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Theme

NOMA Energy Harvesting based on TS Protocol: Performance Evaluation

In front of the jury composed of:

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2022-2023

بسم الله الرحمن الرحيم

وأن ليس للإنسان إلا ما سعى

وأن سعيه سوف يرى

Dedication (1)

"Praise be to God, by whose grace good deeds are done"

Above all else, thank God for enlightening my path and strengthening me to continue and fight to reach my goals and never give up.

The story ended, and I lifted my hat to say goodbye to the years that had passed,

I dedicate the fruit of my effort to the one my eyes did not enjoy seeing and my imagination did not leave his image to my dear father

"Khalifa"

To that great woman who raised and taught, who I always looked into her eyes to draw my strength to complete my scientific career, my words stand unable to thank you, to my tender mother

"Dalila."

And to the candles that light the way for me (my sisters)

"*Amal, Embarka, Ahlam.*

Especially my sister "*Samia*" for her psychological financial support for me.

And to (my brothers)

"*Rachid, Kaiss, Abd Alkarim, and Lakhdar* "

And to beloved my niece "*Hiba*" for supporting me in difficult times.

And to those who are happy with our success and saddened by our failure

Zeineb, Majda, Manel, Douaa, Djaouaher, Ikram, Hafsa, Manar, and Wissal.

And to all my honorable teachers who did not hesitate to extend a helping hand to me.

To my sweetheart

Who shared every moment with me to accomplish this precious work, my partner

"*Mabroka*"

And last but not least, I dedicate this humble work to everyone who takes the trouble to read it, whether to evaluate it, criticize it, increase his knowledge, or satisfy his curiosity.

Miss Amina.

Dedication (2)

To the one whom God entrusted with prestige and dignity. To the one who taught me to give without waiting. To the one whose name, I proudly carry

(My dear father)

Seeing my angel in life to the meaning of love, the meaning of tenderness

And dedication. to the smile of life and the secret of existence

To my dearest loved ones

(My dear mother)

To my brothers

With love and loyalty, you are my support, the belt of my back, my being, and the pleasure of my liver

To my friend"*Amina*" who supported me and was a source of resources for me in this work.

And those close to the heart, supporters and supporters through thick and thin, thank you May you always be with me.

MissMabrouka.

Dedication (3)

To whom words cannot fulfill their right

To whom numbers cannot count its virtues

To my mother, may God perpetuate her for me

To the pure soul of my father (may God have mercy on him)

To my brothers and sisters.

To all my friends and to all the teachers

To everyone who knows us from near or far

To all my graduates, Class of 2023 we dedicate this work.

Mr Larouci.

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Abstract

Recently, non-orthogonal multiple access (NOMA) along with cooperative communications has gained a considerable attention from researchers as a potential solution for upcoming sixth generation (6G) wireless networks. For green communication networks, cooperative NOMA is combined with energy harvesting (EH). The objective of this dissertation is to study a cooperative NOMA with time-switching-based EH. In this work, we start with introducing the requirements, trends and applications of 6G as well as the concept of multiple access technologies focusing on NOMA technology. After that, we shed the light on the cooperative NOMA with its techniques such as Amplify-and-Forward (AF) and Decode-and-Forward (DF). Also, we offer CNOMA with EH, where two common protocols are used in EH, so-called power splitting (PS) and time Switching (TS). In addition, we present the advantages and disadvantages of NOMA cooperative with EH. Finally, we make a simulation of outage probability (OP), capacity and bit error ratio (BER) of downlink cooperative NOMA using the TS protocol. The obtained results show that TS protocol enhances BER, OP and the capacity of NOMA.

Key Words: NOMA, Cooperative, EH, BER, Capacity, Outage Probability.

Résumé

Récemment, l'accès multiple non orthogonal (NOMA) ainsi que les communications coopératives ont suscité une attention considérable de la part des chercheurs en tant que solution potentielle pour les futurs réseaux sans fil sixième génération 6G. Pour les réseaux de communication verts, la coopérative NOMA est combinée avec la récupération d'énergie (EH). Dans ce mémoire, nous étudions un NOMA coopératif avec EH basé sur la commutation temporelle. Ainsi, nous présenterons les exigences, les tendances et les applications de 6G, ainsi que le concept de technologies d'accès multiples en mettant l'accent sur la technologie NOMA. En outre, nous présentons la coopérative NOMA avec ses techniques telles que, Amplification et avant (AF), décodage et avant (DF). Nous proposons également CNOMA avec EH, où deux protocoles communs sont utilisés en EH, à savoir le partage de puissance (PS) et changement d'heure (TS). Nous présentons les avantages et les inconvénients de la coopérative NOMA avec EH. Nous simulons la probabilité de panne (OP), la capacité et le taux d'erreur binaire (BER) de la NOMA coopérative de liaison descendante à l'aide du protocole TS. Les résultats indiquent que le protocole TS améliore le BER, la probabilité de panne et la capacité de NOMA.

Mots clés : NOMA, coopérative, EH, BER, capacité, probabilité de panne.

ملخص

في الآونة الأخيرة ، حظي الوصول المتعدد غير المتعامد (NOMA) جنبًا إلى جنب مع الاتصالات التعاونية على اهتمام كبير من الباحثين كحل محتمل للشبكات اللاسلكية القادمة من الجيل السادس(6G) . بالنسبة لشبكات الاتصالات الخضراء ، يتم الجمع بين NOMA التعاوني وحصاد الطاقة (EH) .هدف هذه المذكرة هو دراسة NOMA التعاوني مع EHالقائم على تبديل الوقت. في هذا العمل نبدأ بتقديم متطلبات واتجاهات وتطبيقات الجيل السادس بالإضافة إلى مفهوم تقنيات الوصول المتعددة بالتركيز على تقنية NOMA .بعد ذلك نسلط الضوء على NOMA التعاوني مع تقنياتها مثل التضخيم والارسال (AF) وفك التشفير والارسال (DF). أيضًا نعرض CNOMA مع EH ، حيث تم استخدام بروتوكولين شائعين في EH ، وهما تقسيم الطاقة (PS) و تقسيم الوقت (TS) . بالإضافة نقدم مزايا وعيوب تعاونية NOMAمع EH. أخيرا قمنا بمحاكاة لاحتمالية الانقطاع والسعة ومعدل الخطأ في البتات BER الخاص بتعاونية NOMA للوصلة الهابطة باستخدام بروتوكول TS. تظهر النتائج المتحصل عليها أن بروتوكول TS يعزز معدل BER واحتمال الانقطاع وقدرةNOMA.

الكلمات المفتاحية: NOMA ، التعاونية ، EH، BER ، السعة ، احتمالية الانقطاع.

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List of Abbreviations

1G:	First Generation
2G:	Second Generation
3G:	Third Generation
4G:	4th Generation
5G:	Fifth Generation
6G:	Sixth Generation
AF:	Amplify-And-Forward
AI:	Artificial Intelligence
AP:	Access Points
AR:	Augmented Reality
AWGN:	Additive White Gaussian Noise
B5G:	Beyond Fifth Generation
BCI:	Brain-Computer Interactions
BER:	Bit Error Ratio
BS:	Base Station
CDMA:	Code Division Multiple Access
DF:	Decode-And-Forward
DL:	Downlink
e3DC:	Extended 3D Coverage
EE:	Energy Efficiency
EH:	Energy Harvesting
eMBB:	Enhanced Mobile Broadband
FDMA:	Frequency Division Multiple
GPS:	Global Positioning System
IIoMT:	Intelligent Internet Of Medical Things
IoNT:	Internet Of Nano-Things
IoT:	Internet Of Things.
IT:	Information Technology
ITU-R:	International Teiecommunications Union-Radio
KPIs:	Key Performance Indicators
LEDs:	Light-Emitting Diodes
MIMO:	Multiple-Input Multiple-Output
ML:	Machine Learning
mMTC :	Massive Machine Type Communications
MTC:	Machine Type Communications
NFV:	Network Functions Virtualization
NOMA :	Non Orthogonal Multiple Access
NR:	New Radio
OFDM:	Orthogonal Frequency-Division Multiplexing
OFDMA:	Orthogonal Frequency Division Multiple Access
OMA:	Orthogonal Multiple Access
OP:	Outage Probability

PS:	Power Splitting
QML:	Quantum Machine Learning
QoE:	Quality Of Experience
QOF:	Quality And Outcomes Framework
QPSK:	Quadrature Phase Shift Keying
RB:	Radio Bearer
RF:	Radio-Frequency
SC:	Superposition Coding
SE:	Spectral Efficiency
SIC:	Successive Interference Cancellation
SINR:	Signal To Interference And Noise Ratio
SNR:	Signal To Noise Ratio
TDMA:	Time Division Multiple Access
THz:	Terahertz
TS:	Time Switching
UAV:	Unmanned Aerial Vehicle
uHPC :	Ultra High Precision Communications
UL:	Up Link
uMBB:	Ultra Mobile Broadband
uMTC :	Ultra-Massive Machine-Type Communication
URLLC:	Ultra Relible Low Latency Communications
VLC :	Visible Light Communication
VR :	Réalité Virtuelle
WSN:	Wireless Sensor Network
XR:	Extended Reality

General Introduction

General Introduction

Mobile communication systems revolutionized the way people communicate. Evolution of wireless access technologies is about to reach its fifth generation (5G) and the sixth generation (6G). Mobile networks will focus on the development of the user terminals where the terminals will have access to different wireless technologies at the same time and will combine different flows from different technologies. Looking at the past, wireless access technologies have followed different evolutionary paths that have a unified target related to performance and efficiency in high mobile environment. The first generation (1G) has fulfilled the basic mobile voice while the second generation (2G) has introduced capacity and coverage. This is followed by the third generation (3G) which has sought for data at higher speeds to open the gates for "mobile broadband" experience and it was realized by the fourth generation (4G). The 4G provides access to wide range of telecommunication services, including advanced mobile services that are supported by mobile and fixed networks and increasingly packet based, along with a support for low to high mobility applications and wide range of data rates, in accordance with service demands in multiuser environment. The 5G brings forward a real wireless world-Wireless World Wide Web. It provides 25 Mbps connectivity speed with data bandwidth higher than the 1Gb with a very high uploading and downloading speed. The sixth generation (6G) is proposed to integrate it with satellite networks for global coverage [1],[2].

From the 1G to the 5G, the design was based on orthogonal multiple access (OMA) schemes, where the service was in the time, frequency or code domain. Also, due to its ability, OMA can't serve multiple number of users with its limited capabilities and low traffic requirements, both in terms of latency and connectivity. Recently, Non-Orthogonal Multiple Access (NOMA) has been identified as a promising technology that will help to meet the massive performance goals of system, connectivity and service latency [3]. The principle of NOMA provides the opportunity to serve multiple users using the same resource (time, frequency, and code), where superposition coding (SC) is used at the transmitter side while the Successive Interference Cancellation (SIC) is used at the receiver side.

Moreover, in order to enhance the performance of the weak user, cooperative communication is one of the solutions proposed. It is integrated with NOMA to improve the NOMA system performance and to increase coverage for enhancing energy efficiency and prolonging the lifespan of energy-limited wireless networks. The integration of CNOMA with energy harvesting (EH) has gained recent attention. This latter employs two commonly protocols in EH, so-called power splitting (PS) and time switching (TS). The objective of our dissertation is to analyse the performance of NOMA with EH using the TS protocol.

This work is divided into three chapters:

- The first chapter provides an overview of the development of wireless communication networks, the expected requirements and applications of the sixth generation, and a look at multiple access technologies with a focus on NOMA technology.
- In the second chapter, we focus on the principle works of NOMA Cooperative system and EH.
- In the last chapter, we present the results of simulation of NOMA downlink cooperative using the TS protocol and compare it without it.

Finally, this work ends with a conclusion.

Chapter I:

NOMA and Future B5G & 6G Wireless Networks

I.1 Introduction

Over the past few decades, wireless communications have faced a technological revolution. Researchers are developing the 5G wireless communication networks and beyond (B5G) and the sixth generation (6G) to meet future needs. In this chapter, we highlight the requirements, trends and applications of 6G. Also, we see the concept of OMA and NOMA and the principle of NOMA's work in the downlink and uplink. Finally, we show the benefits and drawbacks of NOMA where it can be a promising blueprint to meet the demands of an extremely increasing number of users.

I.2 Evolution of Mobile Networks

The evolution of mobile networks has been significant over the past few decades. With each generation bringing new features and improvements, the 1G introduced analog voice communication. After it, the 2G brought digital voice and messaging. It was followed by the 3G that introduced high-speed data and mobile internet. Then, the 4G showed up and brought even faster data speeds, video calling, and improved battery life. The 5G promises to offer even faster speeds, lower latency, and support for massive machine-type communications. Looking forward, the 6G is expected to bring even more significant improvements such as holographic communication, terahertz frequency bands, and cognitive networks. As the demand for mobile data and connectivity continues to grow, the evolution of mobile networks will continue to push the boundaries of what is possible enabling new applications and services that were once only imaginable. We provide a comprehensive overview of the evolution of the 1G mobile wireless networks to the standard of mobile network technology the 6G as shown in the Figure I. 1.

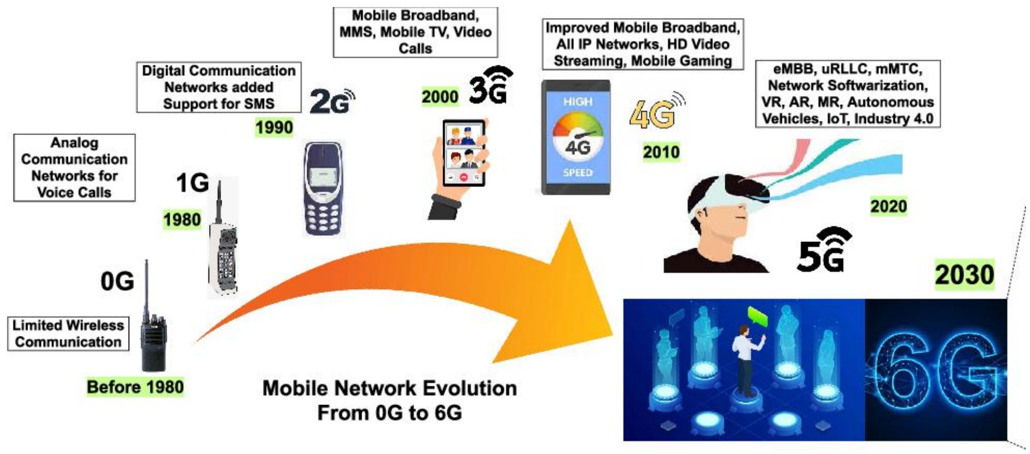


Figure I. 1: Evolution of Mobile Networks from 0G to 6G [4].

I.3 Fifth Generation Networks

The Fifth Generation (5G) Networks are the latest and the most advanced wireless communication systems that aim to provide significantly faster data transfer speeds, higher capacity, lower latency, and improved connectivity than previous wireless generations. They use advanced technologies such as millimeter-wave (mmWave) frequency bands, massive multiple-input/multiple-output (MIMO), and small cell infrastructure to enable more simultaneous connections, faster data transfer rates, and lower latency. The increased data capacity and the lower latency of 5G networks will enable new applications and services, including ultra-reliable and low-latency communication, massive machine-type communication, and enhanced mobile broadband. These features make the 5G networks a significant technological advancement that is expected to revolutionize various domains as healthcare, transportation, and entertainment, among others [5].

I.3.1 Wireless Network Performant Requirement 5G

The performance requirements for 5G wireless networks include high data rates, increased network capacity, low latency, and high reliability. The International Telecommunications Union-Radio (ITU-R) has defined a set of performance requirements for 5G networks which include peak data rates of up [6] to 20 Gbps, network capacity of up to 10 Tbps per square kilometer, and latency as low as 1 ms. The 5G networks must also support high mobility, allowing users to move at speeds of up to 500 km/hour. In addition, they must be energy-efficient and cost-effective, supporting a large number of simultaneous connections with minimal power consumption. These performance requirements are critical for supporting the various new applications and services that the 5G networks are designed to enable such as virtual and augmented reality, autonomous vehicles, and the Internet of Things (IoT) [7].

I.3.2 Technology 5G

The 5G technology is the latest and most advanced wireless communication technology that aims to provide faster data transfer speeds, higher capacity, lower latency, and improved connectivity. The original intention of 5G was to develop three main services and applications: eMBB (Enhanced Mobile Broad Band), URLLC (Ultra Reliable Low Latency Communications) and mMTC (Massive Machine Type Communications), as depicted in

Figure I.2. At present, eMBB has been implemented and applied in the mass consumer market for products such as mobile phones, but uRLLC has multiple application scenarios and high prices, while mMTC has low and different returns [8].

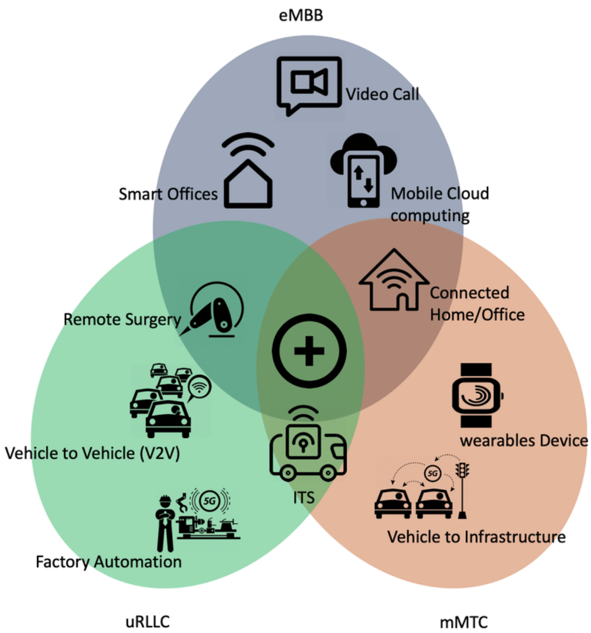


Figure I. 2: 5G three main use cases with examples of associated applications [9].

I.4 Technology Development from 5G to Beyond Fifth Generation Networks

The development of wireless communication technology has been rapidly advanced from the 5G to beyond the Fifth Generation (B5G) networks. The B5G's aim is to provide more advanced features and capabilities such as higher data rates, lower latency, higher spectral efficiency, and greater energy efficiency than the 5G. Some of the key technologies expected to be used in the B5G networks include new waveforms, massive MIMO, NOMA, artificial intelligence (AI), terahertz (THz) communication, and visible light communication (VLC). The B5G networks are expected to enable new applications like virtual and augmented reality, autonomous vehicles, and smart cities, among others. The development of B5G networks is still ongoing, and it is expected to take several years before the technology is fully deployed and operated [10].

