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# A Survey on Cooperative Noma and Energy Harvesting Issues in Wireless Communication

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## Abstract

**Introduction**: Cooperative non-orthogonal multiple-access (C-NOMA) is an enhanced version of NOMA technology to overcome the limitations of wireless signal propagation due to obstacles.

**Objectives**: In this paper, a survey of the C-NOMA mechanism and energy harvesting protocols in the relay nodes of the C-NOMA is presented.

**Methods**: We perform the detailed analyses and discussions of two common power splitting- and time switching-based energy harvesting mechanisms, the applications and the challenges, of the C-NOMA networks based on the published works.

**Results**: We demonstrate the inheritance of C-NOMA based on NOMA to gain insight into enhancing the performance of wireless-powered communication networks. Furthermore, a detailed analysis of two common power splitting- and time switching-based energy harvesting mechanisms is also presented. In addition, the applications of C-NOMA are also discussed. Finally, the challenges, e.g., SIC and CSI, of the C-NOMA networks are analyzed.

**Conclusions**: Thus, this overview provides a background on C-NOMA for deeper investigations into this latest technology.

**Keywords**: NOMA, cooperative NOMA, energy harvesting, CSI, SIC, PSR, TSR.

## 1. Introduction

Non-orthogonal multiple access (NOMA) [1,2] has demonstrated its outperformed emerging benefits for next generation wireless communication networks [1-3]. A wide range of the applications of the NOMA can be categorized such as cellular networks, wireless sensor networks, internet of things (IoTs), cloud radio access network (CRANs), and heterogeneous cloud radio access network (HCRANs) [4-10]. Being different with orthogonal multiple access (OMA) [11], where the resource allocation for different users based on orthogonal mechanism in order to reduce multiple access interference (MAI), the NOMA exploits non-orthogonal features of subcarriers to support multi users in the same frequency/time/code resource at the same time. Thus, NOMA can contribute to the massive connectivity with diverse quality of service (QoS) constraints [1,2]. Additionally, NOMA also demonstrates superior advantages over OMA, e.g., low latency, significantly enhanced spectral efficiency and energy efficiency [1,12-14]. However, unlike NOMA, a single user in OMA mechanisms can only be served in each orthogonal resource block, resulting in ineffective spectrum use in these OMA-aided networks. Time division multiple access (TDMA) and orthogonal frequency division multiple access (OFDMA) are known as the common OMA techniques that have been deployed in previous generations of networks for many decades. NOMA utilizes superimposed coding (SC) [1,15,16] and successive interference cancellation (SIC) [1,15,16] as two main techniques to combine the users' signal to base station (BS) and decode the received signal at the users, respectively. These two techniques have appeared more than five decades ago [16]. The key type of NOMA that is utilized for NOMA mechanism is power domain, whereas the previous generations of the mobile communication networks have employed the time/frequency/code domain [1,11]. Therefore, one can realize that NOMA-based networks have been expected to boost the increased data traffic demand and the expected new services and functionalities compared to the fourth generation (4G) networks. For example, the

NOMA technology contributes to the massive connectivity of users, and devices to satisfy the demands of low latency, diverse service types, low-cost devices, and cloud-based architectural applications when the IoT and other 5G-aided networks have been developing more and more rapidly . The power-domain NOMA (PD-NOMA), along with SC and SIC, was discussed in [1] as a recent progress overview in the NOMA-aided 5G systems. In [17], an insight survey of the latest research, innovations, applications, and challenges of the NOMA technique was reported. Specifically, single-carrier NOMA such as PD-NOMA, cognitive-radio (CR) NOMA, and multi-carrier NOMA, and hybrid NOMA were presented. Some types of NOMA including multiple-input multiple-output (MIMO)-NOMA, user based cooperation NOMA as well as dedicated relay based employment were generalized as fundamental concepts. In [18], a discussion on code domain NOMA and PD-NOMA schemes, along with their benefits, challenges, and future findings for 5G networks, was also studied.

