

## On performance of wireless-powered-based short-packet systems under multiple co-channel interference

Nguyen Quang Sang, Tran Cong Hung, Nguyen Huu Khanh Nhan, Bui Vu Minh & Lubos Rejcek

To cite this article: Nguyen Quang Sang, Tran Cong Hung, Nguyen Huu Khanh Nhan, Bui Vu Minh & Lubos Rejcek (19 Oct 2025): On performance of wireless-powered-based short-packet systems under multiple co-channel interference, Journal of Information and Telecommunication, DOI: [10.1080/24751839.2025.2573507](https://doi.org/10.1080/24751839.2025.2573507)

To link to this article: <https://doi.org/10.1080/24751839.2025.2573507>



© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 19 Oct 2025.



Submit your article to this journal [↗](#)



Article views: 28



View related articles [↗](#)



View Crossmark data [↗](#)

# On performance of wireless-powered-based short-packet systems under multiple co-channel interference

Nguyen Quang Sang<sup>a</sup>, Tran Cong Hung<sup>b</sup>, Nguyen Huu Khanh Nhan<sup>b,c</sup>, Bui Vu Minh<sup>d</sup> and Lubos Rejcek<sup>e</sup>

<sup>a</sup>Posts and Telecommunications Institute of Technology, Ho Chi Minh City, Vietnam; <sup>b</sup>Dean of School of Computer Science & Engineering, The SaiGon International University, Ho Chi Minh City, Vietnam; <sup>c</sup>Communication and Signal Processing Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam; <sup>d</sup>Faculty of Engineering and Technology, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam; <sup>e</sup>Faculty of Electrical Engineering and Informatics, University of Pardubice, Pardubice, Czech Republic

## ABSTRACT

This paper explores the performance of wireless-powered-based short-packet communication systems in light of multiple interference sources. In which, a source node uses energy harvested from multiple power beacons to serve its destination, and data communication is executed using a finite blocklength scheme. To quantify the system performance, an approximation for the cumulative distribution function of the received signal-to-interference-plus-noise ratio at the destination is derived in a closed-form manner. This approximation helps in finding a closed-form expression for the average block error rate (BLER) performance, facilitating the understanding of the relationship between the number of transmitted information bits and packet length design as well as the impact of other system parameters. Monte Carlo simulations validate the mathematical model and show that the average BLER performance decreases with a higher data amount but improves with a larger number of packet lengths and time-splitting coefficients for information transmissions.

## ARTICLE HISTORY

Received 26 November 2024  
Accepted 4 October 2025



## KEYWORDS

Co-channel interference; energy harvesting; short-packet communication; power beacon; performance analysis

## 1. Introduction

Next-generation communication (5G and beyond) are projected to meet various Internet of Things (IoT) applications, such as smart cities, mobile streaming media, and multimodal virtual reality (Shafique et al., 2020). Nevertheless, these emerging IoT applications pose two important questions among the most common challenges:

- (1) *How can we automatically maintain network longevity and connectivity for battery-limited IoT devices?*
- (2) *How can we ensure reliable communication with low transmission latency?*

**CONTACT** Nguyen Huu Khanh Nhan  nguyenukhkhanhnhan@tdtu.edu.vn  Communication and Signal Processing Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group  
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

As for the first challenge, battery replacement can be an alternative to charging IoT devices; however, it requires significant human management and a detailed schedule, making it impractical, expensive, and often infeasible in hazardous environments, underground or isolated areas, and disaster-stricken zones. This barrier motivates using wireless power transfer solutions through radio frequency (RF) energy harvesting (EH) technology. According to Singh et al. (2024), RF-EH can be categorized into two types: Simultaneous Wireless Information and Power Transfer (SWIPT), which uses a unique RF signal to transmit information and charge devices, and Wireless Powered Communications Network (WPCN), which uses dedicated power stations like power beacons or hybrid access points to charge batteryless IoT devices. In terms of design, SWIPT-based receivers require a symmetric structure with both an EH circuit and a decoding circuit to split either time or power signals, making them effective only over short distances; whereas WPCN-based receivers separate EH and information processing, allowing for simpler operations and longer communication distances. Thus, research on the application of SWIPT has received considerable attention in the literature (Ha et al., 2020; Hoang et al., 2020; Lakshmi & Jibukumar, 2021; A.-N. Nguyen et al., 2019; T. N. Nguyen et al., 2022; Phan et al., 2021; Ponnimbaduge Perera et al., 2018; Tran et al., 2024; Vo et al., 2025) and so does WPCN-based investigations (B. V. Minh, Nhan, et al., 2024; T. N. Nguyen, Quang Minh, et al., 2019; T. N. Nguyen, Tran, et al., 2019; Phan et al., 2023).

As for the second challenge, there are various current techniques to maintain reliability such as full-duplex (B. Minh et al., 2024; T. L. Nguyen et al., 2023), multi-hop communication (Dung et al., 2021; Tran Tin et al., 2019; Tu-Trinh & Do, 2021), two-way communication (B. C. Nguyen, Hoang, Dung, et al., 2021; Tin et al., 2020), reconfigurable intelligent surface (V.-D. Le et al., 2025; B. C. Nguyen, Hoang, Tran, et al., 2021; S. Q. Nguyen et al., 2024), cooperative relaying (T. N. Nguyen et al., 2022), or advanced coding scheme (Al-qudah & Darabkh, 2022). However, these techniques-based communications mostly involve the Shannon-Capacity theorem by transmitting infinite blocklength to achieve highly reliable transmission, making increased transmission latency. Therefore, this violates the demands of emerging IoT applications, triggering the emergence of short-packet transmission or finite blocklength. However, it is not easy to capture the performance of short-packet communication due to the outdated Shannon-Capacity theorem and metric involved, which motivates (Polyanskiy et al., 2010) to introduce a new metric, called block-error rate (BLER). This BLER metric, an upper bound of error probability measurements without taking into any modulation or channel coding schemes, enables us to directly evaluate the system performance with a specific number of transmitted information bits and the packet length (channel use, blocklength) over the signal-to-noise ratio (SNR) received by the receiver node. As a result, it opens a new chapter for the research on wireless communication in recent years (Hoang et al., 2024; T.-H. Nguyen & Vu, 2024; T.-T. Nguyen et al., 2022; T.-V. Nguyen et al., 2022; Quang et al., 2024; Vu et al., 2022).