I.5 Sixth Generation Networks

The Sixth Generation **(**6G) networks are the next generation of wireless communication networks that are currently being researched and developed. Their primary goal is to provide even higher data rates, lower latency, higher spectral efficiency, and greater energy efficiency than the current 5G and B5G networks. The 6G networks are expected to use a combination of advanced technologies.

I.5.1 6G Technologies

The 6G is now the current wireless communication technology in development. Scientists from around the world provide cutting-edge technologies such as AI/ Machine Learning (ML), Quantum Communication / Quantum Machine Learning (QML), Blockchain, Terahertz (THz) Communication and mmWave, tactile internet, NOMA [11], small communication cell, fog/edge calculations, etc. as key technologies to realize B5G and 6G communication. Figure I.3 presents potential key technologies of 6G networks.

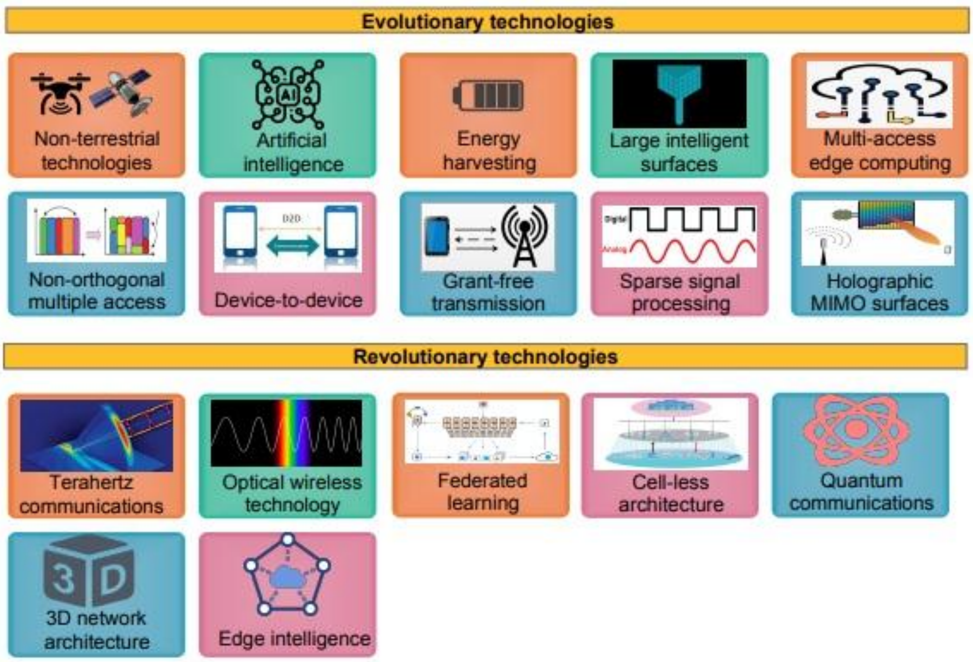


Figure I. 3: Key Technologies of 6G Network [12].

I.5.1.1 Artificial Intelligence

Artificial Intelligence (AI) plays the most important role in the future network compared to the rest of technologies. It has attracted the attention of various research groups. With this growing search, various privacy and security issues have appeared. Although artificial intelligence is also built into 5G, it still sees technology as a key element of the 6G future. AI technologies are divided into physical layers consisting of network infrastructure, architecture layer, processing layer with software-defined networks, edge/cloud computing and virtualization of network functions [13].

I.5.1.2 Quantum Communication

Another promising technology in the 6G network is quantum technology posts. It can greatly increase the reliability and security of data transmission with significant breakthroughs. It can provide solutions and improve the quality of communication, which is not possible with traditional communication techniques. However, it is not the only panacea for all security threats. This reality doesn't deny its potential to revolutionize secure communication and to play a vital role in future technologies such as quantum computing and quantum networks. [13].

I.5.1.3 Blockchain

Another prominent technology is the 6G network blockchain. It has several uses like spectrum sharing, distributed ledger technology and network decentralization. Also, it increases authentication security through distributed ledger technology. Blockchain technology can overcome spectrum monopoly and low spectrum utilization as well [13].

I.5.1.4 Visible Light Communication

Visible Light Communication (VLC) is a wireless communication technology that uses visible light as the medium for data transmission. It leverages the properties of light, such as intensity and color, to carry information. VLC operates by modulating the intensity of light emitted by LED (Light-Emitting Diode) sources, which can be received and detected by light sensors or photodiodes [14].

I.5.1.5 Terahertz Technology

Existing radio frequency (RF) band cannot be utilized for future 6G technologies. It has spurred the demand for THz technology. THz communication technology used 0.1-10 THz band. Moreover, it exploits optical signals and Element Manager (EM) waves. There are several benefits of THz band including 100 Gbps data rate, high security and limited eavesdropping. Researchers have investigated energy consumption problem in THz communication. THz faces security risks of authentication and malicious attack. A comparison between VLC and THz communication is summarized in Table I. 1 below [13].

Feature	VLC	THz
Cost	Cheap	Expensive
Data rate	10 Gbps	100 Gbps
EM radiation	No	Yes
Transmission	LOS	NLOS
Transmission power	Low	High
Spectrum regulation	Unlicensed	Liscensed
Inter cell interference	No	Yes
Bandwidth	10-100 GHz	100 THz

Table I.1: Comparison Between VlC and THz.

I.5.2 Enhancements in 6G Technology

The 5G is expected to become widely available, laying the groundwork for 6G. When comparing all generations, it is clear that internet speed and coverage increase gradually. The 6G target is to provide global coverage. AI applications will distinguish 6G from previous generations. Although it is still in its early stages, the autonomous 6G network is expected to serve as the backbone of 6G technology. Compared to the current 5G capacity, data rates and security quality will increase, and latency will decrease. The 6G is estimated to have a speed of 1–10 Tbps**.** Its frequency will be higher than all other generations. The frequency generally increases as generations move forward. High transmission rates are indicated by the THz frequency. Because of 6G, latency will be in the range of 10–100 ms, connectivity density will be in the range of 10devices/km2, and traffic capacity will be in the range of 1 Gb/s/m2. Furthermore, for those new definition KPIs, 6G will improve coverage percentage to 99 %, reliability to 99.9999 %, positioning error from the current meter level to the centimeter level, and receiver sensitivity better than–130dBm. As shown in Table I .2, spectrum efficiency and energy efficiency will exponentially increase compared to 5G [11].

KPIs	4G	5G	6G
Peak data rate /device	1 Gbps	10 Gbps	1Tbps
Latency	100 ms	1 ms	0.1 ms
Max. spectral efficiency	15bps/Hz	30 bps/Hz	100 bps/Hz
Energy efficiency	<1000× relative to 4G	1000× relative to 4G	> 10× relative to 5G
Connection density	2000 device $/km^2$	1 millon device $/km^2$	> 10 millon device $/km^2$
Coverage percent	<70 %	80 %	> 99%
Positioning precision	Meters precision (50 m)	Meters precision (20 m)	Centimeter precision
End-to-end reliability	99.9%	99.999%	99.9999%
Receiver sensitivity	Around -100dBm	Around -120dBm	< -130 dBm
Mobility support	350 km/h	500 km/h	≥ 1000 km/h
Satellite integration	No	No	Fully
AI	No	Partial	Fully
Atonomous vehicle	No	Partial	Fully
Extended Realiy	No	Partial	Fully
Haptic Communication	No	Partial	Fully
THz Communication	No	Limited	Widely
Service level	Video	VR, AR	Tacitile
Architecture	MIMO	Massive MIMO	Intelligent
Max. frequency	6GHz	90 GHz	10 THz

Table I.2: Comparison of 6G with 4G and 5G mobile communication systems.

The 6G promises an unlimited wireless connection. It will be a communication network that will host numerous systems such as communication, metering, storage, computing, control, Global Positioning System (GPS), radar, imaging, and navigation [11]. The main features of 6G are summarized in Figure I. 4.

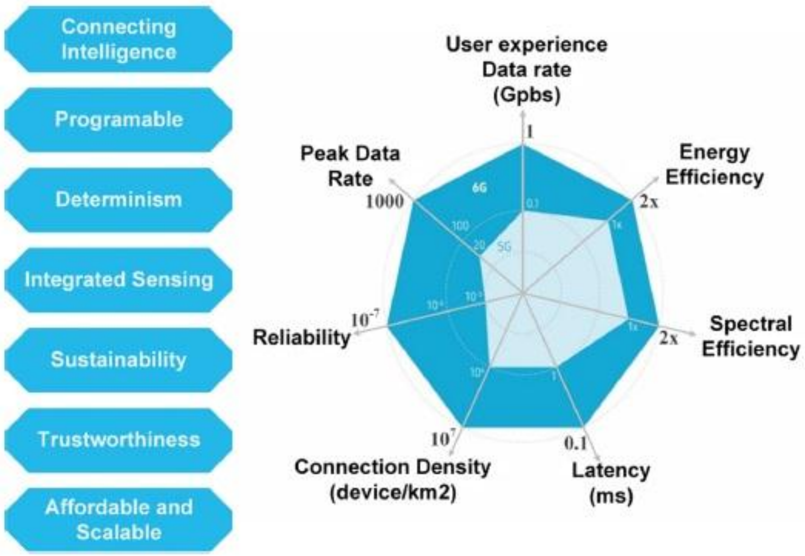


Figure I. 4: Key Enhancements of 6G technology [11].

I.6 6G Networks Requirements and Trends

In terms of data rate, latency and Quality of Experience (QoE), traders need to consider new strategies like exploitation in shared bands, frequency sharing between operators, heterogeneous networks, rental of network segments in a domain, etc. According to the relevant authorities, the 6G will be in need for more stringent requirements than the 5G as embodied in Figure I.5.

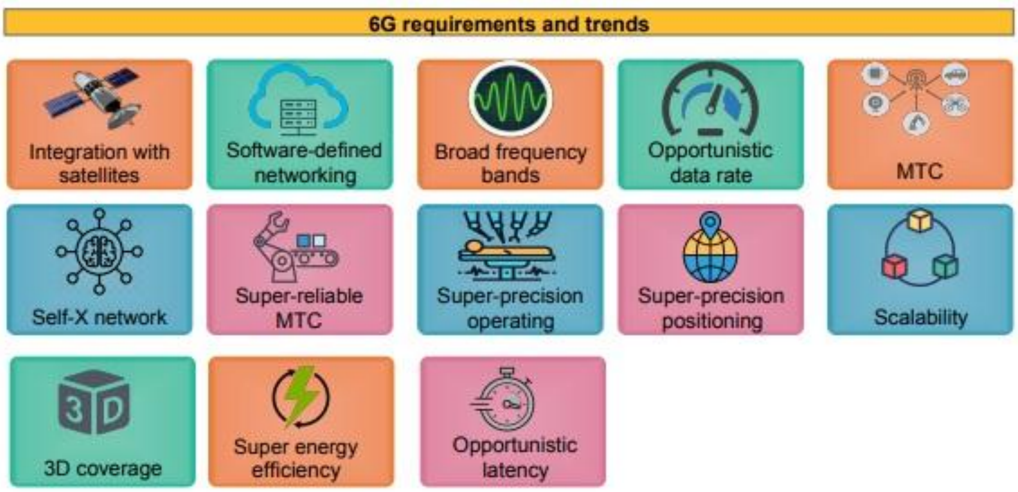


Figure I. 5:6G requirements and trends [12].

Key 6G requirements and trends are introduced as follows:

- **Broad frequency bands:** According to the requirements of the envisioned use-cases of 6G, it is prominent that the bands allocated to New Radio (NR), e.g., sub-6 and mmWave bands, will not be able to support the required Quality of Service (QoS) and

QoE. Therefore, it is predicted that future networks require higher frequency spectrum bands, such as 73 GHz, 140GHz, 1THz, 3THz [12].

- **Opportunistic data-rate:** To support the emerging application such as immersive multimedia, a very high and opportunistic peak data rate is required [12].
- **Opportunistic latency:** 6G requires the latency to be zero and end-to-end delay to be less than 1 ms. For instance, Extended Reality (XR) services require a latency to be close to zero in order to improve the QoS**.** Furthermore, telepresence requires the latency must be lower than sub-millisecond [12].
- **Self-X network:** In comparison with the previous generations, 6G networks must be more flexible and robust. Such kind of flexible and robust networks are out of human ability to control. Therefore, to manage such networks, sophisticated ML techniques are of vital importance. ML techniques are used to support the network autonomy as well as capture insights and comprehension of surrounding environment in which they operate. Hence, with the help of ML algorithms, 6G network will be self-learning, self-reconfiguration, self-optimization, self-healing, self-organization, self-aggregation, and self-protection [12].
- **Super-precision operating:** It is clear to see that the traditional statistical multiplexing techniques are not adequate to support the future high-precision services and applications like tele-surgery and intelligent transportation systems. Such services and applications require very high-level and guaranteed precision, e.g., absolute delivery time. To do so, a bunch of new function components are necessary to utilize such as user-network interfaces, reservation signaling, new forwarding paradigm, intrinsic and self-monitoring operation, administration, and management for network configuration [12].
- **Super-precision positioning:** GPS uses signal and travel time to find a position. However, the precision of such services is not adequate according to the error that they struggle with, even in order of meters**.** The future services require very high precision in positioning even in sub-millimeter accuracy. Tele-surgery and tactile Internet are ones of those services [12].
- **Scalability:** IoT is going to connect billion of devices ranging from high-end devices to sensors, actuators, smartphones, tablets, wearable, home appliances, vehicles, and many more to the Internet**.** A huge amount of data is generated via such connected devices. In order to extract the relevant hidden knowledge, ML is required. ML-enabled devices

can analyse the data and extract the hidden knowledge and hence solve the issue of raw data transmission, which results in improving the network resources utilization [12].

- **Supper energy efficiency:** 6G devices are supposed to operate in higher frequency band and therefore they need much more energy compared to 5G devices. As an example, energy harvesting is under investigation to overcome the issue of energy efficiency in 6G.
- **Integration with satellites:** Satellite communication technologies will be used in 6G to provide global coverage. Telecommunication satellites, earth imaging satellites, and navigation satellites will be integrated in 6G so as to provide localization services, broadcast and Internet connectivity [12].
- **Software Defined Networking (SDN):** network management in 6G needs dynamic and programmatically efficient network configuration. Network Function Virtualization (NFV) enables the consolidation of network instruments onto the servers located at data centers, distributed network devices, or even at end-user premises. Moreover, network slicing offers a cognitive and dynamic network framework on-demand, which can support several virtual networks on top of shared physical infrastructure [12].

I.7 Usage Scenarios And Applications 6G

I.7.1. Usage scenarios

By 5G ratings, 6G use cases, with similar requirements, can be categorized into specific groups or use cases. Here are the recommended usage scenarios for 6G networks.

- **Ultra mobile broadband (uMBB):** The use cases under this scenario require much higher data rate than the one required in 5G eMBB usage scenario [15].
- **Ultra-massive machine-type communication (uMTC):** The use cases under this scenario require much more massive number of simultaneous connections per space than the one required in 5G massive machine-type communication (mMTC) usage scenario [15].
- **Ultra High Precision Communications (uHPC):** The use cases in this scenario require significantly lower latency, higher reliability, more precise timing or positioning than the Ultra High Precision Communications Reliable Low Latency (URLLC) 5G use case. These requirements are applied independently or in combination with each other [15].

- **Extended 3D coverage (e3DC):** The use cases in this scenario require the integration of terrestrial mobile land communications and non-terrestrial satellite communications, including drones, air stations and high land platform stations (HAPS) to ensure connectivity to all corners of the earth [15].
- **Mixed usage scenarios:** uMBB and uHPC are combined in order to provide use cases under this mixed scenario. The requirements for both uMBB and uHPC have to be simultaneously supported [15].

Figure I. 6 explains why mixed usage scenarios are so important in 6G. Many future critical use cases outside of the triangle in Figure I. 7 cannot be provided by the 5G usage scenarios, so-called eMBB, URLLC, and mMTC. Many use cases related to the future intelligent transportation system (ITS), IoT, The uMBB, uMTC, or uHPC utilization can be used to create smart cities, factory automation, or both. The majority of use cases spun off from the above two environments, and applications based on tactile IoT are closely related to the mixed scenarios of 6G [15].

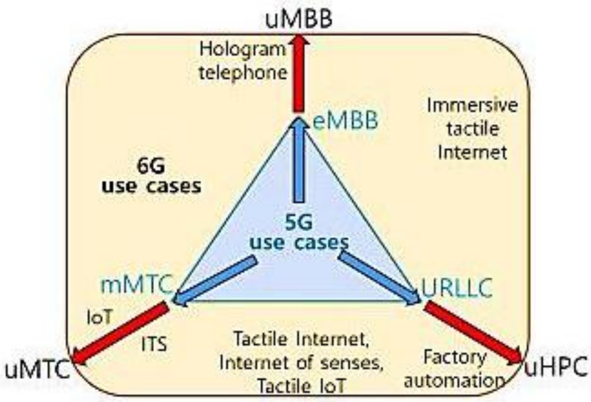


Figure I.6: 6G use case examples based on mixed usage scenarios [15].

I.7.2 Applications

Every new era in network technology heralds new ones services. Potential applications for future 6G technology have been shown.

A) Multi-sensory Extended Reality (XR) Applications: Low latency and high throughput of 5G technology have advanced virtual reality (VR) / augmented reality (AR) capabilities for 5G users. However, some existing challenges should be eliminated in the 6G network. The VR/AR experience is enhanced on 6G network. Multiple sensors can be assigned to collect sensor data. Therefore, XR is formulated with URLLC and eMBB in the 6G network [13].

B) **Connected Robotics and Autonomous Systems:** Another promising application of 6G technology is the comprehensive autonomous system. It is required in 6G network as compared to 5G. This system should be based on a multi-dimensional network. In addition, the system must be capable to embed AI across the network. This feature will support automatic controlling of internal components [13]. They developed an automated factory which contains cloud services, database and Unmanned Aerial Vehicle (UAV) networks to make it a complete autonomous system. The 6G will be helpful for underwater robotic tasks such as security, imaging and rescue. It will also enable efficient surveillance, navigation and robotic communication. It will develop a reliable, secure and smooth communication channel for real-time applications as well. Low latency and highspeed data transmission of 6G will be helpful to obtain video data [13].