The cooperative non-orthogonal multiple access (C-NOMA) [19-22] mechanism is an enhanced version of NOMA that has been introduced to boost the coverage of sources and the performance of the system, in particular for users with weak channel conditions. In C-NOMA systems, the signal paths from transmitting sources to destinations usually exist as direct or indirect links [23-24]. The relays in C-NOMA networks assist in forwarding information from sources to destinations. Therefore, they can be single or multiple relays. To obtain optimal performance in C-NOMA systems, various strategies have been proposed to choose the best relays. When the signal comes to the relays, the relays deploy decode-and-forward (DF) [25,26] or amplify-and-forward (AF) protocols [27,28] to relaying the received information to the desired nodes. In [1], the combination of C-NOMA, MIMO, space-time coding, beam forming, and network coding as proven wireless communications techniques was also studied. In addition, various performance parameters of C-NOMA systems, e.g., optimum power allocation, perfect SC, and error-free SIC, good link adaptation, and appropriate user pairing, were also studied to achieve the optimal benefits. Besides, the challenges and opportunities in investigating NOMA on a larger scale for interested researchers, e.g., dynamic user pairing, the impacts of interference, resource allocation, and outage probability analysis, were introduced. The studies on the integration of C-NOMA, MIMO, CR, energy-efficient communications, and some technical challenges were discussed in [29-32].

Solving the energy-scarce issue of sensors in C-NOMA-based wireless communication networks, e.g., cellular networks, IoT networks, wireless sensor networks (WSNs), and big-scale networks such as CRAN, and HCRAN, is a key challenge for 5G and beyond. The energy harvesting process happens at relay nodes, where the harvested energy from radio frequency (RF) signal sources is charged into their batteries. The time-switching relaying (TSR) [33,34], power-switching relaying (PSR) [33,34], and hybrid relaying [35] protocols are commonly employed at the relay nodes for charging their batteries. Furthermore, a simultaneous wireless information and power transfer (SWIPT) [36] approach is also integrated with the C-NOMA-aided systems to boost their performance.

Motivated by the above mentioned works and filling the gaps in critical issues of C-NOMA, this paper discusses C-NOMA for uplink and downlink communications, energy harvesting and its protocols in relay-based C-NOMA in terms of PSR, TSR, and hybrid protocols, energy harvesting and information processing mechanisms, and reviews the performance and key features in C-NOMA networks based on SWIPT relays. Furthermore, we also summarize the advantages and limitations of C-NOMA over OMA technologies. Finally, the challenges, and future research trends of C-NOMA in the design of these models are offered as C-NOMA research directions.

## 2. Fundamentals of NOMA

NOMA, known as a multiple access technique, permits multiple users to utilize shared communication channels. This technique is at the heart of 5G communication networks. Unlike OMA, NOMA is built to share the same frequency/time/space/code resource with multiple users. Comparing to the four previous cellular network generations, the motivation of the

NOMA-based latest network generations, e.g., 5G and beyond, is to boost the user capacity and data rate, boost the spectral efficiency, and mitigate latency, and solve the limited energy of batteries in user equipment. Thus, the expectations of the NOMA can open several opportunities for the development of innovative products.

As mentioned in the introduction section, two key mechanisms that are employed in NOMA are SC and SIC. The SC technique is used for summing individual signals from users to BSs and is proposed in [16], while the SIC technique is used for decoding the received composite signals from BSs and is proposed in [16]. In the SC, the information of several users can be simultaneously sent to the BSs. In the SIC, the specifications of the received signal strength differences are exploited at the receivers. The principle of the SIC is the employment of the sequential decoding approach. This implies that the signal of the user with the highest power allocation level is first decoded, and the subtraction of this decoded signal and the superimposed signal is then performed to decode the next user's signal [1]. When performing SIC, the user treats the signals of other users as interference sources to achieve its own signal. Therefore, the order of each element in the superimposed signal is decoded from highest amplitude to lowest amplitude.

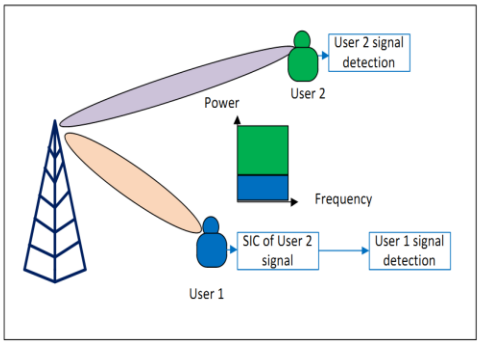


**Figure 1: Illustration of SIC process in a simple NOMA system**

The classification of NOMA consists of three groups, namely PD-NOMA, code domain NOMA, and hybrid NOMA [1,37-39]. Among them, the PD-NOMA has been investigated by several author groups [1,26-28]. The basic background of this scheme is the principle of fair power allocation for each user in the composite signal [1]. This means that the farther the user is, the higher the power level is allocated. This is because the far user has a weak channel condition, while the near user has a stronger channel condition.