However, the convergence of IoT and next-generation leads to diverse interactions from multiple networks. Unlicensed spectrum networks such as LoRa, SigFox and WiFi HaLow will coexist with licensed cellular networks, causing the number of IoT connections to increase exponentially year by year (B. V. Minh, Minh, et al., 2024; Tin et al., 2022; Van Nguyen & Dang, 2021). Therefore, it is important to study the impact of co-channel interference on the performance of IoT networks. Underscoring the importance of this factor in

the development of modern IoT networks, this work investigates the performance of WPCN-based short packet systems in the presence of multiple interference sources. To clarify how this work differs from existing investigations, the following literature review will detail what has been done.

## **1.1. State-of-the-art**

### **1.1.1. Research on short-packet communication-based systems**

Xia et al. (2024) focuses on improving BLER performance and increased coverage transmission simultaneously by introducing intelligent surface-aided short-packet systems. Also, H.-C. Le et al. (2024) analyzed the performance of coordinated direct and relay transmission (CDRT)-based non-orthogonal multiple access systems, which enhances the spectrum utilization by allowing the source to retransmit new signals to nearby users when the relay node performs cooperative communication with distance user. Simultaneously, Hoang et al. (2024) presented a comprehensive performance analysis and optimization framework for multi-antenna UAV-aided multi-user backscatter SPC systems, highlighting how multi-antenna design and UAV mobility can significantly improve energy efficiency and system throughput in short-packet communications. Moreover, Park et al. (2024) proposed to improve the spectrum utilization by considerations of Terahertz communication and rate-splitting multiple-access scheme. Differently, T.-H. Nguyen and Vu (2024) proposed an overlay transmission scheme to enable cellular and IoT to coexist, where the IoT master node enjoys the licensed spectrum of cellular networks by assisting the latter to communicate with cell-edge users. Quang et al. (2024) investigated the possibility of short-packet transmission with multi-hop transmission. Recently, T.-T. Nguyen et al. (2022) proposed to enhance the performance of short-packet transmission by introducing a partial non-orthogonal multiple access scheme along with a simultaneous transmitting and reflecting intelligent surface mechanism. Tu and Lee (2022) derives closed-form end-to-end BLER expressions for a short-packet multi-input multi-output selective decode-and-forward multihop relay network with different combinations of the transmit and receive antenna diversity approaches, provides asymptotic diversity-order and SNR-gap insights, and jointly optimizes power allocation and relay placement to minimize BLER.

Linh et al. (2022) analyzes a dual-hop decode-and-forward relaying system under finite-blocklength with transmit antenna selection, partial relay selection, and destination using maximal-ratio combining receiver, yields approximate and high-signal-to-noise ratio (SNR) asymptotic BLER results, and formulates power and relay-location optimization to minimize end-to-end BLER. Tu et al. (2023) examines underlay cognitive multihop relay networks with imperfect interference-CSI in short-packet regimes, obtains closed-form BLER, throughput, energy-efficiency, latency, and reliability metrics, derives optimal power-allocation and relay-location rules, and employs machine-learning approaches (extreme gradient boosting) for real-time performance prediction, matching analytical accuracy with far lower complexity. Tu and Lee (2024) studies multihop full-duplex relay networks for URLLC, presenting closed-form expressions for BLER, throughput, energy efficiency, reliability, and latency along with high-SNR asymptotics; due to analytical complexity, it leverages multi-output machine-learning approaches to rapidly predict system performance under diverse settings. T.-T. Nguyen et al. (2025) proposes an IoT-based cognitive non-orthogonal multiple access uplink with short-packet communications, derives

average BLER for two secondary users under near/far primary-receiver scenarios, and designs resource-power budget allocation to minimize blocklength and latency, demonstrating BLER targets with lower power than fixed-allocation benchmarks.

### ***1.1.2. Research on short-packet communication-based EH systems***

Raut et al. (2020) derived approximate closed-form expressions for the BLER and outage probability of hybrid power-time splitting-based practical non-linear EH model in characteristics of sensitivity and threshold. Amini and Baidas (2020) introduced random-access techniques to reduce signalling overhead, packet latency, and energy consumption for short-packet-EH-IoT networks considering large numbers of clustered IoT devices with irregular traffic behaviour. Besides, they also extended this work with the cognitive-radio model to enhance spectrum utilization (Amini & Baidas, 2021). T.-V. Nguyen et al. (2022) introduced an efficient deep convolutional neural network (CNN) design for energy-harvesting short-packet communications in multihop cognitive IoT networks, demonstrating notable improvements in detection accuracy and energy efficiency. Meanwhile, Xie et al. (2023) analyzed the freshness of short-packet transmission in the EH system by outlining the age of information expressions. Xu and Zhu (2024) addressed the problem of joint transmit powers and time allocation resources for nonlinear EH short packet systems to provide sustainable energy supplies to IoT devices while meeting ultra-low latency transmission. Hoang et al. (2023) proposed an EH-UAV-relaying scheme to enhance coverage communication in cellular short-packet systems by allowing UAVs to harvest energy from one dedicated PB before performing cooperative communication. Chen et al. (2024) proposed to reuse the RF signal from the existing system to be a powerful energy resource for the transmitter in energy-constrained short-packet systems. Ta et al. (2025) introduce a two-phase cooperative non-orthogonal multiple access scheme with energy harvesting and reverse training to ensure zero-outage secrecy by first sending artificial noise and then a mix of artificial noise and the secure message. By optimally allocating harvested power at the IoT controller, the protocol maximizes IoT secrecy throughput and energy efficiency while barely affecting cellular secrecy, even against multi-antenna or well-positioned eavesdroppers. Analytical and numerical results confirm that secrecy throughput improves with transmit power, underlining the approach's practical viability.

### ***1.1.3. Research on short-packet communication with co-channel interference***

Vu et al. (2022) examines the impact of joint co-channel interference and imperfect SIC on the performance of a short-packet communication-based CDRT scheme, emphasizing the negative impact of interference raised by relaying transmission to the retransmission phase and vice versa. Meanwhile, T.-T. Nguyen et al. (2024) explored the impact of existing co-channel interference at the relay node in short-packet-based relaying systems and extended their work by underscoring the necessity of a power control strategy in interference reduction (Q.-S. Nguyen et al., 2024). Le Anh et al. (2025) studied a problem of the BLER minimization by jointly optimizing the power allocation and relay selection, where relay's operation is affected by co-channel interference. To address this problem, the authors suggest dividing it into two subproblems. They recommend fixing one subproblem and then solving the other to find an optimal solution. This solution can then be used to tackle the fixed subproblem. By repeatedly applying this method, it is possible

to obtain an approximate optimal solution. Compared to benchmark method, it is demonstrated that this approach can significantly improve the BLER performance.