C) **Wireless Brain-Computer Interactions (BCI):** The concept of wireless BCI is to develop a link between device and human brain. This device can be placed inside or outside the body. The key application of wireless BCI is to control auxiliary equipment for disabled people. It is expected that BCI will have more applications with involving 6G technology. The security risks of wireless BCI contain encryption and malicious behavior.

D) **Accurate Indoor Positioning:** With evolving GPS, outdoor positioning systems have been developed accurately, but they still need research attention to cope up with complicated indoor EM propagation. New aspects of full-fledge applications are expected with reliable and accurate indoor positioning services. However, RF communication alone cannot achieve accurate indoor positioning [13]. Such crucial application can only be realized with 6G technology

E) **Holographic Communications:** Virtual in-person meetings will be more feasible thanks to Holographic Communications 6G than through conventional video conferencing. It can be done by making a short-term, realistic projection of real-time motion. To achieve in-person presence, a 3dimentional (3D) image and speech transmission are insufficient. However, 3D video must have stereo audio included. We can say that users interact with holographic data and can make changes as necessary. Reliable communication networks with very wide bandwidth can capture this scenario [13].

F) **Tactile Communications:** After realizing holographic communication for virtual in person meeting, it is advantageous to carry out tactile communication to transfer the physical interaction remotely. Specifically, it includes interpersonal communication, cooperative automated driving and teleoperation. Stringent demands or these applications can be met through reliable cross-layer communication-system. Moreover, delay can be mitigated by carefully handling handover, scheduling, queuing and buffering [13].

G) **Internet of Nano-Things (IoNT):** The ability to design advanced materials is being given incredible prospects by nanotechnology. Nanodevices like nanosensors have been created by it. It is capable of carrying out basic tasks and enabling internet connectivity. IoNT was created by fusing IoT and nanotechnology. It has the capacity to gather and send data. Also, it can be used in conjunction with related technologies like IoT, big data, cloud computing, and Wireless Sensor Network (WSN) and Underwater Wireless Sensor Network (UWSN). However, due to the fact that data storage is based on the size of nano memory, IoNT has trouble implementing in real-time due to memory space constraints. High biological noise and congestion control in nanodevices are possible issues as well [13].

H) **Intelligent Internet of Medical Things (IIoMT):** Operation time and space restrictions will be eliminated via the IIoMT. High speed communication, that became possible by 6G, will enable effective telesurgery across geographic borders. To aid remote clinicians, IIoMT will use holographic communication, tactile communication, and AR/VR. Thus, intelligent healthcare will be made possible by 6G technology. Technology for mobile hospitals that can replace ambulance services is anticipated. In the future, it may provide medical gadgets to carry out specialized medical procedures, dramatically reducing the likelihood of medical professionals coming into touch with viruses. In Figure I. 7, a summary of 6G applications is shown [13].

Figure I. 7: Potential Applications of 6G [4].

I.8 Multiple Access Techniques

I.8.1Orthogonal Multiple Access

To prevent multi-access interference, Orthogonal Multiple Access (OMA) allows any user to utilize orthogonal communication resources within a particular timeframe, frequency band, or code. Previous generations of networks used OMA schemes, such as First-generation FDMA (Frequency Division Multiple Access) 1G, 2G Time Division Multiple Access (TDMA), Time Division Multiple Access in 3G code (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA) 4G. However, each generation has different ways to divide the degrees of freedom, as illustrated in Figure I. 8. In TDMA, time is partitioned into time slots each serving an digital data stream in a round-robin fashion; while in frequency division multiple access (FDMA), the available spectrum is partitioned into non-overlapped frequency sub-bands each accommodating one digital data stream [16].

Orthogonal frequency division multiple access (OFDMA) is a multi-carrier multiple access scheme based on the orthogonal frequency division multiplexing (OFDM) waveform, which enables tight and orthogonal frequency-domain packing of the subcarriers with a subcarrier spacing inverse to the symbol duration. In the light of this, the time and frequency plane with OFDMA are divided into two-dimensional raster, each transmitting a modulated symbol that belongs to one data stream [16].

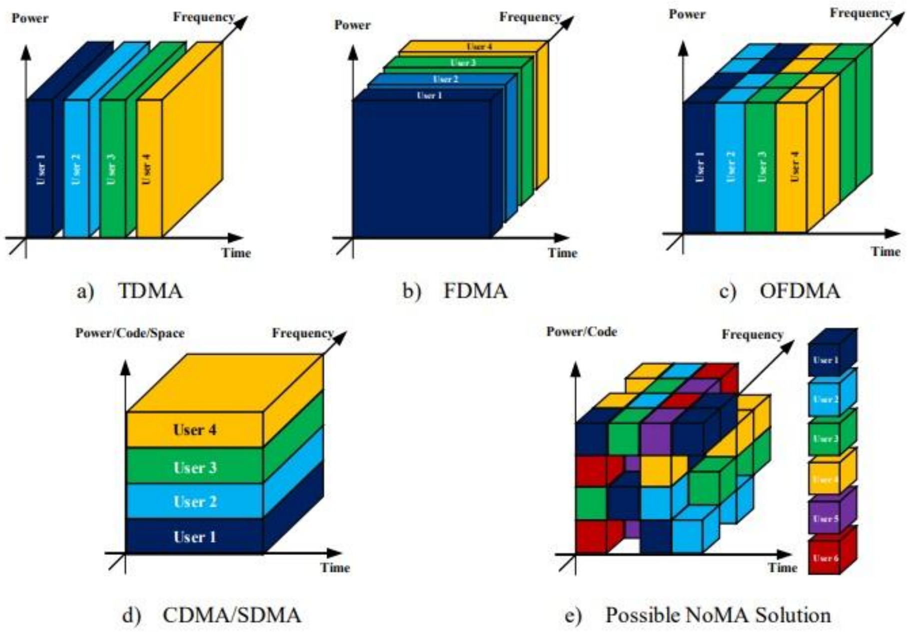


Figure I. 8: Illustrative example of different multiple access schemes [16].

I.8.2 The Non-Orthogonal Multiple Access System

non-orthogonal multiple access (NOMA) is one of the most promising radio access techniques in next-generation wireless communications. Compared to OFDMA, which is the current de facto standard OMA technique, NOMA offers a set of desirable potential benefits, such as enhanced spectrum efficiency, reduced latency with high reliability, and massive connectivity. The baseline idea of NOMA is to serve multiple users using the same resource in terms of time, frequency, and space [17].

A generic example of NOMA is described in Figure I. 9. Each user operates in the same band and at the same time where it is distinguished by its power levels. NOMA uses SC at the transmitter so that the SIC receiver can separate users in both uplink and downlink channels. It has been proposed as a candidate radio access technology for 5G cellular systems. The practical implementation of NOMA in cellular networks requires high computing power to implement real-time power allocation and successive interference cancellation algorithms [18].

I.8.3 Benefits of NOMA over OMA

The followings explain the advantages of NOMA over OMA:

- **High spectral efficiency:** Because one radio bearer (RB) provides services to numerous customers, NOMA has a higher SE than OMA. Each user in OMA systems is given a single RB, which results in bandwidth loss**.** To further increase network throughput, NOMA can also be easily described in terms of mMIMO, mmWave, HetNets, and device-to-device (D2D) systems [19].
- **Massive connectivity:** NOMA may accommodate a large number of smart devices due to its non-orthogonal properties. It is suitable for both the tactile internet and the IoT because its packet sizes are smaller and more erratic [19].
- **Fairness:** NOMA ensures user fairness by giving weak users (those with bad channel conditions) more power and strong ones less power. Then, stronger and weaker users are guaranteed QoS in terms of throughput [19].
- **Extremely low latency:** B5G networks' HetNet design makes ultra-low latency needs more stringent. OMA approaches are not suitable for such designs since they rely on access-grant requests, which increase transmission delay and signaling cost. NOMA, which enables grant-free transmission and is very helpful in the uplink scenario, is used to solve this problem. Additionally, it also enables flexible scheduling of several devices based on application and QoS needs [19].

I.9 Principle of the NOMA Technique

The basic concept of NOMA is based on the exploitation of power domain to serve several users in a non-orthogonal way on the same block of time-frequency resources. On the transmitter side, different users' signals are assigned different power levels, and SC is used to transmit users' combined signals. We designate by X_1 and $X_2$the multiplexed signals of UEs 1 and 2 users, with respective powers p_1 and p_2 , and channel gains h_1 and h_2 with h_1>h_2. In the context of NOMA, UE 1 is referred to as a strong user while UE 2 is the weak one. The superimposed signal transmitted by the base station (BS) is given by x = X_1 +X_2 , and the signals received at UE 1 and UE 2 are given by: y_1 = Xh_1 + n_1 and y_2 = Xh_2 + n_1, where n_i represents noise Gaussian white perceived at the level of UE i , with variance σ^2. At UE 1, a SIC receiver is applied to extract X_1 from y_1 . It proceeds by detecting, demodulating and decoding the X_2 signal and then re-encoding it and subtracting it from the received signal as shown in Figure I. 9 [20].

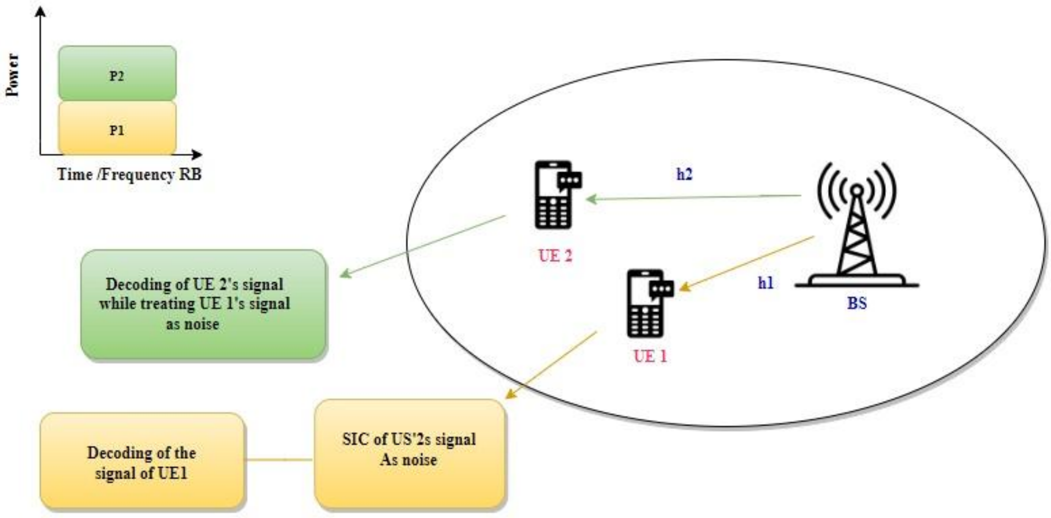


Figure I. 9: Representation of a two-user NOMA system where UE 1 is the strong user implementing a SIC receiver.

The two key operations that make NOMA possible are SC which must be carried out in issue and subsequent cancellation of SIC at reception [21].

I.9.1 Superposition Coding

The fundamental concept of the Superposition Coding (SC) allows the BS to transmit simultaneously signals from multiple users that are encoded and modulated so independent. Each user will have a power level relative to their own state in the channel.

Indeed, the closer the user is to the BS, the higher the power level which is assigned to it will be weak [22]. More clearly, the SC allows you to encode a message for a user associated with poor channel conditions with a power rate relatively strong, then superimpose it on the signal of a user with better channel conditions and coded with a relatively low power rate [23].

In order to show how SC is performed, a schematic diagram is given in Figure I. 10, where the quadrature phase shift modulation (QPSK) constellation of user 1 with higher transmit power is superimposed on that of user 2 with lower transmit power. It may be mentioned that SC is a recognized non-orthogonal scheme that reaches capacity on a scalar Gaussian scattering channel. The author introduces good strategies for SC and proposes a design technique for SC using standard coding and decoding blocks for a single user. In the SC phase, two point-to-point encoders [24].

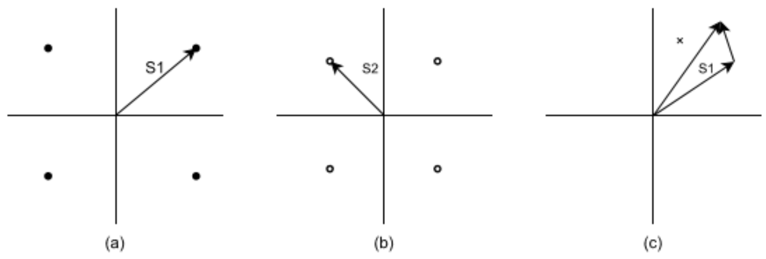


Figure I. 10: An example of SC encoding (a) signal constellation of user 1 (b) signal constellation of user 2 (c) constellation of superposed signal.

1.9.2 Successive Interference Cancellation

Let us define collision as the simultaneous arrival of two or more packet transmissions at a receiver. Traditionally, only the strongest signal can be decoded, treating the other signal as interference. However, Successive Interference Cancellation (SIC) facilitates recovery of even the weaker signal. For this, the bits of the stronger signal are decoded as before. The original (stronger) signal is then reconstructed from these bits, and subtracted (i.e., cancelled) from the combined signal. The bits of the weaker packet are then decoded from this residue. This can be an iterative process to recover multiple packets and hence it is termed SIC [25].

The basic idea of SIC is that user signals are successively decoded. After one user's signal is decoded, it is subtracted from the combined signal before the next user's signal is decoded. When SIC is applied, one of the user signals is decoded, treating the other user signal as an interferer, but the latter is then decoded with the benefit of the signal of the former having already been removed. However, prior to SIC, users are ordered according to their signal strengths, so that the receiver can decode the stronger signal first, subtract it from the combined signal, and isolate the weaker one from the residue. Note that each user is decoded treating the other interfering users as noise in signal reception.

Figure I. 11 presents the technique for decoding the superposed signal (Figure I. 10) at the receiving side [2].

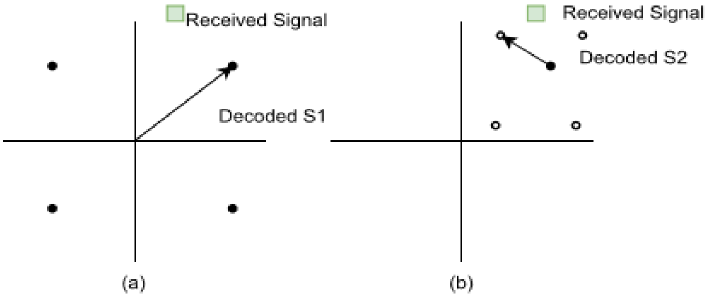


Figure I. 11: An example of SC decoding (a) decoding the signal of user 2 (b) decoding the signal of user 1.

In the following, the SIC process is shown for two users who respectively receive the Two signals $y_1(n)$ and $y_2(n)$.The decoding of overlapping messages can be set by the process mathematically expressed the equations below:

1) A single-user decoder $\boldsymbol{g_2: c^T \rightarrow \{0, 1\}2^{TR_2}}$ for user 2, performs a direct decoding of the

$X_2(n)$ message from the received signal $y_2(n)$. or g_2 is th

e decodersingle-user, c^T The complex sequences of near and far messages each of length L, TR_2 denotes the bandwidth-standardized transmission rates (or spectral efficiencies).

2) User 1 performs the following steps to successively retrieve his message $X_1(n)$from its received signal $y_1(n)$:

a) Decode message the user $2X_2(n)$using the single-user decoder

$$g_2{:}c^T \rightarrow \{0, 1\}^{2^{TR_2}} \quad \text{(I.1)}$$

b) Multiply the signal thus decoded $X_2(n)$by the appropriate power coefficient:

$$\sqrt{pa_2}h_1X_2(n) \quad \text{(I.2)}$$

Subtract the previous term from the received signal $y_1(n)$:

$$y'_1\,(n) = y_1(n) - \sqrt{pa_2}h_1X_2(n) \quad \text{(I.3)}$$

Where h_2 is the complex gain of the channel on the path of user 2

3) Another single-user decoder g_1 is used: $c^T \rightarrow \{0,1\}^{2^{TR_1}}$ to decode the message $X_1(n)$ from received signal $y_1(n)$. g_1 is the single-user decoder, TR_1 refers to the bandwidth-standardized transmission rates (or spectral efficiencies). If all signals from the iteration steps are cancelled, the SIC is successful [26],[27].

I.10 Transmission NOMA:

I.10.1 Downlink NOMA

Figure I. 12, shows a system based on the Power Domain – NOMA with two users, each is equipped with an antenna, and a BS that allows transmit simultaneously two signals on the same frequency, multiplexed in the power domain to both users UE 1 and UE 2.

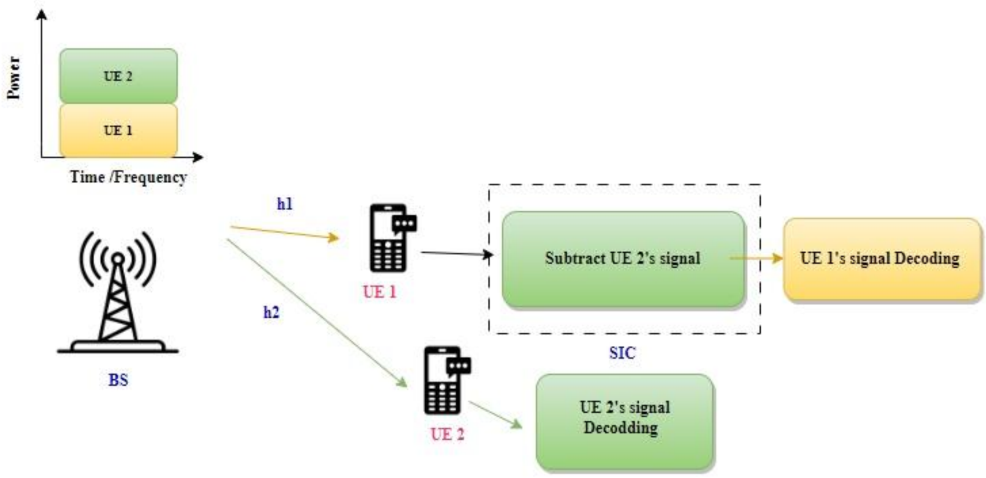


Figure I.12: Downlink NOMA.