Consider a NOMA-aided system model to clarify the PD-NOMA and SIC processes. This system model has one transmitting source, i.e., BS, and two users. In the model, the BS transmits the superimposed signals of two users, i.e., $x_1$ and $x_2$, respectively, where $x_1$ is for the near user and $x_2$ is for the far user. This model is illustrated in Fig.1.

The superimposed signal at the BS is represented by [1]

$$x_T = \sum_{i=1}^{2} \sqrt{P_i} x_i \tag{1}$$

where $P_i$ is the BS's power allocation to two users, respectively.

The received signal expression for each user is given by [1]

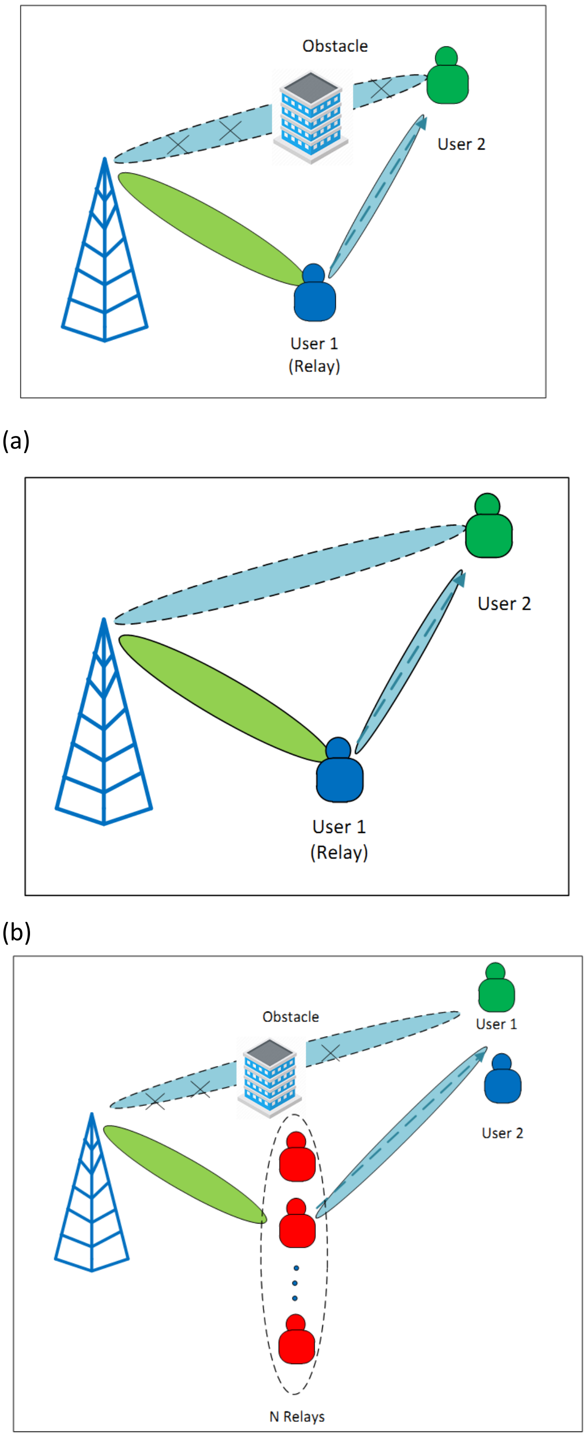
$$x_i = h_i x_T + n \tag{2}$$

Where $h_i$ $(i = \{1,2\})$ denotes the channel coefficients of the near and far users, respectively, $n$ represents for the additional white Gaussian noise (AWGN) .

To decode the received superimposed signals of users employing SIC technique, the far user with a weak channel condition first detects its own signal, while the near user with a strong channel condition exploits the SIC to cancel the far user's information and then decodes its own information.