### 1.2. Motivation and contribution

Inspired by the above observations, this paper aims to study the reliable performance of an energy-constrained source communicating with a destination via short packets within the coverage area of existing wireless systems. Different from the above-mentioned (see Table 1), focussing on short-packet systems with either EH or co-channel interference, we consider short-packet systems harvesting energy from multiple PBs to perform short-packet delivery under numerous interference. This investigation not only provides a simple way to describe a realistic scenario but also shows the potential to provide green solutions for various sensing applications. It is of particular significance when considering interference sources as green PBs due to the increasing scarcity of spectrum

**Table 1.** Comparison between this work and the existing studies in the literature.

Reference	Objective	Scenario	Contribution
(Hoang et al., 2024; Linh et al., 2022; T.-H. Nguyen & Vu, 2024; T.-T. Nguyen et al., 2025, 2022; Quang et al., 2024; Tu et al., 2023; Tu & Lee, 2022, 2024; Xia et al., 2024)	Short-packet-based system	Source communicates with users via either direct link or cooperative communication under perfect or imperfect channel conditions.	Derive BLER formulation, thereby capturing the system reliability and transmission latency. Develop cooperative scheme and/or algorithm for improving the BLER performance.
(Amini & Baidas, 2020, 2021; Chen et al., 2024; Hoang et al., 2023; T.-V. Nguyen et al., 2022; Raut et al., 2020; Ta et al., 2025; Xie et al., 2023; Xu & Zhu, 2024)	Energy harvesting perspective	Source communicates with users but has limited energy and thus, must harvest energy from a power beacon. Or, the source requests the aid of a relay to bridge the communication, but the relay faces with limited energy budget.	Derive the BLER expressions and analyse the relation between the energy harvesting phase and the information transmission phase.
(Le Anh et al., 2025; Q.-S. Nguyen et al., 2024; T.-T. Nguyen et al., 2024; Vu et al., 2022)	Co-channel interference	Users or relays in short-packet systems face either inter-cell or intra-cell interference	Derive the BLER formulation and goodput to measure the system performance. Optimize resource allocation to improve the system performance, thereby compensating for the performance loss caused by the negative impacts of co-channel interference.
This work	All-in-one	Multiple power beacon assisted source with energy limitation, destination operates with multiple co-channel interference, and source communicates with destination by short-packet transmission	This work analyzes a batteryless, wireless-powered short-packet link where a source harvests energy from multiple beacons and transmits under co-channel interference. By deriving closed-form approximations, we quantify how BLER varies with data size, blocklength, energy/data time splits, beacon count, and interference power, as well as clarify how revealing the necessity of optimizing time allocation and developing more beacons in mitigating interference and improving the BLER.

resources. Furthermore, the transmission from the power-constrained transmitter is more or less likely to face interference from existing wireless systems, which causes a reliable communication reduction. The main contributions of this paper are as follows:

- This work investigates the effect of co-channel interference on the performance of wireless-powered short-packet communication systems. In which, a batteryless source harvests energy from multiple dedicated PBs and reuses this energy to serve the communication with its destination under the presence of multiple interferers.
- To evaluate the considered system performance without taking any simulation, this work derives closed-form approximations for the cumulative distribution function (CDF) of the received signal-to-interference-plus-noise ratio (SINR) at the destination, facilitating the foundation of the average BLER expression. Monte Carlo simulations are then provided to validate the derived BLER formulation.
- This work provides several quantitative BLERs to clarify the relationship in packet design, such as how much information bits or blocklength should be transmitted along with impacts of time scheduling between energy and data transmission phases, the number of power beacons, as well as the domination of number of interferers and interference power signals. Through this quantitation, we realize that the average BLER performance decreases with larger data amounts but improves with larger packet lengths and time partitioning factors for information transmission. Especially, scaling up a larger number of PBs can reduce the impact of the co-channel interference on the BLER performance.

The remainder of the paper is organized as follows. Section 2 gives an overview of the system model. Section 3 presents the information-theoretic mathematical framework, guiding on how to achieve the average BLER. Section 4 presents numerical results and discussions to validate the developed framework as well as deeply explore the impacts of system key parameters, while Section 5 provides concluding remarks. For convenience, we list frequently used notations and their descriptions in Table 2.

## 2. System model

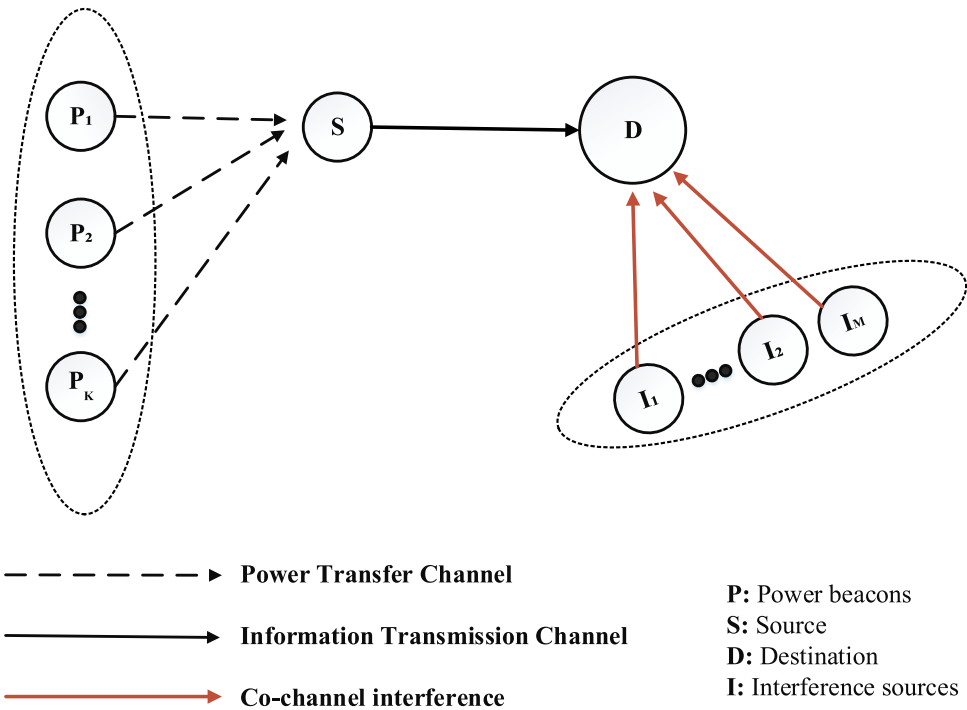
In this work, we consider a wireless-powered system including one source information denoted by  $S$ , one destination denoted by  $D$ , one set of  $K$ - PBs denoted by  $P_k$  with  $k = 1, 2, \dots, K$ , and one set of  $M$  external interference denoted by  $I_m$  with  $m = 1, 2, \dots, M$ . Details of this system can be illustrated in Figure 1.