The BS transmits the x signal with its two components encoded and superimposed in the form:

$$x = \sqrt{p_1}X_1 + \sqrt{p_2}X_2 \qquad \text{(I.4)}$$

Where p_1 and p_2 represent the portions of power assigned to both users. If the total power emitted is P, then:

$$p_1 + p_2 = P \qquad \text{(I.5)}$$

The signal received by the user "i" is given by the equation:

$$y_i = h_i \text{ X} + w_i \tag{I.6}$$

Avec$i$ = 1, 2 and wi denotes the Gaussian white noise power additive N_0. h_i is the Complex channel coefficient between user ‹‹i›› and BS.

UE 2 is the one away from the BS, so it is the first one who will decode his X_2 signal at start from the received signal y_2 and shall treat the X_1 signal of UE 1 as a interference, its rate is then expressed by:

$$R_2 = log_2\left(1 + \frac{p_{2|h_2|^2}}{p_{1|h_2|^2+N_0}}\right) bit\ /s/Hz \tag{I.7}$$

Then, UE 1 can decode theX_2 signal in order to subtract it from the received signal y_1, its flow rate is given by:

$$R_{1\to 2} = log_2\left(1 + \frac{p_{2|h1|^2}}{p_{1|h_1|^2+N_0}}\right) \tag{I.8}$$

After performing the SIC subtracting X_2 fromy_1, the flow rate achievable by the UE 1 data by:[28]

$$R_1 = log_2\left(1 + \frac{p_{1|h1|^2}}{N_0}\right) \tag{I.9}$$

I.10.2 Uplink NOMA

Figure I.13 shows a diagram of the NOMA for the UL. It is actually the reverse process of Downlink (DL) in which users 1 and 2 transmit.

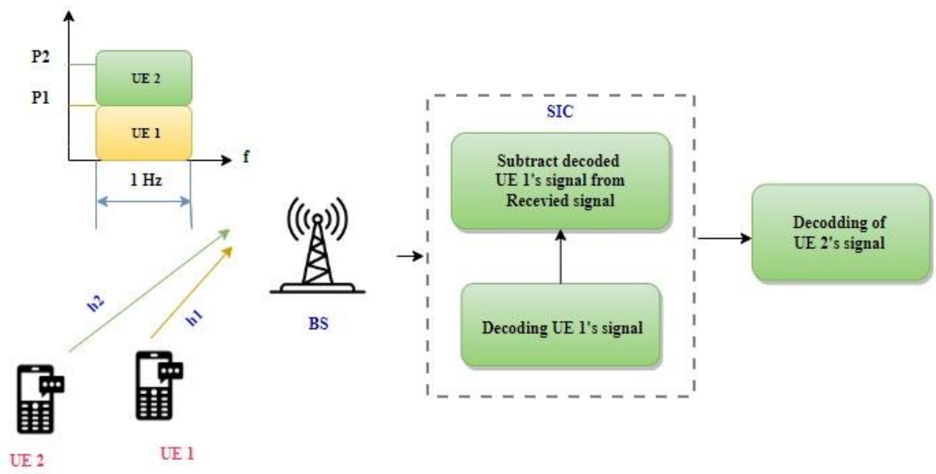


Figure I. 13: Uplink NOMA.

Their X_1 and X_2 signals with the same power pvers the BS [28].

The signal received at the BS is defined by the following equation:

$$y = \sqrt{p}h_1X_1 + \sqrt{p}h_2X_2 + w \qquad \text{(I.10)}$$

This means that the BS will treat UE 2 as interference and decode directly the term X_1 from dey, Spectral efficiency at the BS level to decode the data of UE 1 is:

$$\mathrm{R}_1 = log_2\left(1 + \frac{p_{|h2|^2}}{p_{|h_1|^2+\sigma^2}}\right) \qquad \text{(I.11)}$$

Where $\sigma^2$is the power spectral density of the noise, $h_1$and h_2 the complex coefficients of the canal on both routes.

Then, SIC can be performed to recover component X_2. The effectiveness at the level of UE 2 will therefore be [29]:

$$\mathrm{R}_2 = log_2\left(1 + \frac{p_{|h2|^2}}{\sigma^2}\right) \qquad \text{(I.12)}$$

I.11The Benefits and The Drawbacks of NOMA

I.11.1The Benefits

The benefits of NOMA are as follows:

- Due to the utilization of numerous users on the same frequency resource, it enables improved spectral efficiency.
- By supporting many concurrent users at once, it provides huge connection.
- Due to continuous simultaneous transmission rather than a specific set time window, it delivers decreased latency.
- It uses flexible power control techniques to provide improved QoS to all users. Throughput at the cell edges is increased, and users have a better experience there.
- NOMA with MIMO provides better performance.

I.11.2 The Drawbacks

The drawbacks of NOMA are as follows:

- ❖ All users in the cluster, even those with the lowest channel gains, must decode each other's information. The receiver becomes more complicated as a result. Additionally, there is a rise in energy use.
- ❖ If a single user has a SIC mistake, the information decoded for all other users will be incorrect. As a consequence, each of the clusters in the cell can only serve a certain number of consumers at a time.
- ❖ The gain differential of Channel across users must be sufficient to achieve the intended functions of the domain notion of power in NOMA at the receiver. This restricts the amount of user pairs that clusters can serve.
- ❖ Because channel gain information must be sent by each user to the base station as feedback, NOMA is sensitive enough to gather these measurements.

I.12 Conclusion

NOMA is expected to play an important role in the development of 6G wireless networks. In this chapter, we have provided a look at the requirements, trends, and applications of 6G. Also, we have defined the concept of OMA and NOMA and the principle of NOMA’s operation in downlink and uplink. Finally, we have mentioned the benefits and drawbacks of NOMA. NOMA’s ability can help efficiently share time frequency resources among multiple users. In addition to that, the combination of NOMA with other advanced technologies such as cooperative NOMA and energy harvesting, is very important to meet the requirements of users in new and future communication systems. This combination is the objective of the next chapter.

Chapter II:

Energy Harvesting for Wireless Networks

II.1 Introduction

Cooperative NOMA embodies the concept of collaboration between users to enhance system capacity and spectral efficiency. This chapter is organized as follows. First, we explain how the NOMA cooperative system works. Then, we study some cooperative techniques such as AF and DF. Next, we present the energy harvesting (EH) and the types of its sources, paying particular attention to NOMA with EH. Finally, we conclude with the advantages and disadvantages of the cooperative NOMA -EH.

II.2 Cooperative Relaying Communication

Cooperative relaying communication refers to a communication protocol in which multiple users collaborate with each other to transmit data to their intended destinations. In cooperative relaying, some users with better channel conditions act as relays to help weaker users. Specifically, the source user transmits the data to the relay user, who forwards the data to the destination user. Cooperative relaying can improve the reliability and coverage of wireless communication systems, as it allows users with poor channel conditions to communicate with their intended recipients through the help of relay users.

II.3 Cooperative NOMA

Cooperative NOMA refers to a communication protocol that combines the benefits of cooperative communication and NOMA. In cooperative NOMA, multiple users collaborate with each other to share their resources and help each other achieve better performance, while using NOMA techniques to efficiently share time-frequency resources among multiple users.

II.3.1 Concept of the Cooperative System

Cooperative communications refer to systems or techniques that allow the relay to help transmit messages to users who suffer from poor quality of service due to their too great distance from the base station, or by depending on their channel conditions [30]. Most cooperative transportation systems involve two phases of transmission:

1- **A coordination phase:** The relay receives messages from users of the base station.

2- **A cooperation phase:** The relay retransmits messages to users in cooperation, as illustrated in Figure II.1. To enable such cooperation, different relay technologies can be used based on the user's relative location, channel conditions, and transceiver complexity.

In our study, we present two techniques of basis of cooperative relays: Decode-and-Forward (DF), Amplify-and-Forward (AF).

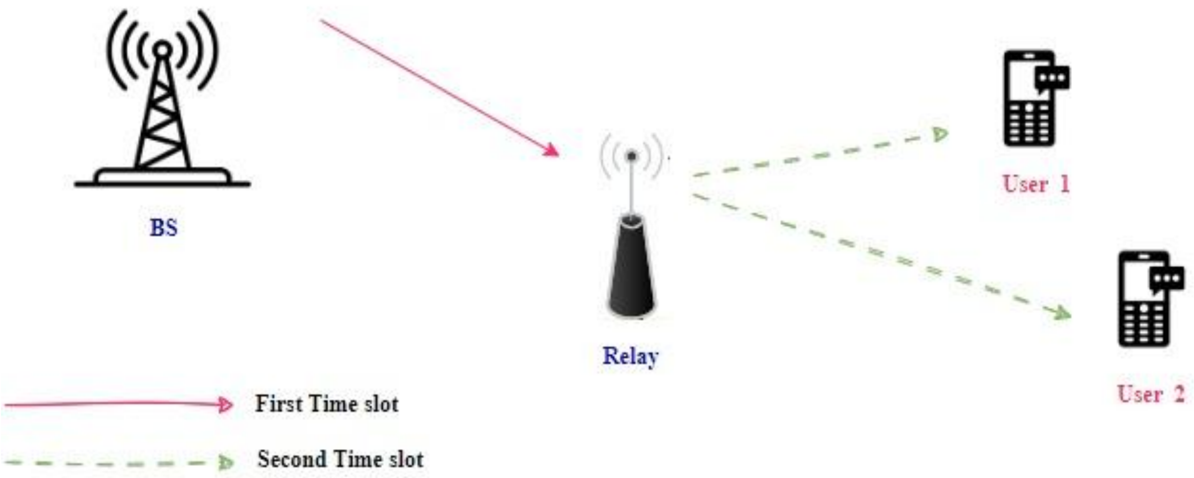


Figure II.1: Illustration of a relay-based NOMA cooperative system.

II.4 Techniques Cooperative Systems

Cooperative communication uses the broadcasting nature of wireless media. During the broadcast period, the neighboring node or relay node surprises the information and passes it on to users [31].

Cooperative NOMA systems combine the advantages of cooperative communication and NOMA to enhance the performance of wireless communication systems. Different techniques can be used to implement cooperative NOMA systems, some of which are:

II.4.1 Decode-and-Forward

The Decode-and-Forward (DF) relay scheme refers to cases where the relay decodes the signal transmitted by the base station and recodes it and transmits it to users, as illustrated in Figure II.2.

In the base DF relay scheme, the base station first transmits a SC to the relay in Phase I. Then, if the relay is able to decode successfully SC signal, it will recode SC signal again and transmit it to users of Phase II.

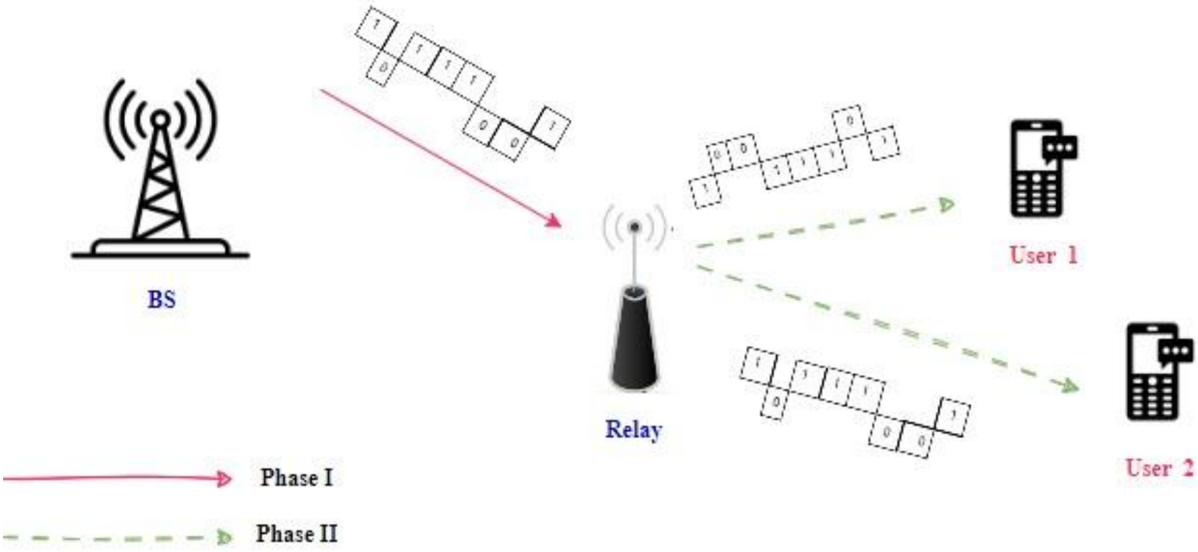


Figure II. 2: Illustration of DF relaying schemes.

User 2 is far from the BS and User 1 is near. An encoding message SC is sent, containing messages from user 1 and 2 with a distribution of different power depending on channel quality [32]-[34],[37].

The SC signal sent to the relay can be expressed as follows:

$$x_{sc} = x_1\sqrt{p_1} + x_2\sqrt{p_2} \quad \text{(II.1)}$$

The signal received at the relay is given by:

$$y_r = h_r x_{sc} + n_r \quad \text{(II.2)}$$

$$y_r = h_r\left(x_1\sqrt{p_1} + x_2\sqrt{p_2}\right) + n_r \quad \text{(II.3)}$$

Where

$p_1 = p_s \times \alpha_1$ $\alpha_2 = 1 - \alpha$

$p_2 = p_s \times \alpha_2$ $\alpha_1 = \alpha$

$\alpha_1 + \alpha_2 = 1$ $\alpha_2 > \alpha_1$

p_1: The power allocated to user message 1 to the BS.

p_2: The power allocated to user message 2 to the BS.

α_1, α_2: User power factors 1 and 2, respectively.

p_s: The transmit power of the BS.

n_r: AWGN at the relay

$x_1$and x_2: Message from users 1 and 2, respectively.

h_r: The channel coefficients BS – relay.

x_{sc}: The signal SC.

In relay, the SIC is used to identify user messages. User 2 is detected first and User 1's message is perceived as noise. Then, the message from user 2 is subtracted from the received signal to specify the message from user 1 [32]-[36].

The SINR of messages x_1 and $x_2$in the relay can be written as

$$SNIR_R^{u_2} = \frac{p_2|h_r|^2}{p_1|h_r|^2+\sigma_r^2} \quad \text{(II.4)}$$

$$SNIR_R^{u_1} = \frac{p_1|h_r|^2}{\sigma_r^2} \quad \text{(II.5)}$$

In the relay, the superposition encoding message is again sent with a Different power allocation to users [32]-[34],[37].The signal sent to each user can be expressed in the following form:

$$x_{sc} = x_1\sqrt{p_{u_1}} + x_2\sqrt{p_{u_2}} \quad \text{(II.6)}$$

The signal received to each user is given by:

$$y_i = h_i x_{sc} + n_i \quad \text{(II.7)}$$

$$y_i = h_i\left(x_1\sqrt{p_{u_1}} + x_2\sqrt{p_{u_2}}\right) + n_i \quad \text{(II.8)}$$

Where

$i = u_1,\ u_2$

$p_{u_1} = p_r \times \beta 1$ $\beta 2 > \beta 1$

$p_{u_2} = p_r \times \beta 2$

$\beta 1 + \beta 2 = 1$

p_{u_1}: The power allocated to user message 1 to the Relay.

p_{u_2}: The power allocated to user message 2 to the Relay.

$\beta 1, \beta 2$: User power factors 1 and 2, respectively.

p_r: Relay transmission power.

n_i: AWGN for every user.

h_i: The relay channel coefficients – user.

x_{sc}: The signal SC.

$$SNIR_{DF,u_2} = \frac{p_{u_2}\left|h_{u_2}\right|^2}{p_{u_1}\left|h_{u_2}\right|^2 + \sigma_{u_2}^2} \tag{II.9}$$

User 1 uses the SIC. User 1 first recognizes User 2's message and then subtracts it from the total received signal to recognize its own message. The SNIR for the signal received from user 1 can be written as:

$$SNIR_{DF,u_1}^2 = \frac{p_{u_2}\left|h_{u_1}\right|^2}{p_{u_1}\left|h_{u_1}\right|^2 + \sigma_{u_1}^2} \tag{II.10}$$

$$SNIR_{DF,u_1} = \frac{p_{u_1}\left|h_{u_1}\right|^2}{\sigma_{u_1}^2} \tag{II.11}$$

Where σ_{u1}^2 , σ_{u2}^2 is the variance of each of the nodes

The end-to-end SNIR for User 2 and User 1 can be expressed as [33],[38]:

$$\gamma_2 = min\{ SNIR_R^{u_2}, SNIR_{u_2} \} \quad \text{(II.12)}$$

$$\gamma_1 = min\{ SNIR_R^{u_1}, SNIR_{u_1} \} \quad \text{(II.13)}$$

II.4.1.1 System Capacity

In this subsection, we express the capability of the DF-NOMA protocol for User 1 and User 2, respectively.

The capacity of the BS- relay -U2 can be expressed as:

$$C_{DF,u_2} = \frac{1}{2}\log_2(1+\gamma_2) \quad \text{(II.14)}$$

The capacity of the BS-relay -U1 can be expressed as:

$$C_{DF,u_1} = \frac{1}{2}\log_2(1+\gamma_1) \quad \text{(II.15)}$$

II.4.1.2 Outage probability

In this subsection, we express the Outage probability (OP) for the DF-NOMA protocol for user 1 and user 2, respectively [32],[36].

The failure occurs in the BS- relay path -U2 when:

$$\frac{1}{2}\log_2(1+\gamma_2) < R \quad \text{(II.16)}$$

$$\gamma_2 < 2^{2R} - 1 \quad \text{(II.17)}$$

Therefore, the Outage probability of BS- relay -U2 is obtained by:

$$P_{out,DF}^{u_2} = P\left(\frac{1}{2}\log_2(1+\gamma_2) < R\right) = P(\gamma_2 < 2^{2R} - 1) \quad \text{(II.18)}$$

The failure occurs in the BS- relay path -U1 when:

$$\frac{1}{2}\log_2(1+\gamma_1) < R \quad \text{(II.19)}$$

$$\gamma_1 < 2^{2R} - 1 \quad \text{(II.20)}$$

Therefore, the Outage probability of BS- relay -U1 is obtained by:

$$P_{out,DF}^{u_1} = P\left(\frac{1}{2}\log_2(1+\gamma_1) < R\right) = P(\gamma_1 < 2^{2R} - 1) \qquad \text{(II.21)}$$

II.4.2 Amplify-and-Forward

Amplify-and-Forward (AF) relay schemes, the relay amplifies the signal received from the BS and transmits it to users (without explicitly decoding or demodulating messages or symbols) as shown in Figure II.3. These schemes are also called non-regenerative relay schemes. Here, relays do not need to know the Coding or modulation schemes used at the source.in addition to its low complexity, AF schemes are also desirable when the quality of the BS-relay link is not Sufficient to ensure reliable decoding at the relay level. In this case, the amplification of the Analog signal preserves soft information that can be further exploited at the destination [32]-[40].