## 3. Cooperative NOMA

C-NOMA is known as an enhanced version of NOMA to overcome the barriers to wireless signal propagation caused by obstacles, such as buildings and trees, or considerably weak received signal strength [23,26-29,40]. This technique is intended to enhance the reliability of information transmission from sources to users due to path loss, shadowing, and fading. These phenomena characterize channel impairments. In particular, the C-NOMA contributes by extending the coverage of the sources. In this type of NOMA, a transmitting source that needs to send its signal to a desired user but is not able to directly send it to this user selects one user/user group as a relay to help transfer the information from the source to the desired node. The chosen users exhibit a good channel condition. Therefore, the links from the source to the destination are indirect links. In some cases, there is also a direct communication link with weak signal strength from the source to the destination. The simplest model of C-NOMA networks consists of one BS as a source node, one user as a destination node, and another user as a relay node. The relay node plays the role of an assistance node. Fig. 2 illustrates C-NOMA systems with/without direct links and different relay numbers.



(a)

(b)

(c)

**Figure 2: Illustration of a C-NOMA system with (a) single relay and without direct link, (b) single relay and direct link, and (c) multiple relay and without direct link**

The relaying users [32,40], also known as relaying nodes, are classified into two main groups: AF relay groups and DF relay groups. For the first relay group, the relay first receives the signal from the transmitting node, i.e., source, amplifies it, and then forwards it to the desired receiving node, i.e., destination node. Specifically, each transmission block from the source to the destination is divided into two time slots (TSs): the first TS is utilized for broadcasting the superimposed signal of the source, and the second TS is dedicated for the relay, which amplifies the previous received signal by multiplying this signal with an amplifying gain and then broadcasts it to destination users while the source simultaneously remains silent. Therefore, the information -processed protocol of this relay type is known as an amplify-and-forward protocol [41,42]. On the contrary, although there are still two TSs in each transmission block of the remaining group, the first TS is dedicated for the source to broadcast the superimposed messages to all other nodes, and the second TS is utilized for the relay to decode the received signal by employing the SIC scheme and then forward the decoded message to the desired nodes [42,43]. However, the relay in FD mode-based C-NOMA simultaneously transmits and receives signals [44]. The summary of the classification of relay groups with different selection methods and links is illustrated in Fig. 3.

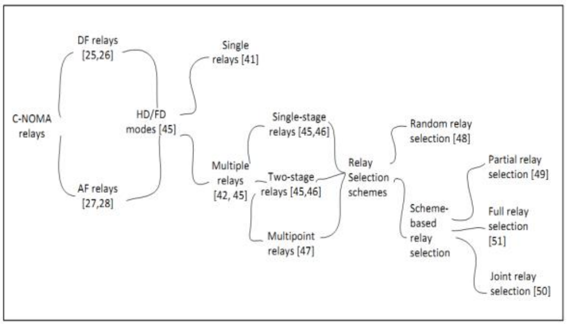


**Figure 3: Classification of C-NOMA relays**

## 4. Energy harvesting protocols in C-NOMA based networks

In this section, we discuss radio frequency (RF) based energy harvesting issues in C-NOMA. We first introduce the radio frequency (RF)-based energy harvesting mechanisms from the ambient environment. Then we present energy harvesting protocols such as PSR, TSR, and hybrid PSR/TSR. Besides, SWIPT mechanisms at the relaying node are briefly described in this section, including the AF, and DF protocols. Furthermore, SWIPT-aided uplink in C-NOMA is also introduced