In this system, we suppose that the estimated channels between two arbitrary nodes experience Rayleigh block fading, and for the ease of notation, we denote by  $|h_{P_k S}|^2$ ,  $|h_{SD}|^2$ , and  $|h_{I_m D}|^2$  as the channel gain of links from  $P_k$  to  $S$ , from  $S$  to  $D$ , and from  $I_m$  to  $D$ , respectively. Under Rayleigh fading consideration (Amini & Baidas, 2020, 2021; Hoang et al., 2023; T.-T. Nguyen et al., 2022; Raut et al., 2020; Vu et al., 2022; Xie et al., 2023), channel gain  $h_X \in \{|h_{P_k S}|^2, |h_{SD}|^2, |h_{I_m D}|^2\}$  follows exponential RVs whose CDF and PDF, referenced by Ha et al. (2020), can be respectively expressed as

$$F_{h_X}(x) = 1 - \exp(-\lambda_X x), \quad f_{h_X}(x) = \lambda_X \exp(-\lambda_X x), \quad (1)$$

**Table 2.** List of notations used in this study.

Notation	Description
$S$	Source
$D$	Destination
$P_k$	The $k$ th PB
$K$	Total number of PBs
$I_m$	The $m$ th interferer
$M$	Total number of interferers
$ h_{P_k S} ^2$	The channel gain of link from $P_k$ to $S$
$ h_{SD} ^2$	The channel gain of link from $S$ to $D$
$ h_{I_m D} ^2$	The channel gain of link from $I_m$ to $D$
$F_{h_X}(x)$	The cumulative CDF of channel $h_X$
$f_{h_X}(x)$	The probability density function (PDF) of channel $h_X$
$\lambda_X$	The mean of the exponential random variable (RV) $h_X$
$d_X$	The average distance $d_X$ between two nodes
$E_s$	The harvested energy at $S$
$p_P$	The transmit power of the PBs
$\alpha$	The time-splitting coefficient
$N$	Information bits of a packet
$L$	Packet length or blocklength
$\psi_P$	The average transmit SNR
$\psi_I$	The average interference-to-noise ratio
$\zeta$	The SNR received at $D$
$\epsilon_D$	The average BLER at $D$



**Figure 1.** The considered wireless-powered-based short-packet system under multiple co-channel interference.

where  $\lambda_X$  is the mean of the exponential RV  $h_X$ . Note that when taking the impact of path-loss, we can model  $\lambda_X$  as a function of the pathloss exponent  $\beta$  and the average distance  $d_X$  between two corresponding nodes as  $\lambda_X = d_X^\beta$ . The justification of our Rayleigh assumption is as follows. In the finite-blocklength regime, where packets are deliberately kept short to meet low-latency or energy-constrained requirements, modelling small-scale fading as Rayleigh lets us capture both the average and the variability of link quality with a single exponential law. This statistical simplicity makes it possible to derive tight approximations for the maximum achievable rate and the corresponding error probability without resorting to lengthy simulations. By averaging these rate and reliability bounds over the Rayleigh distribution, we can expose precisely how packet length, target error, and energy-harvesting constraints interact under severe, non-line-of-sight conditions. Establishing this worst-case baseline ensures that any design validated here will only improve in channels with a line-of-sight component, and it provides a clear, common benchmark for extending the analysis to more complex fading models like Rician or Nakagami-m (Vu et al., 2022; Xia et al., 2024).

Throughout this work, we adopt an idealized model that assumes perfect channel state information akin to Raut et al. (2020), Amini and Baidas (2021), Xie et al. (2023), Xu and Zhu (2024), Hoang et al. (2023) and Chen et al. (2024). Specifically, we assume that the instantaneous channel state information for all links is perfectly estimated, shared, and accessible to both the power beacons and the source. Additionally, we treat the wireless channels as undergoing static/quasi-static block fading, meaning that channels remain constant and error-free throughout one coherence interval before changing independently at the start of the next block. This assumption allows us to isolate and evaluate the theoretical upper bounds of the energy-harvesting mechanism without the interference of performance losses due to estimation errors or feedback delays. Consequently, this setup enables us to leverage the potential benefits of coordinated multi-beacon transmission and coherent combining.

In communication terms, the considered system operates in two consecutive phases.

### 2.1. Energy harvesting phase

During this phase,  $S$  harvests energy from  $P_k$  and its energy is formulated as in T. N. Nguyen, Tran, et al. (2019) as

$$E_S = \mu\alpha T \sum_{k=1}^K |h_{P_k S}|^2 p_P, \quad (2)$$

where  $\mu$  is the energy conversion efficiency belonging to  $[0,1]$ ,  $p_P$  is the fixed transmit power of the power beacons,  $\alpha$  is the time-splitting coefficient, and  $T$  is the coherent block duration. Hence, the possible transmit power that  $S$  can be used for the data exchange phase can be formulated as in T. N. Nguyen, Quang Minh, et al. (2019), Phan et al. (2023) and T. N. Nguyen, Tran, et al. (2019) as

$$p_S = \frac{E_S}{(1-\alpha)T} = \kappa \gamma_{ps} p_P, \quad (3)$$

where  $\kappa = \frac{\mu\alpha}{(1-\alpha)}$  and  $\gamma_{ps} = \sum_{k=1}^K |h_{P_k S}|^2$ .