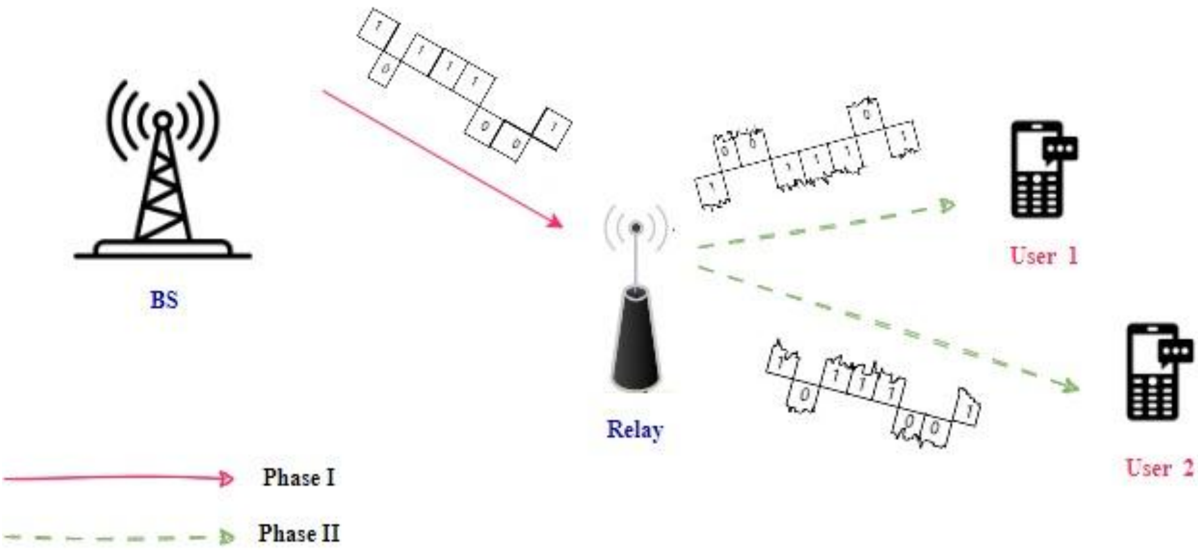


Figure II. 3: Illustration of NOMA based on AF relays.

In Phase I, the BS sends the SC signal to the relay.

The AF relay node amplifies the SC signal and retransmits it to users regardless of the quality of the BS-relay link [32]-[40].

The signal received at the relay can be expressed in the following form:

$$y_r = h_r x_{sc} + n_r \qquad \text{(II.22)}$$

With

$$x_{sc} = x_1\sqrt{P_1} + x_2\sqrt{P_2} \qquad \text{(II.23)}$$

$$y_r = h_r\left(x_1\sqrt{P_1} + x_2\sqrt{P_2}\right)+n_r \qquad \text{(II.24)}$$

In Phase II, the relay first scales the received signal. If the instantaneous gain of the channel $|h_r|^2$ is known at the relay level, the relay can multiply the signal received by the gain β:[32].

Knowing that:

$$\beta = \frac{1}{\sqrt{p_s|h_r|^2+\sigma_r^2}} \qquad \text{(II.25)}$$

The amplified signal at the relay level is given by:

$$x_{sc,r} = \beta\, y_r \qquad \text{(II.26)}$$

$$x_{sc,r} = \beta\left[h_r\left(x_1\sqrt{P_1} + x_2\sqrt{P_2}\right) + n_r\right] \qquad \text{(II.27)}$$

Note that the gain β depends on the BS-relay channel (h_r) and, therefore, varies between transmission intervals. Thus, this scheme is often referred to as a gain AF relay scheme variable [34]. Then, with the power P_r, the relay transmits the signal $x_{sc,r}$to users.

The signal received to the U2 user is as follows:

$$y_{u2} = \beta\sqrt{P_r}h_2\left[h_r\left(x_1\sqrt{P_1} + x_2\sqrt{P_2}\right) + n_r\right] + n_2 \qquad \text{(II.28)}$$

The signal received to the U1 user is as follows:

$$y_{u1} = \beta\sqrt{P_r}h_1\left[h_r\left(x_1\sqrt{P_1} + x_2\sqrt{P_2}\right) + n_r\right] + n_1 \qquad \text{(II.29)}$$

User 2 directly detects his message and considers User 1's message like a noise. While User 1 uses the SIC, he first recognizes the user 2, then subtracts it from the global signal to extract its message [34],[38],[40].

The SNIR in U2 can be expressed as:

$$SNIR_{AF,u2} = \frac{\beta^2 p_2 p_r |h_r|^2 |h_{u2}|^2}{\beta^2 p_1 p_r |h_r|^2 |h_{u2}|^2 + \beta^2 p_r |h_{u2}|^2 \sigma_r^2 + \sigma_{u2}^2} \quad \text{(II.30)}$$

U1 implements SIC, and it first recognizes the U2 signal, then recognizes its message special. The SNIR from U1 to U2 can be expressed as:

$$SNIR_{AF,u1}^2 = \frac{\beta^2 p_2 p_r |h_r|^2 |h_{u1}|^2}{\beta^2 p_1 p_r |h_r|^2 |h_{u1}|^2 + \beta^2 p_r |h_{u1}|^2 \sigma_r^2 + \sigma_{u1}^2} \quad \text{(II.31)}$$

Then the SNIR of U1 is expressed by:

$$SNIR_{AF,u1} = \frac{\beta^2 p_1 p_r |h_r|^2 |h_{u1}|^2}{\beta^2 p_r |h_{u1}|^2 \sigma_r^2 + \sigma_{u1}^2} \quad \text{(II.32)}$$

II.4.2.1 System Capacity

In this subsection, we express the capability of the AF-NOMA protocol to User 1 and User 2, respectively.

The capacity of the BS-relay -U2 can be expressed as:

$$C_{AF,u_2} = \frac{1}{2}\log_2\left(1 + SNIR_{AF,u2}\right) \quad \text{(II.33)}$$

The capacity of the BS- relay -U1 can be expressed as:

$$C_{AF,u_1} = \frac{1}{2}\log_2\left(1 + SNIR_{AF,u1}\right) \quad \text{(II.34)}$$

II.4.2.2 Outage probability

In this subsection, we express the OP for the AF-NOMA protocol for user 1 and user 2, respectively.

The OP occurs in the BS- relay path -U2 when:

$$\frac{1}{2}\log_2\left(1 + SNIR_{AF,u2}\right) < R \quad \text{(II.35)}$$

$$SNIR_{AF,u2} < 2^{2R} - 1 \quad \text{(II.36)}$$

Therefore, the OP of BS- relay -U2 is obtained by:

$$P_{out,AF}^{u_2} = P\left(\frac{1}{2}\log_2\left(1 + SNIR_{AF,u2}\right) < R\right) \tag{II.37}$$
$$= P\left(SNIR_{AF,u2} < 2^{2R} - 1\right)$$

The OP occurs in the BS- relay path -U1 when:

$$\frac{1}{2}\log_2\left(1 + SNIR_{AF,u1}\right) < R \tag{II.38}$$

$$SNIR_{AF,u1} < 2^{2R} - 1 \tag{II.39}$$

Thus, the OP in the path BS- relay -U1 is obtained:

$$P_{out,AF}^{u_1} = P\left(\frac{1}{2}\log_2\left(1 + SNIR_{AF,u1}\right) < R\right) \tag{II.40}$$
$$= P\left(SNIR_{AF,u1} < 2^{2R} - 1\right)$$

II.5 Energy Harvesting

Energy Harvesting (EH) is of extracting and converting energy from the environment into electrical power that can be used to supply energy to various electronic devices. This process involves capturing and utilizing the energy from sources such as solar radiation, thermal gradients, mechanical vibrations, and RF waves.

II.5.1 Definition Energy Harvesting

Gathering energy from the environment and turning it into useful electric power is a technique known as EH, this approach eliminates the need for traditional power sources, such as batteries or wired connections, by enabling electronic devices to operate in locations where a constant power supply is not readily available. By harnessing energy from ambient sources like solar radiation, mechanical vibrations, thermal gradients, or electromagnetic radiation, EH technology enables self-sustainable and autonomous operation of electronic devices. It provides an alternative power solution that reduces the reliance on batteries, extends device lifetimes, and eliminates the need for frequent battery replacements or running electrical wiring [41].

II.5.2 Types of Energy Harvesting Sources

As shown in Figure II. 4, the EH sources can be generally divided into four types: solar/light, thermoelectric power, mechanical motion and electromagnetic radiation.

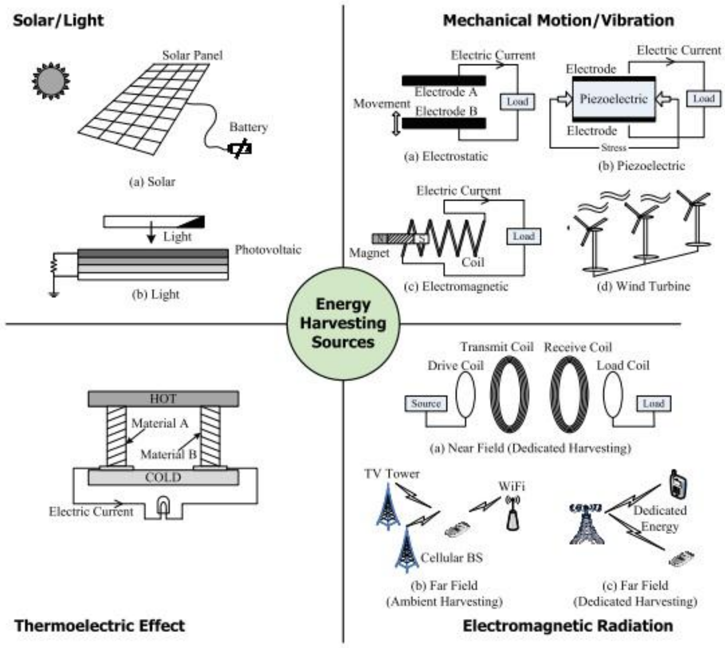


Figure II. 4: Types of energy sources [42].

- ✓ **Solar or light EH:** involves the conversion of light energy into electrical energy. This is typically done through the use of photovoltaic (PV) cells or solar panels. PV cells are made up of semiconducting materials, which produce an electric current when exposed to sunlight. This method is commonly used in outdoor wireless sensor networks, wearable devices, and other low-power devices that can benefit from the availability of natural light [43].
- ✓ **Thermoelectric EH:** is a process of converting temperature differences between two surfaces into electrical energy. The technology is based on the thermoelectric effect, which produces a voltage difference when there is a temperature difference between two dissimilar materials. Thermoelectric generators can harvest energy from a variety [44].
- ✓ **Mechanical motion/vibration energy sources:** refer to the conversion of mechanical energy, such as motion or vibration, into electrical energy using devices such as piezoelectric transducers, electromagnetic generators, or triboelectric nanogenerators. This type of energy harvesting is suitable for applications where mechanical energy is readily available, such as in industrial machinery, human motion, and transportation [45].

- ✓ **Electromagnetic radiation energy sources:** refer to the harvesting of energy from various forms of electromagnetic waves, including radiofrequency waves, microwave radiation, and ambient electromagnetic fields. This type of EH is commonly used in wireless power transfer and communication systems [46].

Radio frequency (RF) EH is the most acceptable approach out of all the many forms of EHs for a variety of reasons. It is inexpensive since there is no additional expense for the use of the spectrum, straightforward to deploy, and has a sustainable and controllable power source that is readily available in the form of transmitted energy (TV/radio broadcasting, cellular network signal, and handheld radios), even interference can be used by EH to its advantage

II.6 RF Energy Transfer

Recently, RF-EH techniques, which enable the process of generating electricity from the received RF signals, have received considerable research interests**.** Thus, a number of solutions have been proposed in terms of RF-EH to enhance power energy-constrained wireless networks for information transmission (IT) and signal processing due to a lack of radio resources. Since RF-EH technology has been deployed in wireless sensor networks (WSNs)**,** wireless body networks**,** and wireless charging systems**,** it is increasingly challenging to come up with new models to make RF-EH more efficient. Furthermore, wireless energy transfer has been presented in wireless systems for RF-EH, where a robust model was introduced so-called simultaneous wireless information and power transfer**.** In such a technique, both energy and information can be carried by RF signals [47].

Here, as shown in Figure II.5, an RF-EH network model with information gateways, sources, and nodes as its three primary constituents is taken into consideration. The information gateways, or BSs, act as wireless routers or relays. In theory, RF sources can be set up as RF transmitters or ambient RF sources to enable communication between user equipment nodes and information gateways. It should be noted that while energy from RF sources can be used to power the network nodes, the gateways and sources have a fixed power source [47].

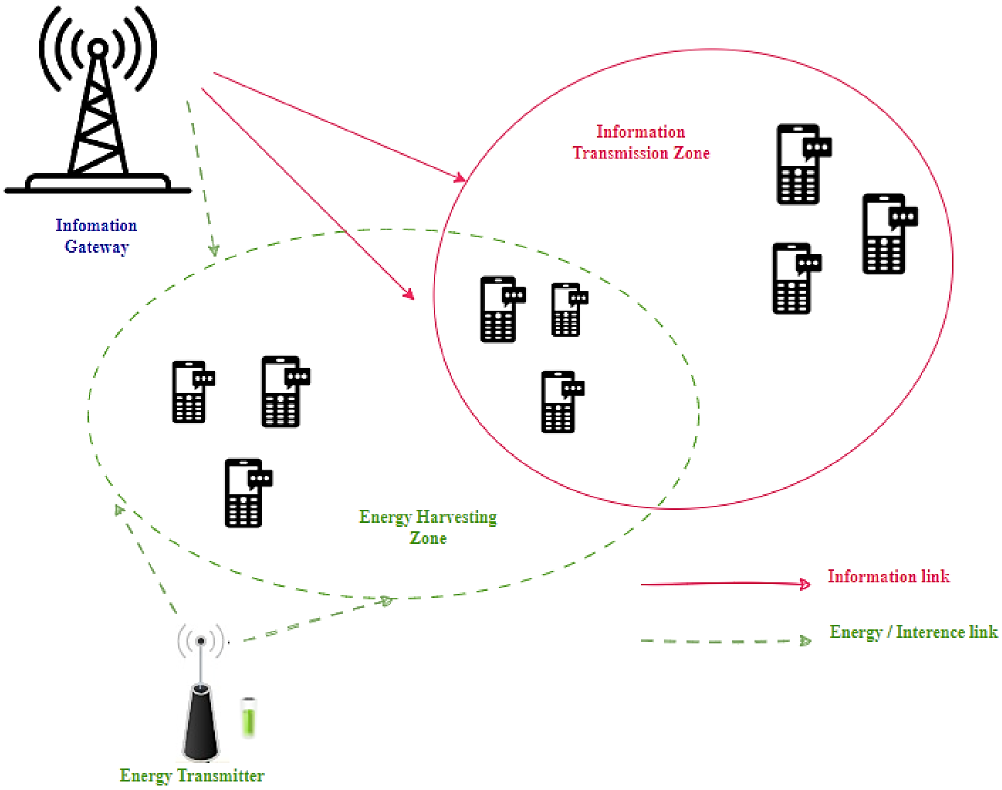


Figure II.5.: Infrastructure-based Architecture RF-EH.

Regarding Figure II.5, components in the IT zone (the line zone) can decode information, whereas devices in the EH zone (the dashed line zone) scavenge energy from BS. It should be remembered that each node in the EH and IT zone has its own RF energy. respectively, a harvester and an RF transceiver. EH and IT can therefore be done simultaneously [47].

The sources of RF energy can be categorized into two types:

a) Dedicated sources, which are specific devices designed for power transfer, such as Powercast.

b) Ambient sources, which are not dedicated devices and can include sources like access points.

In EH networks, there are two main types of power management schemes:

Harvest-use: In this scheme, the harvested energy is used immediately without storage for future use. To ensure effective operation, the amount of harvested energy must be greater than the energy consumed by a node.

Harvest-store-use: In this scheme, the harvested energy is stored in energy storage mechanisms like rechargeable batteries or super-capacitors. It is then used when the amount of harvested energy exceeds the energy consumption requirements.

RF-EH involves the utilization of the frequency range of the medium that carries electromagnetic signals, spanning from 3kHz to 300GHz. Apart from RF-EH, which is a technique for transferring energy over longer distances (referred to as far-field), there are other wireless energy transfer techniques, namely inductive coupling and magnetic resonance coupling. These techniques enable energy transfer through the use of magnetic fields and resonance phenomena, where Figure II.6 illustrates a generalized representation of an RF-EH network (EHN). The network comprises three key components [42]:

- RF energy sources, which can include Access Points (APs), BS, dedicated devices like Powercast, or even existing infrastructure such as TV or cellular towers.
- Information gateways, which encompass BS, AP, routers, relay nodes, and other similar devices. Both BS and AP serve as hybrid components, functioning as both energy sources and information gateways.
- Network nodes/devices, which consist of end-users such as sensors and other wireless communication devices.

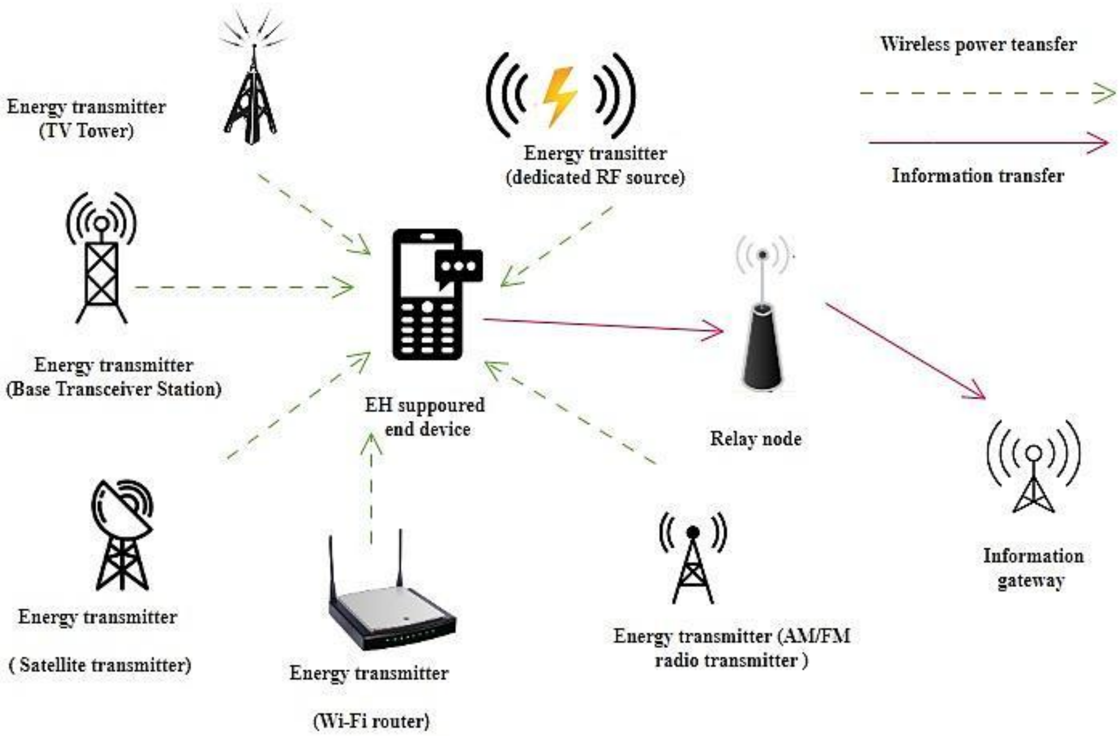


Figure II.6: RF-EH Network.