### 4.1 A brief of energy harvesting

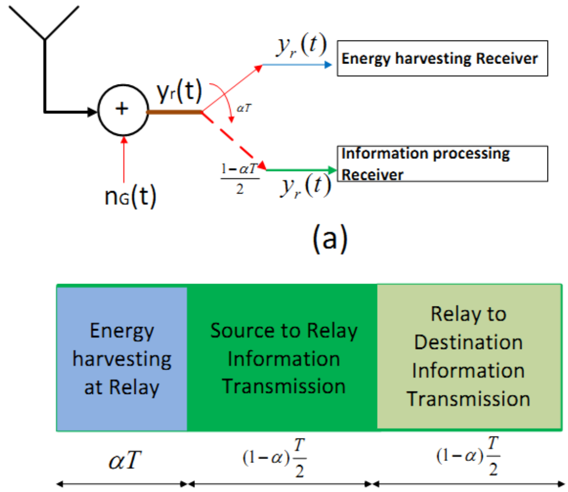
Energy harvesting is a critical problem in 5G and beyond networks. All mobile devices, smart devices, wireless sensors, etc. almost exclusively utilize batteries to maintain their operation. This power is limited in its use. Thus, the battery needs to be recharged, resulting in their operation being affected or interrupted. In order to solve this issue, one of the potential solutions to increase their lifetime is ambient RF source based energy harvesting. Energy harvesting can be based on near- and far-field wireless transmission [52]. Magnetic resonance coupling and inductive coupling are known as two near-field wireless transmission methods. The magnetic resonance coupling [52, 53] uses an evanescent-wave coupling mechanism to create the electrical energy conversion of two resonators, while the inductive coupling [52, 54] applies the electrical energy delivery mechanism between two resonant-tuned coils. These coupling methods can only be employed at small distances, such as some parts within transmitters/receivers. As a result, they are limited in power transfer distance and thus are not able to exploit mobile and remote replenishment/charging. On the contrary, the RF frequency, which spreads in the range of 3 kHz to 300 GHz, is exploited as a radio signal medium to convey electromagnetic radiation energy. This energy source is harvested using the RF energy harvester. This type is known as far-field wireless transmission [52]. This wireless energy transmission mechanism opens a potential research direction that simultaneously combines wireless power transmission and wireless communication based on the principle of carrying both information and energy in RF signals at the same time [55]. RF wireless energy transmission can be categorized into wireless energy transfer (WET), wireless-powered communication networks (WPCN), and SWIPT. RF-based WET is commonly applied in low-power devices, e.g., sensors, since the microwave energy is attenuated over distance. Thus, the WET can be applied to build power charging centers for wirelessly powered devices in NOMA-aided IoT/IoE networks, wireless sensor networks that serve environmental monitoring, and smart power grids. SWIPT is a mechanism in which wireless energy and information transfer occur simultaneously. The SWIPT mechanism has widely been studied for many types of channel models, such as the AWGN channel, the relay channel, the multi-antenna channel, cognitive radio channel, as well as the multi-carrier-enabled broadcast channel. In relaying node based NOMA networks, SWIPT is usually employed at the relaying nodes to harvest energy for its operation and information decoding. Compared with WET, SWIPT can help increase spectral efficiency. In contrast, in WPCN, the harvested energy of wireless devices is used for information transmission [56]. Compared to the SWIPT system, in the WPCN, an energy AP transmits the RF signals intended for the downlink WET. This energy is harvested by users and then transmitted as WIT signals to a data AP in the uplink. The WPCN utilizes wireless power transfer technology for broadcasting and harvesting energy. The WPCN is also equipped with full control over the transfer of its power. By tuning the waveforms, transmitting power, and transmitted time/frequency parameters, the WPCN system can support stable energy power when changing the service requirements and physical conditions [57]. In the WPCN, energy and information can be communicated in HD or FD. In WPCN, the energy harvesting can be modeled as linear or nonlinear [58]. The nonlinear model demonstrated an achievable and significant performance gain instead of the conventional linear EH model [58]. The WPCN can also be exploited in MIMO.

### 4.2 Time switching

In TSR protocol [33,34], each time block is divided into three parts: the first part is employed to harvest the energy from the BS, the second part is employed to process the received information from the BS to relay, and the third part is dedicated to forwarding the information from relay to destination. For this protocol, the block time fraction, i.e., α, is the main parameter and has an impact on the achievable throughput at the destination [59]

Furthermore, Fig. 4 plots the relay receiver's block with the PSR protocol. As shown in the figure, the received signal at the receiver, i.e., yr(t), which is sent from BS, suffers from the Gaussian noise, i.e., nG(t), caused by its receiving antenna , thus, yr(t) is the sum of nG(t) and the original received signal. Based on the time switching mechanism, the yr(t) is provided to the energy harvesting receiver during the first phase of the time block, i.e., αT; this signal is then provided to the information receiver during the remaining time, i.e., (1-α)T/2. The harvested energy at the relay node during αT is expressed by [60]

$$E_h = \frac{\eta P_s |h|^2}{d_1^m} \alpha T \qquad (3)$$



(a)

(b)

