna, and Aditya K. Jagannatham, "Selective DF Protocol for MIMO STBC Based Single/Multiple Relay Cooperative Communication: End-to-End Performance and Optimal Power Allocation," *IEEE Transactions on Communications*, vol. 63, no. 7, pp. 2458-2474, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[10] Kifah Hussein Alzoubi, Mardeni Bin Roslee, and Mohamed Ahmed A. Elgamati, "Interference Management of D2D Communication in 5G Cellular Network," *2019 Symposium on Future Telecommunication Technologies (SOFTT)*, Kuala Lumpur, Malaysia, pp. 1-7, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Yanli Xu, Feng Liu, and Ping Wu, "Interference Management for D2D Communications in Heterogeneous Cellular Networks," *Pervasive and Mobile Computing*, vol. 51, pp. 138-149, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Sultangali Arzykulov et al., "On the Capacity of Wireless Powered Cognitive Relay Network with Interference Alignment," *GLOBECOM 2017 - 2017 IEEE Global Communications Conference*, Singapore, pp. 1-6, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[13] Yuan Liu, Rui Wang, and Zhu Han, "Interference-Constrained Pricing for D2D Networks," *IEEE Transactions on Wireless Communications*, vol. 16, no. 1, pp. 475-486, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[14] Shuping Dang, Gaojie Chen, and Justin P. Coon, "Outage Performance Analysis of Full-Duplex Relay-Assisted Device-to-Device Systems in Uplink Cellular Networks," *IEEE Transactions on Vehicular Technology*, *Technology*, vol. 66, no. 5, pp. 4506-4510, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[15] Guoling Liu et al., "Performance Analysis and Optimization of Cooperative Full-Duplex D2D Communication Underlaying Cellular Networks," *IEEE Transactions on Wireless Communications*, vol. 18, no. 11, pp. 5113-5127, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Yiling Yuan et al., "Two-Timescale Resource Allocation for Cooperative D2D Communication: A Matching Game Approach," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 1, pp. 543-557, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[17] Xiaowen Cao et al., "Cooperative Interference Management for Over-the-Air Computation Networks," *IEEE Transactions on Wireless Communications*, vol. 20, no. 4, pp. 2634-2651, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[18] Yang Yang et al., "Robust MIMO Cognitive Radio Systems Under Interference Temperature Constraints," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 11, pp. 2465-2482, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[19] Subhra Sankha Sarma, Ranjay Hazra, and Peter Han Joo Chong, "Performance Analysis of DF Relay-Assisted D2D Communication in a 5G mmWave Network," *Future Internet*, vol. 14, no. 4, pp. 1-16, 2022. [CrossRef] [Google Scholar] [Publisher Link]