The RF-EH network operates based on the reception of RF signals transmitted in free space wireless communication. The received power is then harvested for energy utilization in the network.

II.7 NOMA with EH

Energy efficiency (EE) is another crucial issue in the 5G wireless networks that needs to be addressed in addition to improving SE. Most communication devices come with batteries, which have a finite lifespan. EH is a more effective strategy for increasing the lifespan of these energy-constrained devices as a result. EH techniques originally harness energy from renewable resources like the sun and wind, but because they rely on the environment, they are inconsistent. on the other hand, is a typical EH strategy where energy is captured throughout the decoding process. Even with interference from transmissions, it still gathers energy. According to C-NOMA, when stronger users act as relays for lesser users, their batteries quickly discharge. Consequently, both powerful and weak user signals Strength is declining. This problem encouraged researchers from academia and industry to combine EH and C-NOMA to enhance network EE in the following ways [43].

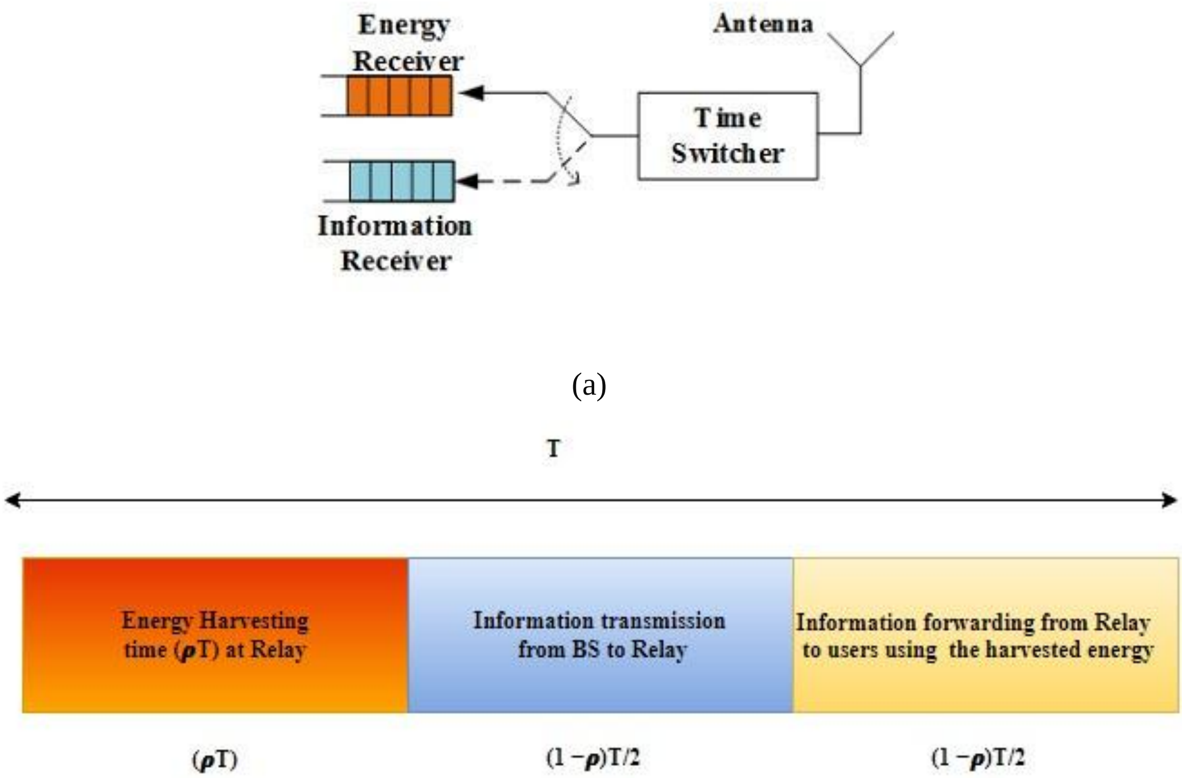
II.8 Techniques NOMA with EH

NOMA techniques combined EH offer innovative solutions for improving the efficiency and sustainability of wireless networks.

In NOMA with EH, two primary techniques are commonly used:

II.8.1 Time Switching (TS)

For TS, the signal is split in the time domain. A switch is used such that during one part of the transmission time the received signal is connected to an energy harvester for power transfer and during the other part of the transmission time the received signal is switched to an information decoder for message delivery, [48]-[50] Figure II.7 gives an example.



(a)

(b)

Figure II.7: (a): Time Switcher Architecture ;(b): TS-based relay protocol.[47].

Thus, the most important design parameter in this method is called the time-switching coefficient. The switching can happen within one packet between its data part and energy part, or between packets, depending on whether the whole packet or only part of the packet is used for power transfer. Without loss of generality, one can assume that the total transmission time is T seconds, of which αT seconds are used for power transfer and (1 − α)T seconds are used for information delivery, where $0 \leq \alpha \leq 1$ is the TS coefficient. The time T could be the symbol, frame or packet interval. Thus, the signal received for processing can be expressed as [48]-[50]:

$$y(t) = \begin{cases} h\sqrt{P_s}s(t) + n(t), & 0 \leq t \leq \alpha T \\ h\sqrt{P_s}s(t) + n(t), & 0\,T \leq t \leq T \end{cases} \quad \text{(II.41)}$$

where Ps is the transmission power, $s(t)$ is the transmitted data symbol or any symbol, h is the complex channel gain between the transmitter and the receiver and $n(t)$ is the complex AWGN with mean zero and variance $2\sigma^2$. Note that this model is a baseband model where the signal has already been down-converted and the in-phase and quadrature components have been combined. From (II.41), the first part is used for EH to give the total harvested energy as:

$$E = \eta \alpha P_s |h|^2 T \quad \text{(II.42)}$$

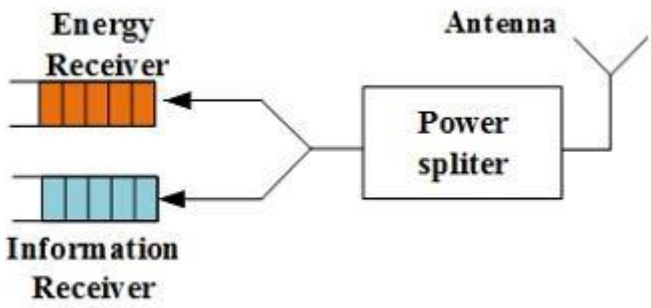
where η ($0 \leq \eta \leq 1$) is the energy conversion efficiency factor [48]-[50]. Thus, the transmit power of the relay through the harvested energy is given by:

$$P_r = P_s |h_r|^2 2\eta\alpha(1-\alpha) \quad \text{(II.43)}$$

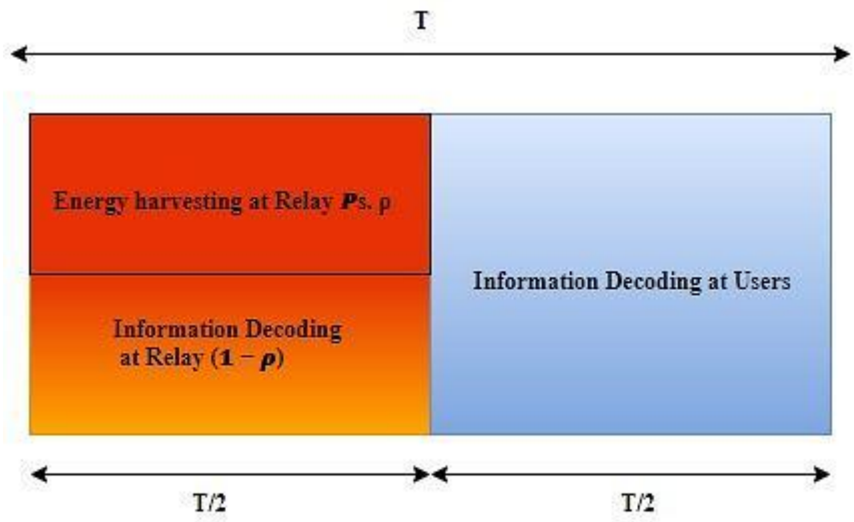
$E[|s(t)|^2] = 1$ has been assumed so that all the transmitted symbols have unit power[48],[49].

II.8.2 Power Splitting (PS)

For PS, the signal is split in the power domain. A power splitter is used in the circuit so that the received signal as an input will be divided into two parts: one part is fed into the energy harvester for energy harvesting and the other part is fed into the decoder for information decoding Figure II.8 gives an example [45],[49].



(a)



(b)

Figure II.8: (a): Power Splitter Architecture; (b): PS-based relay protocol [47].

Thus, unlike TS, energy harvesting and information decoding can be processed simultaneously but separately. The most important design parameter in this case is the PS factor, similar to the TS coefficient. Thus, the received signals for power transfer and for information delivery, respectively, can be written as [48]-[51]:

$$y_1(t) = \sqrt{\rho P_s} hs(t) + \sqrt{\rho} n_\alpha + n_d(t), 0 \le t \le T \qquad \text{(II.44)}$$

$$y_2(t) = \sqrt{(1-\rho) P_s} hs(t) + \sqrt{1-\rho} n_\alpha + n_d(t), 0 \le t \le T \qquad \text{(II.45)}$$

where $\rho$is the PS factor, $n_\alpha(t)$is the complex AWGN introduced by the antenna with mean zero and variance $2\sigma_\alpha^2$, and $n_d(t)$is the complex AWGN introduced by the conversion with mean zero and variance $2\sigma_d^2$. Again, this is a baseband signal model [48]-[51].

Several observations can be made. First, $n(t)$in (II.41) is related to $n_\alpha(t)$and $n_d(t)$in (II.44,45) as $n(t) = n_\alpha(t) + n_d(t)$. In other words, the AWGN in (II.41) actually consists of noise from the antenna as well as noise from processing. Thus, $2\sigma^2 = 2\sigma_\alpha^2 + 2\sigma_d^2$.

Secondly, the power splitting is applied to the received RF signal. Thus, one has $\sqrt{\rho} n_\alpha(t)$ and $\sqrt{1-\rho} n_\alpha(t)$, as $n_\alpha(t)$is part of the RF signal and is also split.

Using (II.44,45), the total energy harvested from the energy signal is given [48]-[51] by

$$E = \eta \rho P_s |h|^2 T \qquad \text{(II.46)}$$

where η (0 ≤ η ≤ 1) is the energy conversion efficiency factor. Thus, the transmit power of the relay through the harvested energy is given [48]-[51] by

$$P_r = P_s |h_r|^2 \eta \rho \qquad \text{(II.47)}$$

II.9 Advantages and Disadvantages Cooperative EH-NOMA

II.9.1 Advantages

- **Enhanced Energy Efficiency:** Cooperative EH-NOMA enables energy-efficient communication by leveraging energy harvesting capabilities. Users can harvest energy from the environment, reducing reliance on external power sources and extending network operation time [52].

- **Increased Network Lifetime:** By integrating energy harvesting into NOMA, the network's lifetime can be extended as users can replenish their energy reserves during communication. This is particularly beneficial in scenarios where battery replacement or recharging is challenging or not feasible [52].
- **Improved Spectral Efficiency:** Cooperative EH-NOMA allows multiple users to share the same time and frequency resources, increasing spectral efficiency and accommodating a larger number of users within the system.
- **Enhanced Coverage:** Energy harvesting capabilities in Cooperative EH-NOMA can enhance coverage in areas where power infrastructure is limited or unreliable, enabling communication in remote or challenging environments [52].

II.9.2 disadvantages

- **Energy Harvesting Constraints:** The availability and reliability of ambient energy sources for harvesting may vary depending on the environment, which can impact the performance and reliability of EH-NOMA systems [52].
- **Complexity:** The design and implementation of Cooperative EH-NOMA systems can be more complex compared to traditional communication systems. Coordinating energy harvesting, power allocation, and decoding strategies requires sophisticated algorithms and protocols.
- **Interference Management:** As NOMA relies on the superposition of signals, interference management becomes crucial in Cooperative EH-NOMA systems. Interference from multiple users can degrade the system performance and require effective interference cancellation techniques [52].
- **System Design Trade-offs:** Balancing the energy harvesting, power allocation, and user fairness considerations requires careful system design trade-offs. Optimizing the system for different objectives, such as energy efficiency, fairness, or throughput, may introduce trade-offs in performance metrics [52].

II.10 Conclusion

In conclusion, the cooperative NOMA with EH are promising technologies that enhance the performance and efficiency of wireless communication systems. In this chapter, we have introduced the concept of cooperative system and its most prominent techniques. In addition, we have presented the EH and the types of its sources, precisely Radio frequency (RF) as well as the advantages and disadvantages of the cooperative NOMA -EH. In the next chapter, we will introduce the downlink cooperative NOMA feature with EH using the TS protocol.

Chapter III:

Simulation of Downlink Cooperative NOMA Using TS Protocol

III.1 Introduction

According to the previous chapter, we have shown the advantage of downlink cooperative NOMA with EH. In this chapter, we focus on downlink cooperative NOMA using TS protocol. We study and evaluate the performance of the downlink cooperative NOMA using TS protocol. Also, we evaluate the BER, outage probability and capacity of the system through simulation results. We finish up with comparing our results with downlink cooperative NOMA without TS protocol.

III.2 System model

We consider a downlink NOMA system consisting of a BS, one relay and two users 1 (U1) and user 2 (U2). U1 is far and U2 is close to the BS as presented in Figure 1. It is assumed that the relay does not have any power to forward the signals in the second phase. Thus, we assume that the relay uses EH technology from the BS using the TS protocol. The Rayleigh fading channel is assumed to be between nodes.

By assuming T is a total communication time duration, the BS first transmits a signal in ρT seconds, and the relay harvests energy during this time. In the first $(1-\rho)$T/2, the BS transmits an SC signal to the relay consisting of the signals of users with different power levels based on the channel gain $|h_2|^2>|h_1|^2$. Then, the relay uses the harvested energy to forward this signal to the users in the second $(1-\rho)$T/2 (see ***Figure III.1.*** (a) and ***Figure III.1.*** (b)). The received signal at relay is given by

$$y = \sqrt{P_S}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)h_r + n \tag{III.1}$$

where $\alpha_1 + \alpha_2 = 1$. $\alpha_1 > \alpha_2$. α_1 and α_2 are the power allocation coefficients of U1 and U2, respectively. x_1 and x_2 are the signals of the U1 and U2, respectively. P_S is the total transmit power. $n \sim \mathrm{CN}(0, \sigma^2)$ at the AWGN. h_r is the Rayleigh fading channel between BS-relay, where $h_r \sim \mathrm{CN}(0, \sigma_r^2)$. $\sigma_r^2 = d_r{}^{-\alpha}$, where d_r denote the distances between the BS-relay, respectively and α is the path loss exponent.

The relay decodes x_1 first without SIC. Then, using the SIC process its decodes x_2 signal. The SINR relay is given by

$$\gamma_{relay}^{1} = \frac{a_1 P_S |h_r|^2}{a_2 P_S |h_r|^2 + \sigma^2} \tag{III.2}$$

$$\gamma_{relay}^{2} = \frac{a_2 P_S |h_r|^2}{\sigma^2} \quad \text{(III.3)}$$

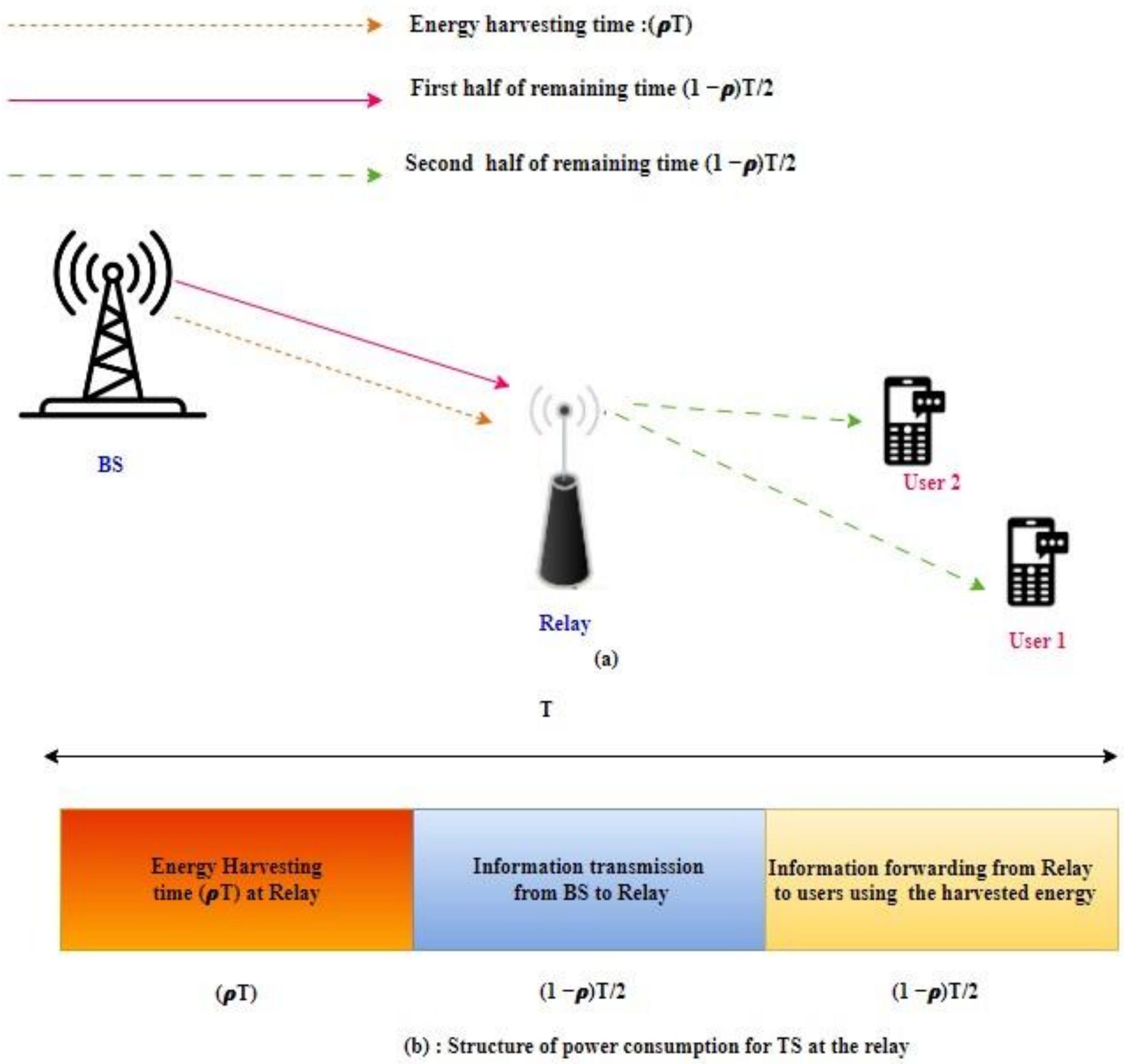


Figure III.1: (a): System model of the TS aided DF-relay NOMA; (b): Structure of power consumption for TS at the relay.