**Figure 4: Illustration of (a) the block diagram of the TS-based relay receiver, and (b) the TSR with key parameters**

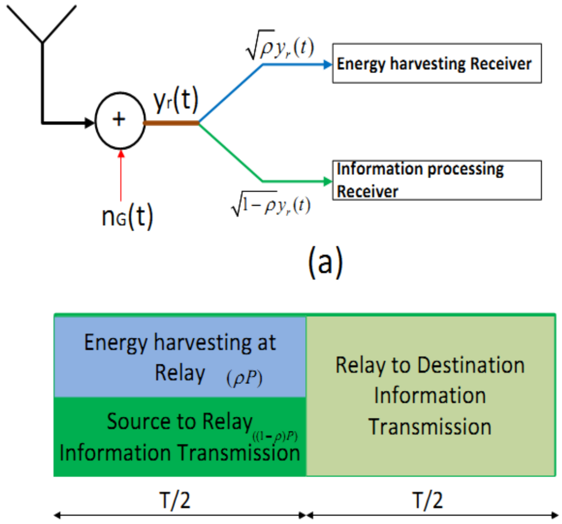
### 4.3 Power splitting

This section discusses a power splitting-based energy harvesting protocol, namely PSR [33,34]. As illustrated in Fig. 5, in the first half of the time block, relay first harvests energy from BS and then consumes a part of this energy to relay the information to the destination node in the remaining half of the time block. The main parameter in the PSR is the power fraction ρ. It directly contributes to the quantification of the relay node's harvested energy. Furthermore, the ρ also has effects on the throughput of the destination node [59].

Fig.5 shows the block diagram of the PSR protocol in the relay receiver. RF signals received from the transmitting source go through the power splitter, then split into ρ/( ρ-1) proportion. The first part of this signal is provided to the energy harvesting receiver, while the remaining part is provided to the information receiver to drive its operation. The expression of the harvested energy at the relay node is computed by [60]

$$E_h = \frac{\eta \rho P_s |h|^2}{d_1^m} (T/2) \qquad (4)$$

Where 0<η <1 relates to the energy conversion efficiency of the receiver, the η factor depends on the energy harvesting and rectifier circuitries, Ps relates to the transmitted power from the source, m relates to the path loss exponent, h relates to the source-to-relay channel gain, and d1 relates to the source-to-relay distance.



(a)

(b)

**Figure 5: Illustration of (a) The block diagram of the PS-based relay receiver, and (b) the PSR with key parameters**

### 4.4 Hybrid

Besides the two main energy harvesting protocols aforementioned in the sections 4.2 and 4.3, several reports have proposed the combination of the PSR and TSR as hybrid energy harvesting protocols [35,61-63]

Table 1 presents a summary of the performance of C-NOMA-based networks with AF/DF relays.

Table 1: Performance of C-NOMA-based networks with AF/DF relays

| References | Type of relaying protocols employed in C-NOMA networks | Technical Contributions |
|---|---|---|
| [13] | -Downlink C-NOMA network with a PS-based FD relay | - Obtain the optimal energy efficiency for the C-NOMA system based on the transmit beam forming vectors and power splitting ratio by developing an iterative algorithm. |
| [35] | - Reconfigurable intelligent surface-aided downlink C-NOMA network with hybrid SWIPT protocol | -Achieve a better performance over OMA and non-cooperative NOMA.<br>- Boost the diversity gain highly when employing more RIS elements and transmit antennas. |
| [42] | - Downlink C-NOMA network with K relays and AF/DF protocols. | - Achieve the secrecy diversity orders with relay selection schemes.<br>- Compare the performance between AF and DF relays.<br>- The secrecy outage probability (SOP) tends to lower as the relay number increases. |
| [62] | -Downlink C-NOMA network with PS/TS hybrid protocol-based EH relay | - Optimize the PA and TS ratios and transmission power of the system to minimize energy consumption with the constraints of correct user information detection |
| [64] | - A downlink C-NOMA network with HD mode and DF relay. | - Derive closed form expressions of outage probability (OP).<br>- Investigate the performance at the receiver when occurring perfect and imperfect SIC<br>- The higher the NOMA order, the more the OP increases and the worse the performance for all the signals.. |
| [65] | - Downlink C-NOMA cellular networks with FD mode and PS protocol relay. | - Investigate the non-linear EH model-based PS protocol<br>- Choose the parameters of the battery energy and PS to achieve a maximum throughput for the far user while satisfying the constraints of the near user in the case of imperfect interference cancellation.<br>-The far user's performance is |