## 2.2. Packet data exchange phase

During this period of  $(1 - \alpha)T$ ,  $S$  sends short-packet data to  $D$  using a finite blocklength scheme, with  $N$  information bits and packet length  $L$ . However, the communication between  $S$  and  $D$  is interference by the presence of  $M$  outside source, which results in the signal at  $D$  as

$$y_D = \sqrt{p_S} h_{SD} x_d + \sum_{m=1}^M \sqrt{p_I} h_{I_m D} s_m + w_D, \quad (4)$$

where  $x_d$  is the symbol data of  $D$ ,  $s_m$  is the interference signal,  $p_I$  is assumed to be the average transmit power of  $I_m$ , and  $w_D$  is the additive white Gaussian Noise with zero-mean and the power noise density  $N_0$ . From (4), the SINR at  $D$  is calculated as

$$\zeta = \frac{\mathbb{E}\{|signal|^2\}}{\mathbb{E}\{|noise|^2\}} = \frac{p_S |h_{SD}|^2}{p_I \sum_{m=1}^M |h_{I_m D}|^2 + N_0} = \frac{p_S \gamma_{sd}}{p_I \gamma_{id} + N_0}, \quad (5)$$

where  $\gamma_{sd} = |h_{SD}|^2$  and  $\gamma_{id} = \sum_{m=1}^M |h_{I_m D}|^2$ .

Now, injecting (3) in (6) and denote by  $\psi_p = \frac{p_S}{N_0}$  the SNR, we get that

$$\zeta = \frac{\kappa \psi_p \gamma_{ps} \gamma_{sd}}{\psi_I \gamma_{id} + 1} \simeq \frac{\kappa \psi_p \gamma_{ps} \gamma_{sd}}{\psi_I \gamma_{id}}, \quad (6)$$

where  $\psi_I = \frac{p_I}{N_0}$  is the interference-to-noise ratio (INR).

Next, we present how to evaluate the performance of the considered system in the following section.

## 3. Information-theoretic mathematical framework

Under finite blocklength transmission, Polyanskiy et al. (2010) states that a short packet transmitted over a wireless channel has the block-error-rate (BLER) as

$$\epsilon = Q \left( \frac{C(\zeta) - \frac{N}{L}}{\sqrt{\frac{V(\zeta)}{L}}} \right), \quad (7)$$

where  $Q(x) = \int_x^\infty 1/\sqrt{2\pi} \exp(-t^2/2) dt$ ,  $C(x) = \log_2(1+x)$ , and  $V(x) = \log_2(e)^2 [1 - 1/(1+x)]$  are the Gaussian Q-function, Shannon capacity, and channel dispersion, respectively. Taking a linear approximation (T.-V. Nguyen et al., 2022, Appendix A), the right-hand-side of (7) can be approximated as

$$\theta(\zeta) = \begin{cases} 1, & \zeta \leq v, \\ 0, & \zeta \geq u, \\ 1/2 - \rho(\zeta - \tau), & \zeta \in (u, v), \end{cases} \quad (8)$$

where  $\rho = [\frac{2\pi}{L}(2^{2N} - 1)]^{-1/2}$ ,  $\tau = 2^N - 1$ ,  $v = \tau - \frac{1}{2\rho}$ , and  $u = \tau + \frac{1}{2\rho}$ .

From (7) and (8), the average BLER at  $D$  can be derived as (T.-V. Nguyen et al., 2022)

$$\epsilon_D = \int_0^\infty \theta(x) f_\zeta(x) dx = \rho \int_v^u F_\zeta(x) dx. \quad (9)$$

Based on (9), we next go into deriving the CDF of RVs  $\zeta$ , which is defined as

$$F_{\zeta}(x) = \Pr(\zeta < x). \tag{10}$$

Invoking (6), we can derive the result above as

$$\begin{aligned} F_{\zeta}(x) &\simeq \Pr\left(\frac{\kappa\psi_p\gamma_{ps}\gamma_{sd}}{\psi_l\gamma_{id}} < x\right) = \Pr\left(\gamma_{sd} < x\frac{\psi_l\gamma_{id}}{\kappa\psi_p\gamma_{ps}}\right) \\ &= \int_0^{\infty} \int_0^{\infty} F_{\gamma_{sd}}\left(x\frac{\psi_l y}{\kappa\psi_p z}\right) f_{\gamma_{id}}(y) dy f_{\gamma_{ps}}(z) dz. \end{aligned} \tag{11}$$

To derive the CDF of  $\zeta$ , it is necessary to have the PDFs of  $\gamma_{id}$  and  $\gamma_{ps}$ . Fortunately, this can be done by using the aid from Ha et al. (2020), i.e.

$$f_{\gamma_{id}}(y) = \frac{(\lambda_{id})^M}{\Gamma(M)} y^{M-1} \exp(-\lambda_{id}y) \tag{12}$$

$$f_{\gamma_{ps}}(z) = \frac{(\lambda_{ps})^K}{\Gamma(K)} y^{K-1} \exp(-\lambda_{ps}z) \tag{13}$$

By injecting the PDF of  $\gamma_{ps}$  into (11) combined with (1), we can rewrite the CDF of  $\zeta$  as

$$\begin{aligned} F_{\zeta}(x) &= \int_0^{\infty} \int_0^{\infty} \left[1 - \exp\left(-x\lambda_{sd}\frac{\psi_l y}{\kappa\psi_p z}\right)\right] f_{\gamma_{id}}(y) f_{\gamma_{ps}}(z) dy dz \\ &= 1 - \int_0^{\infty} \int_0^{\infty} \exp\left(-x\lambda_{sd}\frac{\psi_l y}{\kappa\psi_p z}\right) \frac{(\lambda_{ps})^K}{\Gamma(K)} y^{K-1} \exp(-\lambda_{ps}z) f_{\gamma_{id}}(y) dy. \end{aligned} \tag{14}$$