The harvested energy at relay during ρT of time is given by:

$$E_h = \rho T \eta P_S |h_r|^2 \quad \text{(III.4)}$$

The transmission power of relay during second $(1 - \rho)\,T/2$ of time can be given as:

$$P_r = \frac{E_h}{(1-\rho)\,T/2} = \frac{2\rho\eta P_S |h_r|^2}{(1-\rho)} \quad \text{(III.5)}$$

where ρ is the TS factor and η (0 < η < 1) is the energy conversion efficiency factor.

The relay uses the harvested power to re-encode the received signals and combine them in a new SC signal and forward it to the users during the $(1-\rho)\,T/2$. The received signal at users is given by

$$y = \sqrt{P_r}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)h_i + n \qquad \text{, where i=1,2} \tag{III.6}$$

where h_i is the Rayleigh fading channel between BS and users, where $h_i \sim CN(0,\sigma_i^2)$. $\sigma_r^2 = {d_i}^{-\alpha}$, where d_i denote the distances between BS and users.

The U1 decodes its signal x_1 without SIC and U2 uses the SIC process to decodes its signal x_2. The SINR users are given by

$$\gamma_{U1}^1 = \frac{a_1 P_r |h_1|^2}{a_2 P_r |h_1|^2 + \sigma^2} \tag{III.7}$$

$$\gamma_{U2}^1 = \frac{a_1 P_r |h_2|^2}{a_2 P_r |h_2|^2 + \sigma^2} \tag{III.8}$$

$$\gamma_{U2}^2 = \frac{a_2 P_S |h_2|^2}{\sigma^2} \tag{III.9}$$

III.3 Simulation and Results

In this section, we simulate the BER, outage probability and capacity of a downlink cooperative NOMA system using TS protocol.

III.3.1 Simulation Parameters

In the simulations, we use the following parameters:

Parameters	Values
Distance between BS and relay	**1 m**
Distance between relay and U1	2 m
Distance between relay and U 2	1 m
ρ	0.2
η	0.95
Path loss	4
Power allocation coeffiecent of U1	α_1=0.2
Power allocation coeffiecent of U2	α_2=0.8
Transmission rate of users	R_2 = 0.5 bps/Hz and R_1 = 0.5 bps/Hz
Channel	Rayleigh

Table III.1. Simulation parameters.

III.3.2 Capacity of System

In this subsection, we perform the simulation capacity of downlink cooperative NOMA using TS protocol. We compare our system with downlink cooperative NOMA without TS protocol.

The capacity of U1 and U2 of downlink cooperative NOMA using TS protocol are given by

$$C_{U1}^{TS} = \frac{1 - \rho}{2} log2\left(1 + \min\left(\gamma_{relay}^{1}, \gamma_{U1}^{1}\right)\right) \tag{III.10}$$

$$C_{U2}^{TS} = \frac{1 - \rho}{2} log2\left(1 + min(\gamma_{relay}^{2}, \gamma_{U2}^{2})\right) \tag{III.11}$$

The capacity of U1 and U2 of downlink cooperative NOMA without TS protocol are given by

$$C_{U1} = \frac{1}{2}log2\left(1 + min(\frac{a_1 P_S |h_r|^2}{a_2 P_S |h_r|^2 + \sigma_r^2}, \frac{a_1 P_r |h_1|^2}{a_2 P_r |h_1|^2 + \sigma^2})\right) \quad \text{(III.12)}$$

$$C_{U2} = \frac{1}{2}log2\left(1 + min(\frac{a_2 P_S |h_r|^2}{\sigma^2}, \frac{a_2 P_r |h_r|^2}{\sigma^2})\right) \quad \text{(III.13)}$$

Note: In the downlink cooperative NOMA without TS protocol, we assume that $P_s = P_r$.

- **SNR**

Figure III.2 presents the capacity of the two users of downlink cooperative NOMA using TS protocol compared to without TS protocol. We observe that the capacity of U2 is better than U1 with and without TS protocol. It is observed also the capacity of users with TS achieve better performance gain than the case of without TS protocol.

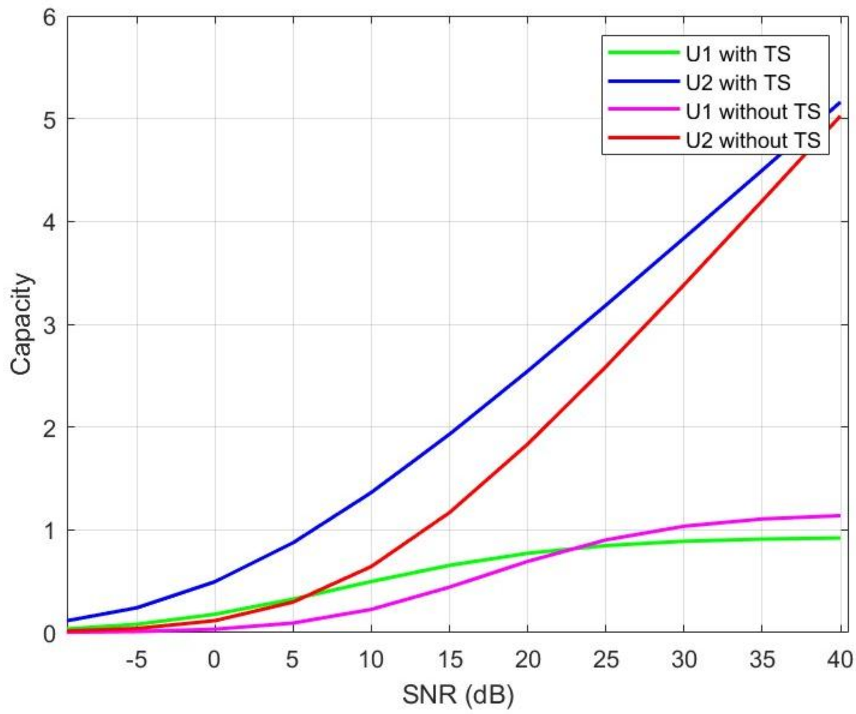


Figure III.2: Capacity of U1 and U2 of downlink cooperative NOMA using TS protocol compared to without TS protocol.

❖ **Factor ρ, η and α_2**

Figure III.3 presents the capacity of downlink cooperative NOMA using TS protocol vs ρ, when SNR=20 dB. We observe that the increase of ρ increase the capacity of users in lower values of ρ and in the high values of ρ, the capacity performance degrades. It seen also the maximum performance is achieved based on ρ. The capacity of downlink cooperative NOMA using TS protocol is not always better than downlink cooperative NOMA without TS protocol, rather it depends on the values of ρ.

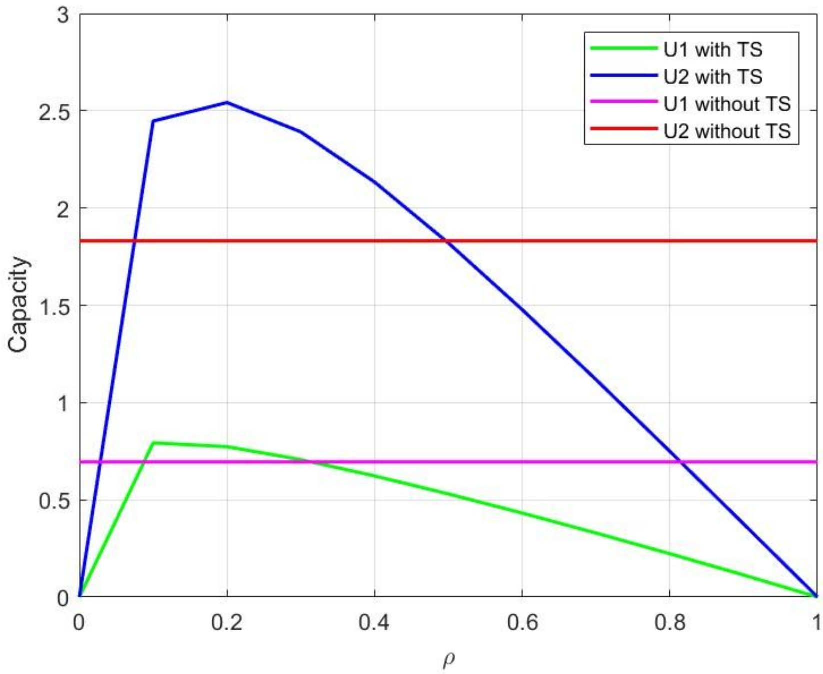


Figure III.3: Capacity of U1 and U2 of downlink cooperative NOMA using TS protocol vs ρ.

Figure III.4 presents the capacity of downlink cooperative NOMA using TS protocol vs η, when SNR=20 dB. We observe that the increase of η increase the capacity of users. The capacity of downlink cooperative NOMA using TS protocol is better than downlink cooperative NOMA without TS protocol as the values of η increase.

Figure III.5 presents the capacity of downlink cooperative NOMA using TS protocol vs a_2, when SNR=20 dB. We observe that the change of a_2, change the capacity of the two users. The change of a_2 effect the SIC and the detection of the users. Again, the capacity of downlink cooperative NOMA using TS protocol is better than downlink cooperative NOMA without TS protocol in all a_2 values.

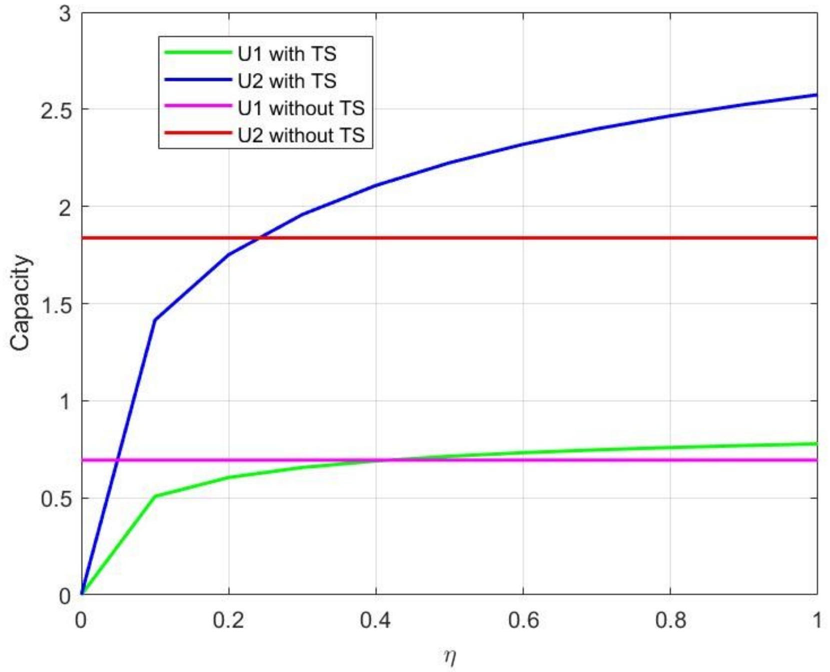


Figure III.4: Capacity of U1 and U2 of downlink cooperative NOMA using TS protocol vs η.

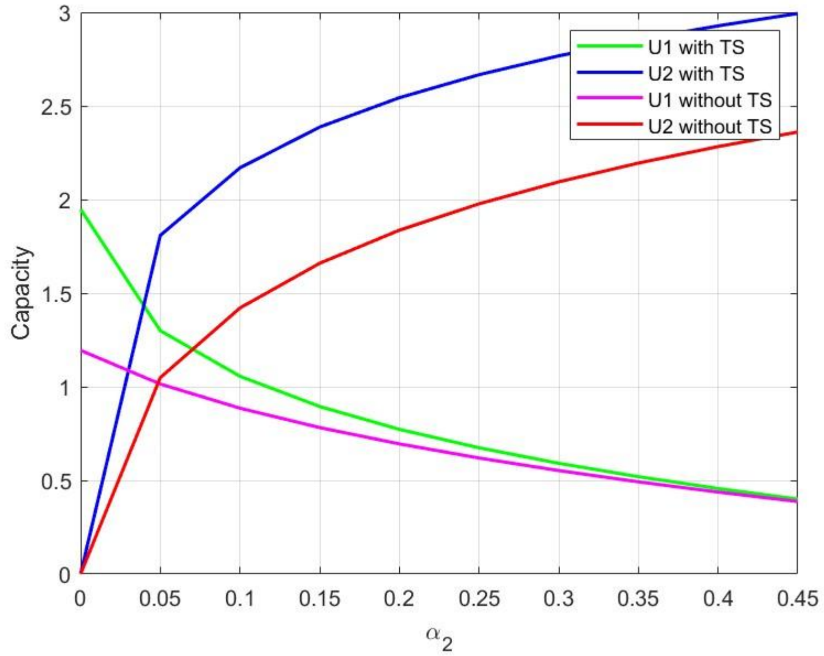


Figure III.5: Capacity of U1 and U2 of downlink cooperative NOMA using TS protocol vs a_2.

III.3.3 Outage probability

In this subsection, we perform the simulation outage probability of downlink cooperative NOMA using TS protocol. We compare the outage probability of our system with downlink cooperative NOMA without TS protocol.

The outage probability of U1 is defined as the capacity C_{U1} of U1 and is less than the rate R_1, i.e.,

$$P_{out,U1} = \mathrm{P}(C_{U1}^{TS} < R_1) \qquad \text{(III.14)}$$

The outage probability of U2 is defined as the sum of: When x_1 is detected erroneously and correctly. Thus, the outage probability of U2 signal can be expressed by

$$P_{out,U2} = \mathrm{P}(C_{U1}^{TS} < R_1, C_{U1}^{TS} < R_2 \qquad \text{(III.15)}$$

Likewise, in the downlink cooperative NOMA without TS protocol, the outage probability of U1 and U2 are defined as

$$P_{out,U1} = \mathrm{P}(C_{U1} < R_1) \qquad \text{(III.16)}$$

$$P_{out,U2} = \mathrm{P}(C_{U1} < R_1, C_{U2} < R_2 \qquad \text{(III.17)}$$

- **SNR**

Figure III.6 presents the outage probability of the two users of downlink cooperative NOMA using TS protocol compared to without TS protocol. We observe that the U2 achieve better performance gain compared to U1. It is seen also the users of downlink cooperative NOMA using TS protocol achieve better performance than users of downlink cooperative NOMA without TS protocol.

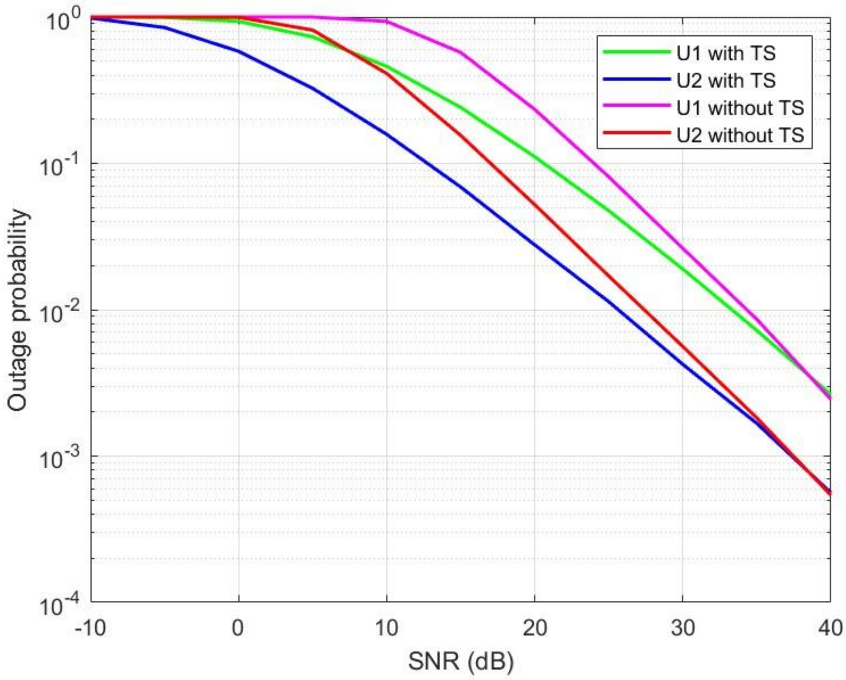


Figure III.6: Outage probability of U1 and U2 of downlink cooperative NOMA using TS protocol compared to without TS protocol.

❖ **Factors ρ and η , α_2**

Figure III.7 presents the outage probability of the two users of downlink cooperative NOMA using TS protocol vs ρ, when SNR=20 dB. We observe that the increase of ρ decrease the outage probability of users. Again, the outage probability of the two users of downlink cooperative NOMA using TS protocol achieve better performance gain compared to outage probability of downlink cooperative NOMA without TS protocol.