| | | |
|---|---|---|
| | | boosted with the energy-harvested relay. |
| [66] | -.Downlink HD mode C-NOMA network with DF multiple EH relays | -. Achieve the asymptotic and closed-form expressions of OP and ergodic rate for imperfect CSI and SIC constraints.<br>- Boost the users' performance by increasingly employing active relays.<br>-Analyze the dependences of the user's performance on the a fraction of block time and power allocation coefficient to choose their suitable values for the achievement of a minimum OP. |
| [67] | TS relay-assisted C-NOMA network | -Obtain closed-form expressions of OP and throughput in the delay-limited transmission mode<br>- The throughput of the system can achieve maximum values when carefully choosing the ratio factor of energy harvesting over information processing. |
| [68] | - SWIPT-based multiple relay C-NOMA network | - Propose relay selection schemes for fixed and dynamic power allocation schemes.<br>- Achieve a maximum performance gain for two-stage relay in high SNR regime. |
| [69] | - Multiple SWIPT-enabled AF relay-assisted downlink C-NOMA networks | -Evaluate the error performance in terms of BER in the C-NOMA system with SWIPT-based relays.<br>- Derive the PEP expressions of C-NOMA users based on relay selection |

### 4.5 Energy harvesting and information processing mechanisms at relaying node

SWIPT is a mechanism in which power and information are transferred simultaneously through wireless media. In NOMA, the SWIPT can be employed in relay aided cooperative NOMA networks [70,71], massive MIMO NOMA [72], cooperative cognitive radio networks [73]. When SWIPT is utilized in NOMA-based networks, it can improve energy efficiency because the extraction of both energy and information can be obtained from the same RF-received signals [74]. Furthermore, unlike WET, the SWIPT technique can also enhance spectral efficiency due to its characteristic of simultaneous information and power transfer. The SWIPT can also be combined with information processing protocols, e.g., DF, AF, and quantize-map-forward (QMF) [75] at relay nodes for harvesting energy and forwarding information to the destination node to improve energy efficiency, spectral efficiency, outage probability, and throughput.

For further discussion, let us consider an example of a C-NOMA system model, as illustrated in Fig. 6, in which one user operates as a relay node to aid in forwarding the information from the BS to another user.

In this model, the BS wishes to communicate with User 1 and User 2. Due to the obstacle between BS and User 2, the transmitted signal from the BS cannot reach User 2. Therefore, User 2 wishes the aid of User 1 to receive the information from the BS. In this case, User 1 plays a role of a relay node and needs to harvest the energy from the transmitted signal of the BS due to its power constraints. In the same time block, the relay is simultaneously transferred both information and power from the BS. This is the mechanism of the relay based on the SWIPT in C-NOMA. It is assumed that the relay in this model operates DF mode and two PSR and TSR energy harvesting are considered.

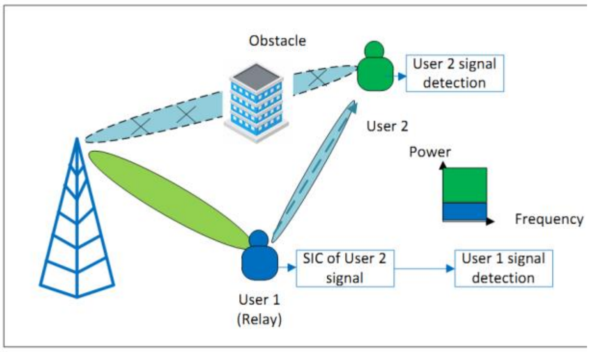


**Figure 6: Illustration of a C-NOMA system with one user operating as a relay**

The expression of the harvested energy at user D1 is computed by

$$E_h = \left[ \begin{array}{l} \beta\eta|h_1|^2\, \rho(T/2), PSR \\ \alpha\eta|h_1|^2\, \rho T, TSR \end{array} \right. \qquad (5)$$

## 5. Challenges and future trends

### 5.1 Imperfect SIC

The imperfect SIC [22,44,66] is a phenomenon in which user/relay nodes are not able to completely decode the received signal, resulting in residual inter-user interference for the decoding user. This is due to a lack of information from other users. The common causes of imperfect SIC are usually errors in estimating channels, the limitations of the hardware of the devices, and the finite length of the code. The imperfect SIC has negative impacts on the system's performance, OP, and ergodic capacity, for example. More specifically, the higher the imperfect SIC, the higher the OP, and the lower the ergodic capacity. In the case of the FD relay-aided C-NOMA system, the OP of the users was lower than that for HD mode [44]. This is because loop self-interference appears in the system, resulting in a lower proportion of imperfect SIC in system interference. Compared to the C-NOMA system with perfect SIC, the performance of that with imperfect SIC was massively degraded [66].