By using Jeffrey and Zwillinger (2007, Equation (3.471.9)),  $F_{\zeta}(x)$  can be simplified to be

$$\begin{aligned} F_{\zeta}(x) &= 1 - \frac{1}{\Gamma(K)} \int_0^{\infty} 2\left(x\lambda_{sd}\lambda_{ps}\frac{\psi_l y}{\kappa\psi_p}\right)^{\frac{K}{2}} \mathcal{K}_K\left(2\sqrt{x\lambda_{sd}\lambda_{ps}\frac{\psi_l y}{\kappa\psi_p}}\right) f_{\gamma_{id}}(y) dy \\ &= 1 - \int_0^{\infty} \frac{2(\lambda_{id})^M y^{\frac{K}{2}+M-1}}{\Gamma(M)\Gamma(K)} \left(\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{\kappa\psi_p}\right)^{\frac{K}{2}} \mathcal{K}_K\left(2\sqrt{\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{\kappa\psi_p}} y\right) \exp(-\lambda_{id}y) dy, \end{aligned} \tag{15}$$

where  $\mathcal{K}_K(\bullet)$  is the  $K$ th order modified Bessel of the second kind (Jeffrey & Zwillinger, 2007). Next, we recall the PDF of  $\gamma_{id}$  to get

$$\begin{aligned} F_{\zeta}(x) &= 1 - \int_0^{\infty} \frac{2(\lambda_{id})^M y^{\frac{K}{2}+M-1}}{\Gamma(M)\Gamma(K)} \left(\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{\kappa\psi_p}\right)^{\frac{K}{2}} \mathcal{K}_K\left(2\sqrt{\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{\kappa\psi_p}} y\right) \exp(-\lambda_{id}y) dy \\ &= 1 - \frac{\Gamma(M+K)}{\Gamma(K)} \left(\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{\kappa\lambda_{id}\psi_p}\right)^{\frac{K-1}{2}} \exp\left(\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{2\kappa\lambda_{id}\psi_p}\right) \\ &\quad \times \mathcal{W}_{-\frac{K}{2}-M+\frac{1}{2}, \frac{K}{2}}\left(\frac{x\lambda_{sd}\lambda_{ps}\psi_l}{\lambda_{id}\kappa\psi_p}\right), \end{aligned} \tag{16}$$

where the last step is derived using the help from Jeffrey and Zwillinger (2007, Equation (6.643.3)) and  $\mathcal{W}_{-\frac{K}{2}-M+\frac{1}{2}, \frac{K}{2}}(\bullet)$  is the Whittaker function (Jeffrey & Zwillinger, 2007).

Although the derived expression in (15) can be obtained, it is challenging to directly get the BLER expression in (9). Thus, we apply the Gaussian-Chebyshev quadrature method as in B. Minh et al. (2024) with the weight  $\omega_q = \cos\left(\frac{(2q-1)\pi}{2Q}\right)$  and the number of accuracy terms  $Q$ .

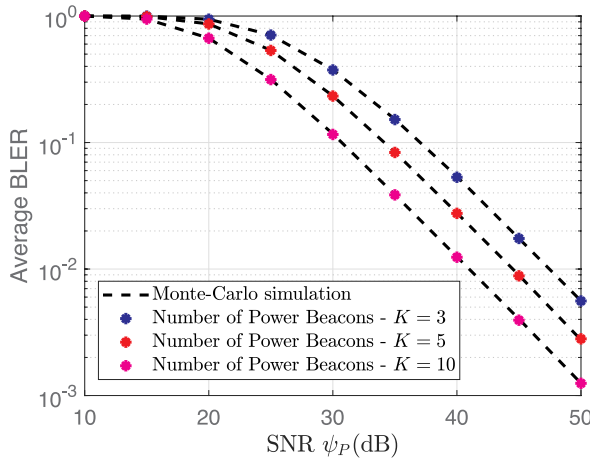
**Lemma 3.1:** *The average BLER at D can be approximately derived as*

$$\epsilon_D \approx 1 - \rho \frac{\pi}{2Q} \sum_{q=1}^Q \sqrt{1 - \omega_q^2} \left[ 1 - F_{\zeta} \left( \frac{\omega_q}{2\rho} + \tau \right) \right]. \quad (17)$$

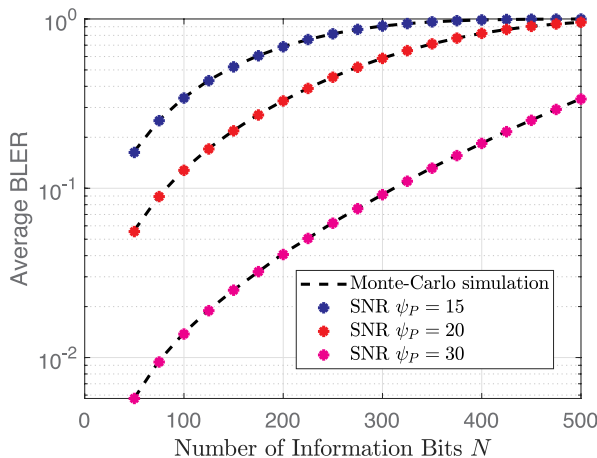
#### 4. Numerical results

In this section, we verify the accuracy of the derived mathematical framework through some simulation results based on the Monte Carlo method. It is worth noting that this work developed an accurate mathematical framework for evaluating the system's performance without taking any simulations or experimental tests. Therefore, the following results are arbitrarily set to check the efficacy of the developed framework. For realistic application and scenarios, we can totally change parameters according to a standard set of parameters without challenge. Since our developed framework characterizes all system parameters by a unique expression, and it can be programmed using popular programming software packages like MATLAB, Maple, or Mathematica, such a task does not affect the quality of the developed framework. For generality, we set  $\lambda_{ps} = \lambda_{sd} = \lambda_{id} = 1$  while other parameters are specified in figures.

In Figure 2, the average BLER of  $D$  is plotted as a function of the SNR  $\phi_p$  [dB], where the analytical curves (dash line) are derived in (17). As depicted in the figure, the gap between the approximation and simulation results is negligible as  $\phi_p$  varies from 10 to 50. Besides, we can observe that the larger the  $\phi_p$ , the smaller the average BLER. Furthermore, we can also notice that no matter of the number of power beacons, the approximation results



**Figure 2.** The average BLER of the proposed system versus  $\phi_p$  [dB] with different of power beacon  $K$ . Setups:  $\phi_l = 10$  dB,  $\alpha = 0.25$ ,  $\mu = 0.8$ ,  $M = 10$ ,  $N = 200$ , and  $L = 100$ .