Figure III.8 presents the outage probability of the two users of downlink cooperative NOMA using TS protocol vs η, when SNR=20 dB. We observe that with the increase of η values, improves the outage probability of the two users of downlink cooperative NOMA using TS protocol. The outage probability of downlink cooperative NOMA using TS protocol achieve better performance gain compared to downlink cooperative NOMA without TS protocol.

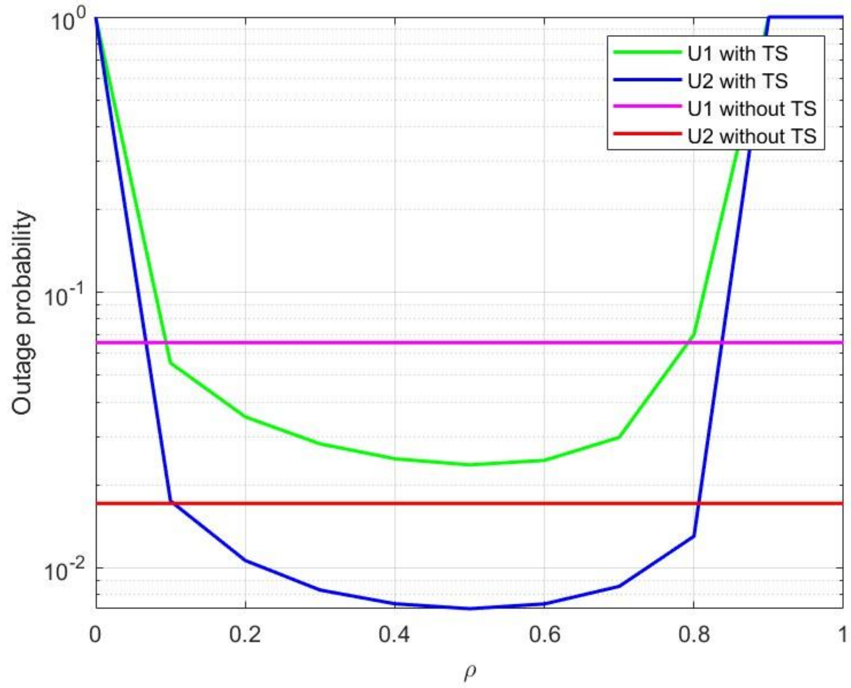


Figure III.7: Outage probability of U1 and U2 of downlink cooperative NOMA using TS protocol vs ρ.

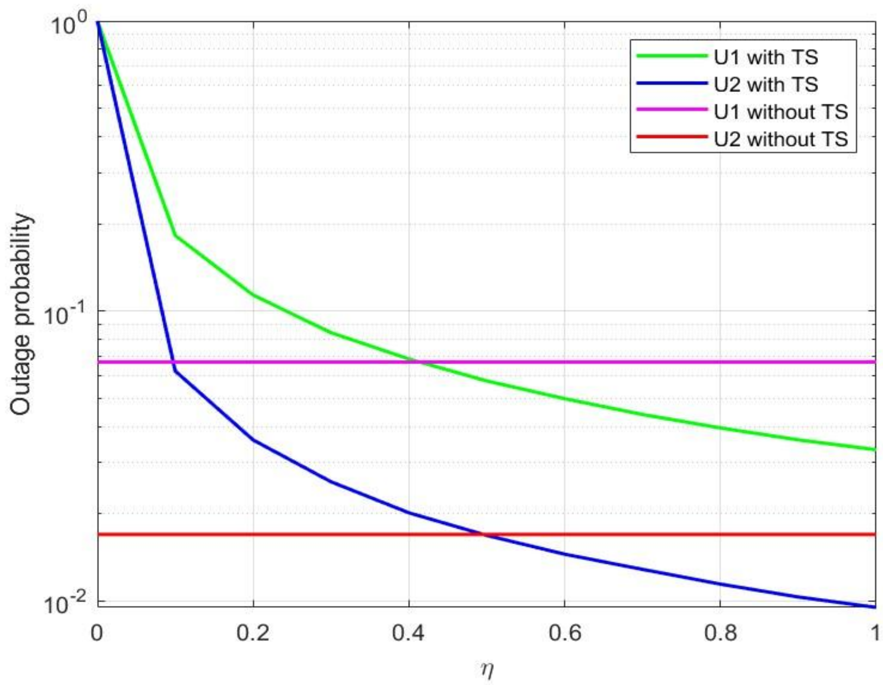


Figure III.8: Outage probability of U1 and U2 of downlink cooperative NOMA using TS protocol vs η.

Figure III.9 presents the outage probability of the two users of downlink cooperative NOMA using TS protocol vs a_2, when SNR=20 dB. We observe that the change of a_2 effect the performance of the two users. The change of a_2 effect the SIC the detection of users signals. The outage probability of downlink cooperative NOMA using TS protocol achieve better performance gain compared to downlink cooperative NOMA without TS protocol.

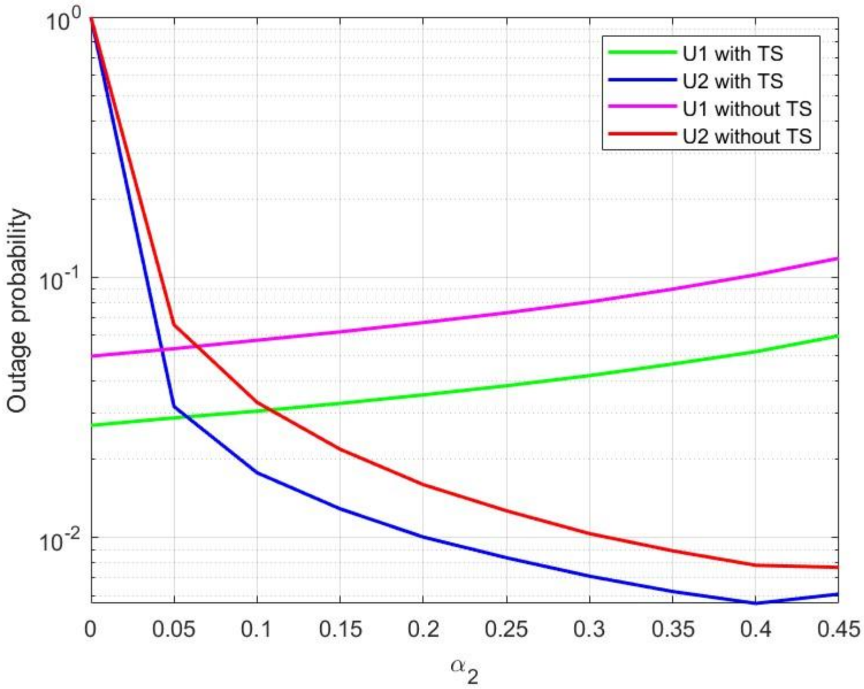


Figure III.9: Outage probability of U1 and U2 of downlink cooperative NOMA using TS protocol vs a_2.

III.3.4 Bit Error Rate

Bit Error Rate (BER) stands is a measure used to quantify the number of bit errors occurring in a communication system. The BER is expressed as the ratio of the number of bits that are received in error to the total number of bits transmitted.

The (BER) can be calculated using the following equation:

BER = (Number of bit errors) / (Total number of bits transmitted)

❖ **SNR**

Figure III.10 presents the BER of the two users of downlink cooperative NOMA using TS protocol compared to downlink cooperative NOMA without TS protocol. It is observed that increase SNR increase the BER performance. The U2 achieve better performance than U1. The BER of downlink cooperative NOMA using TS protocol achieve better performance gain compared to downlink cooperative NOMA without TS protocol.

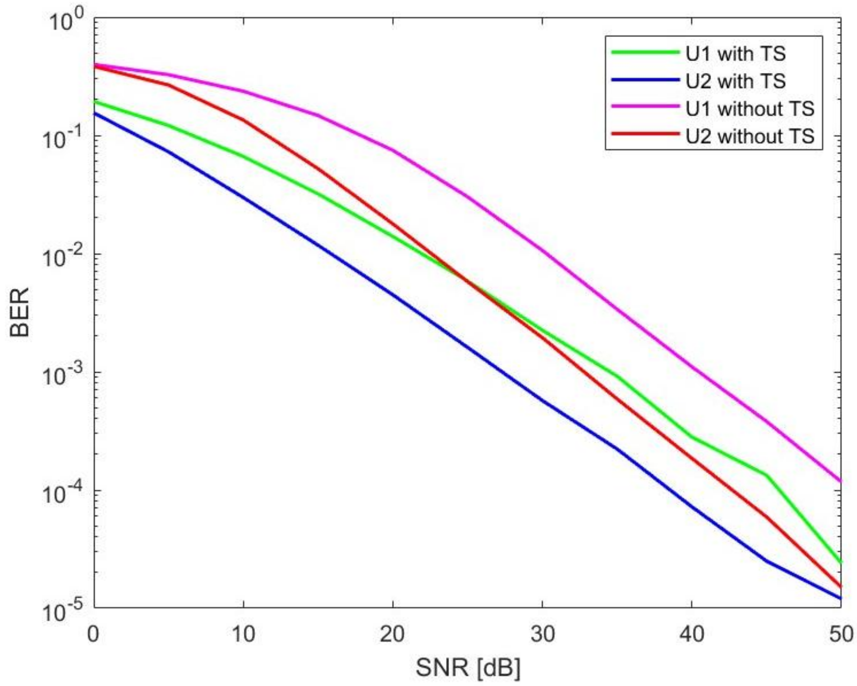


Figure III. 10: BER of U1 and U2 of downlink cooperative NOMA using TS protocol compared to without TS protocol.

❖ **Factors ρ and η , α_2**

Figure III.11 presents the BER of the uplink NOMA vs ρ, when SNR=20 dB. We observe that the increase of ρ improves the BER performance of users. Again, the downlink cooperative NOMA using TS protocol has higher performance gain compared to downlink cooperative NOMA without TS protocol.

Figure III.12 presents the BER of the uplink NOMA vs η, when SNR=20 dB. We observe that the increase of η improves the BER performance of users. The change of η values has an effect on the performance of the downlink cooperative NOMA using TS protocol. Increasing η improves the performance of downlink cooperative NOMA using TS protocol compared to downlink cooperative NOMA without TS protocol.

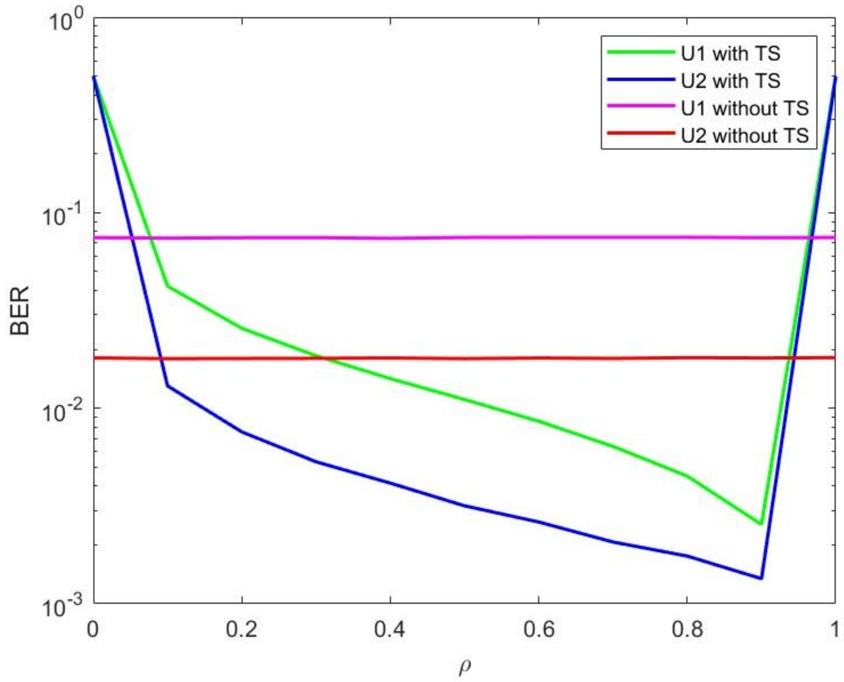


Figure III.11: BER of U1 and U2 of downlink cooperative NOMA using TS protocol vs ρ.

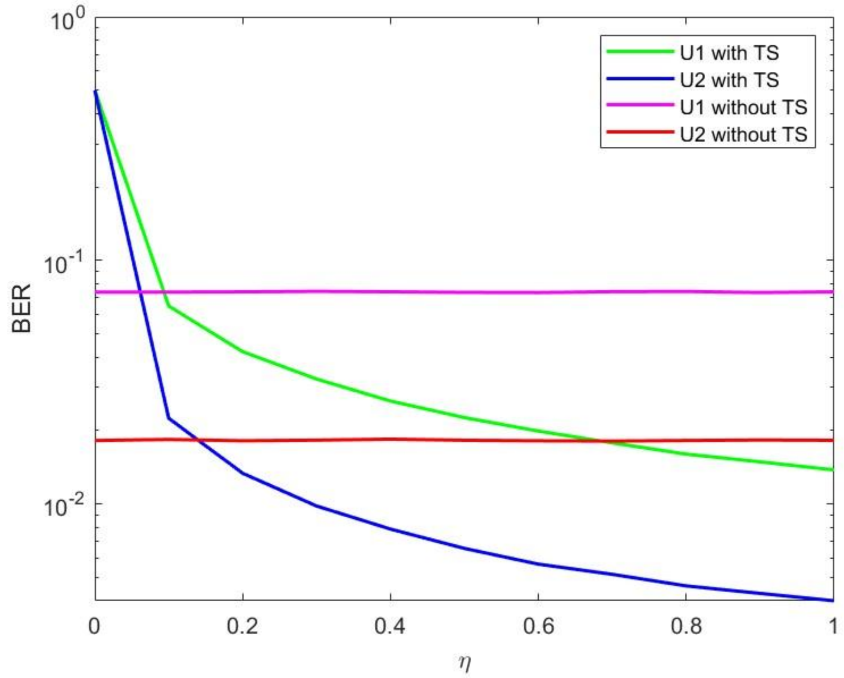


Figure III.12: BER of U1 and U2 of downlink cooperative NOMA using TS protocol vs η.

Figure III.13 presents the BER of downlink cooperative NOMA using TS protocol vs α_2, when SNR=20 dB. We observe that the increase of α_2 effect the BER of the two users. The change of α_2 effect the SIC and the detection of the users signals. Also, the downlink cooperative NOMA using TS protocol has better performance than without TS protocol.

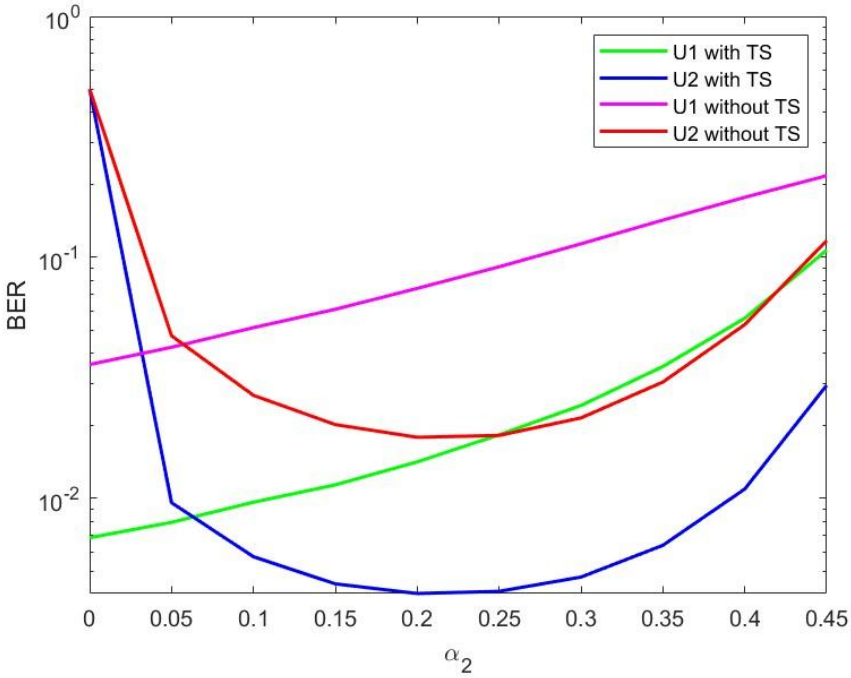


Figure III.13: BER of U1 and U2 of downlink cooperative NOMA using TS protocol vs α_2.

III.4 Conclusion

In this chapter, we have simulated the downlink cooperative NOMA using the TS protocol. We have compared our results with downlink cooperative NOMA without TS protocol. We also have simulated the BER, outage probability and capacity performances of our system. The simulation results have shown that the BER, outage probability and capacity of downlink cooperative NOMA using the TS protocol achieve better performance than without it. Moreover, the change in power allocation effects the SIC process and the detection of users. The improvement of the system performance depends on the values of the TS parameters.

General Conclusion

General Conclusion

NOMA scheme is envisioned as an emerging radio access technique to achieve high bit-rate and capacity for 6G networks. NOMA's main idea is to serve multiple users in terms of time, frequency and space. NOMA is different from OMA techniques in that the high needs of upcoming radio access systems cannot be met by OMA. In NOMA, we can serve multiple users at the same time, code or frequency with different power levels. NOMA uses the SC at the transmitter side and the SIC technique at the receiver side. Particularly, on the transmitter side, the information is combined in ac SC with different power level according to the channel gain. On the receiver side, SIC is applied for decoding the signals.

Furthermore, to improve the coverage, reliability, and system performance of the NOMA system, cooperative communication is proposed. Many techniques are used in cooperative NOMA, such as AF and DF. In AF, the relays amplify and forward the received signals, while in DF, the relays decode and forward the signals, enabling better signal quality and coverage. In a cooperative system, the relay is supposed to use its power to forward the signal in the second phase. The EH is a new technology in which the relay collects energy to forward the signal in the second phase. The integration of EH with CNOMA brings additional benefits to wireless networks where two commonly protocols in CNOMA are employed: PS and TS. EH allows devices to harvest energy from the environment, reducing the reliance on internal power sources and enhancing energy efficiency.

In this dissertation, we simulate the downlink cooperative NOMA using the TS protocol which is containing one BS, one relay and two users. We compare our results with downlink cooperative NOMA without TS protocol. We simulate the outage probability, capacity and BER of our considered system as well. The simulation results indicate that the BER, outage probability and capacity of downlink cooperative NOMA using the TS protocol achieve better performance than without it. We observe that the near user is better than the far one. Finally, the improvement of the system performance depends on the values of the TS parameters.

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