### 5.2 Imperfect CSI

Another dominant loss/error source that causes the degradation of the performance gain in C-NOMA-aided practical wireless communication systems is known as imperfect CSI [22,23,44]. The source of this CSI type can come from channel estimation errors (CEE) [76], partial CSI [77], and limited channel feedback [78]. The CEE happens when the channel estimation algorithms are designed imperfectly, while the partial CSI happens in cases of path loss due to small-scale fading. The imperfect CSI also causes the degradation of the OP and ergodic capacity of the C-NOMA system. Specifically, in [66], the imperfect CSI leads to the degradation of OP, ergodic rate, and throughput of the system. In [22], the OP decreases when the imperfect CSI increases. In [79], the SIC performance of each user reduces and the error floor increases at high SNR regimes when the EH parameter increases and the CSI deteriorates.

### 5.3 Future trends

The trends of NOMA-enabled wireless communication networks with the assistance of relays can be employed in a broad range of cellular networks, IoT-UAV-based networks, SWIPT-enabled wireless networks, and satellite-terrestrial networks. In these networks, the data rate can be boosted to an extremely high level, the latency can be reduced to zero, the energy harvesting efficiency can be significantly increased, and the three-dimensional coverage can be extended.

## 6. Applications of C-NOMA

C-NOMA has demonstrated its outperformance in cellular, UAV-based IoTs, as well as satellite-terrestrial networks. In cellular communication networks, the C-NOMA contributes to enhancing their performance, e.g., OP, throughput, and ergodic capacity. With the help of the relays, the source can extend its coverage, the information thus reaches more users with poor channel conditions, edge-cell users, and users without direct links. By developing optimal algorithms and the best relay selection techniques, the performance of C-NOMA-enabled wireless communication networks is improved more significantly than that of NOMA-based networks.

Unmanned aerial vehicles (UAVs) have shown their deployable applications in various fields such as advanced cargo distribution, wildfire management, and disasters [80,81]. In C-NOMA, the UAVs act as flying base stations, i.e., relays, to relay the received signal from the sources to desired nodes in cases of rescues and destroyed infrastructure areas. The critical factors that contribute to boosting the UAV's benefits in C-NOMA-based UAV-IoT networks are mobility, path loss, and agility. The mobility feature implies that the UAVs can serve several ground users by changing their coverage areas when flying around. Two other features, i.e., path loss and agility, show that the fading and shadowing caused by these UAVs are not considerable due to the characteristics of light-of-sight, fast deployment, low cost, and controlled position among UAVs and destination users.

In satellite-terrestrial communication networks, the C-NOMA scheme is employed for primary sources and secondary transmitters.

The C-NOMA-aided wireless networks have been studied by several research groups over the past decade. Specifically, in [82], a new C-NOMA scheme for uplink that exploits the backhaul links among BSs was proposed to avoid the reduction of the data rate caused by the interference of the UAVs. In [83], a C-NOMA scheme was deployed at a secondary transmitter with its pre-paired users, where the nearby user acts as an FD relay with FD mode. In [84], a C-NOMA-enabled satellite-terrestrial network was investigated to handle the deep fade channel between the satellite and the weak user. The relay's protocols in this network model are considered in two cases, including AF relay and DF relay.

## 7. Conclusion

This paper has provided an insight survey of C-NOMA, its application in cellular and UAV-enabled IoT networks, and the SWIPT-enabled wireless energy harvesting problem at relay nodes in C-NOMA-based networks. Fundamental concepts of NOMA and C-NOMA, including SIC and SC mechanisms, DF/AF information relaying techniques, and PS/TS energy harvesting approaches, were discussed. For the purpose of illustration, we also discussed the simplest NOMA/C-NOMA system models, i.e., with one BS and two users, where the far user is exploited as a relay. The expressions of the harvested energy for the PSR and TSR, are also provided. In addition, the employment of the C-NOMA in the fields of cellular networks, IoT-UAV networks, and terrestrial networks was deeply discussed. In addition, two challenges in terms of imperfect SIC and CSI were addressed. Finally, the future trends of C-NOMA were also surveyed in this work.

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