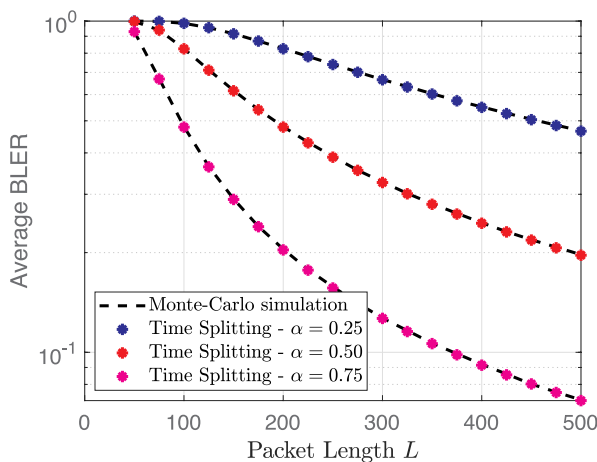


**Figure 3.** The average BLER of the proposed system versus  $N$  with different of  $\psi_p$  [dB]. Setups:  $\phi_p = 15$  dB,  $\phi_l = 10$  dB,  $\alpha = 0.5$ ,  $\mu = 0.8$ ,  $M = 10$ ,  $K = 10$ , and  $L = 100$ .

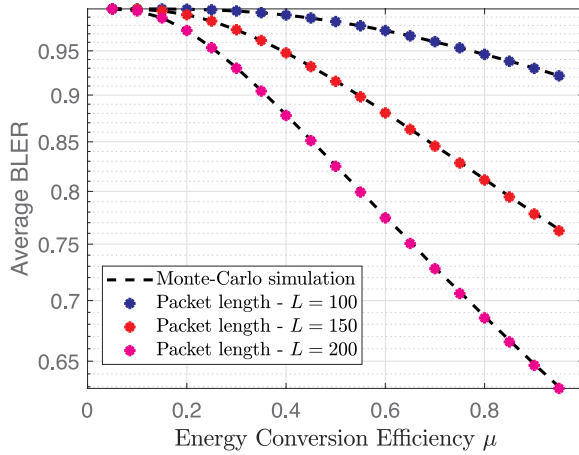
almost accurately predict the simulation one. Therefore, the impact of network parameters can be thoroughly examined through easy-to-understand approximations.

Figure 3 shows the average BLER versus a number of transmitted information bits  $N$  with different of  $\psi_p$  [dB]. As can be straightforwardly seen, increasing  $N$  will lead to an increase in the average BLER, thus reducing the reliability of the considered systems. Nonetheless, the average BLER performance can be ameliorated by simply increasing the SNR  $\psi_p$ .

Figure 4 illustrates the average BLER performance as a function of packet length  $L$  with different values of  $\alpha$ . We see that the average BLER is a monotonic decrease function of  $L$ . Moreover, when  $\alpha$  decreases, we achieve a considerable improvement performance of the average BLER.



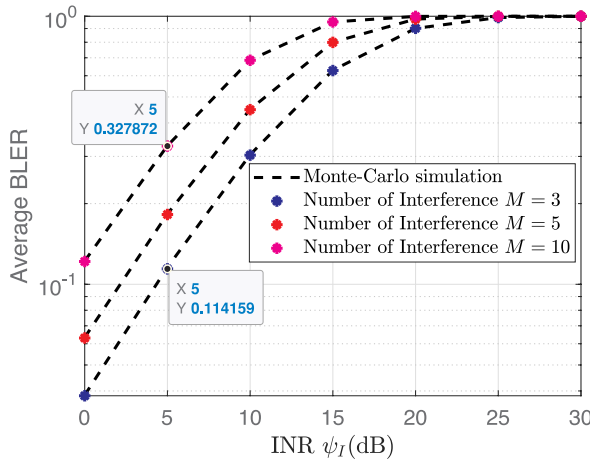
**Figure 4.** The average BLER of the proposed system versus  $L$  with different of  $\alpha$ . Setups:  $\phi_p = 15$  dB,  $\phi_l = 10$  dB,  $\alpha = 0.25$ ,  $\mu = 0.5$ ,  $M = 10$ ,  $K = 10$ , and  $N = 200$ .



**Figure 5.** The average BLER of the proposed system versus  $\mu$  with different of  $L$ . Setups:  $\phi_p = 15$  dB,  $\phi_l = 10$  dB,  $\alpha = 0.25$ ,  $M = 10$ ,  $K = 10$ ,  $N = 200$  and  $L = 100$ .

The performance of the average BLER to the energy conversion efficiency at  $S$  under different packet designs  $L$  is provided in Figure 5. This figure shows that if the energy conversion efficiency increases, the average BLER is significantly improved, which justifies the fact that the higher the energy conversion efficiency, the larger the harvested energy. However, in practice, it is not always to ensure that the source is integrated with a proper energy harvesting circuit. In this case, using a large number of  $L$  can simply improve the average BLER; however, this might cause an increase in transmission latency due to the proportion of  $L$  with the number of channels used for bandwidth transmission.

The impact of the interference amount on the average BLER performance is given in Figure 6. Increasing the INR  $\psi_I$  certainly leads to a negative effect on the average BLER



**Figure 6.** The average BLER of the proposed system versus  $\psi_I$  with different of  $M$ . Setups:  $\phi_p = 15$  dB,  $\alpha = 0.5$ ,  $\mu = 0.8$ ,  $K = 10$ ,  $N = 200$ , and  $L = 100$ .

performance. Specifically, when  $\psi_I$  goes from 0 to 20 dB, the average BLER goes up from less than  $10^{-1}$  to under 1 and maintains at 1 for the remaining region. Especially, the impact of the number of interferers  $M$  on the average BLER is also considerable, where the average BLER with  $\psi_I = 5$  dB at  $M=10$  is three-fold higher than that of  $M=3$ . Therefore, we confirm again that co-channel interference becomes non-favourable to the average BLER of the considered systems.

## 5. Conclusions

This paper discussed the performance of wireless-powered-based short-packet communication systems in the presence of multi-interference sources, where a destination node is served by a source-harvested energy resource from multiple power beacons and the process of data exchange takes place by using a finite blocklength scheme. In this context, we have derived the CDF approximation for the received SINR at the destination, which then facilitates finding a closed-form expression for the average BLER performance. Numerical results not only validated the correctness of the mathematical development but also exhibited several impacts of the system's key parameters on the average BLER performance. In particular, key findings and insights drawn from these evaluations are as follows:

- *Key 1:* When the system transmits more data bits to users, it can lead to an increase in decoding errors. To address this issue, utilizing a greater number of power beacons can be beneficial. However, this comes with the trade-off of higher implementation costs. Therefore, there is a need for further investigation into diversity antenna techniques to minimize implementation costs as much as possible.
- *Key 2:* As the time-splitting coefficient for the energy harvesting process increases, the system gains a larger energy budget for communication, which can reduce the probability of decoding errors. However, if this coefficient is increased excessively, it may limit the time available for communication, potentially disrupting the communication process. Thus, a well-considered strategy for selecting this value is essential.
- *Key 3:* When the system utilizes a longer block length (also referred to as channel usage), the probability of decoding errors decreases. However, this can lead to increased transmission latency, which is the product of block length and packet transmission duration.
- *Key 4:* As the number of interferers or the strength of interference signals increases, the probability of decoding errors also rises. This degradation in performance can violate the goals of ultra-reliable low-latency communications.

Building on our investigation, we identify four concrete avenues for future work. First, exploring multi-antenna source and destination architectures, ranging from full-dimension multiple-input multiple-output with eigenbeamforming and Grassmannian signaling to hybrid analogue/digital beamforming that allocates radio frequency chains between information decoding and energy harvesting, can systematically quantify the trade-off between spatial multiplexing gains and harvested power under fixed transmit budgets. Second, incorporating practical impairments, such as finite-rate feedback with pilot contamination, transceiver nonidealities like I/Q imbalance and power-amplifier nonlinearity,

and timing/frequency synchronization errors into our joint rate-energy optimization, will enable robust beamforming and margin-based designs that guarantee performance in realistic hardware environments. Third, advancing nonlinear energy-harvesting models by deriving radio frequency-to-direct current conversion efficiencies from diode current-voltage characteristics, optimizing multisine and modulated waveform shapes for peak rectifier output, and integrating ambient scavengers (solar, vibration, thermal) via cross-domain allocation algorithms can dramatically boost average direct current power under fluctuating input conditions. Finally, investigating full-duplex transmission with energy recycling, where residual self-interference after analogue/digital cancellation is tapped into the harvesting chain, requires co-designing cancellation filters and beamforming weights, adapting physical-layer protocols to harvested-energy budgets, and prototyping receiver architectures to validate end-to-end throughput and energy gains. On the other hand, it is also interesting to further extend this work for emerging topics, such as integrated sensing and communication, near-field, and movable antennas.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## ORCID

Nguyen Huu Khanh Nhan  <http://orcid.org/0000-0002-7347-7446>

## References

- Al-qudah, Z., & Darabkh, K. A. (2022). A simple encoding scheme to achieve the capacity of half-duplex relay channel. *Advances in Electrical and Electronic Engineering*, 20(1), 33–42. <https://doi.org/10.15598/aeee.v20i1.4347>
- Amini, M. R., & Baidas, M. W. (2020, December). Random-access NOMA in URLL energy-harvesting IoT networks with short packet and diversity transmissions. *IEEE Access*, 8, 220734–220754. <https://doi.org/10.1109/ACCESS.2020.3042744>
- Amini, M. R., & Baidas, M. W. (2021, May). Performance analysis of URLL energy-harvesting cognitive-radio IoT networks with short packet and diversity transmissions. *IEEE Access*, 9, 79293–79306. <https://doi.org/10.1109/ACCESS.2021.3083095>
- Chen, D., Li, J., Hu, J., Zhang, X., Zhang, S., & Wang, D. (2024, January). Interference-assisted energy harvesting short packet communications with hardware impairments. *International Journal of Intelligent Networks*, 5, 231–240. <https://doi.org/10.1016/j.ijin.2024.05.005>
- Dung, C. T., Hoang, T. M., Thang, N. N., Tran, M., & Tran, P. T. (2021). Secrecy performance of multi-user multi-hop cluster-based network with joint relay and jammer selection under imperfect channel state information. *Performance Evaluation*, 147, 102193. <https://doi.org/10.1016/j.peva.2021.102193>
- Ha, D.-H., Nguyen, T. N., Tran, M. H. Q., Li, X., Tran, P. T., & Voznak, M. (2020, October). Security and reliability analysis of a two-way half-duplex wireless relaying network using partial relay selection and hybrid tpsr energy harvesting at relay nodes. *IEEE Access*, 8, 187165–187181. <https://doi.org/10.1109/ACCESS.2020.3030794>
- Hoang, T. M., Dung, L. T., Nguyen, B. C., Van Vinh, N., & Kim, T. (2023, September). BLER and throughput analysis of power beacon-based energy harvesting UAV-assisted NOMA relay systems for short-packet communications. *IEEE Access*, 11, 105115–105129. <https://doi.org/10.1109/ACCESS.2023.3316716>

- Hoang, T. M., Nguyen, B. C., Thang, N. N., Tran, M., & Tran, P. T. (2020). Performance and optimal analysis of time-switching energy harvesting protocol for mimo full-duplex decode-and-forward wireless relay networks with various transmitter and receiver diversity techniques. *Journal of the Franklin Institute*, 357(17), 13205–13230. <https://doi.org/10.1016/j.jfranklin.2020.09.037>
- Hoang, T. M., Van, Q.-N., Dung, L. T., Nguyen, B. C., Van Vinh, N., & Kim, T. (2024). Performance analysis and optimization of multi-antenna uav-aided multi-user backscatter spc systems. *IEEE Transactions on Intelligent Vehicles*, 9(1), 1028–1039. <https://doi.org/10.1109/TIV.2023.3315281>
- Jeffrey, A., & Zwillinger, D. (2007). *Table of integrals, series, and products*. Elsevier.
- Lakshmi, P. S., & Jibukumar, M. G. (2021). A hybrid protocol for swipt in cooperative networks. *Advances in Electrical and Electronic Engineering*, 19(1), 28–41. <https://doi.org/10.15598/aeee.v19i1.3901>
- Le, H.-C., Thu Pham, A., Thu Hang Nguyen, T., & Tuan Nguyen, K. (2024). Performance analysis of ris-aided noma-based cdrt systems with multiple decode-and-forward relays over nakagami-m fading channels. *IEEE Access*, 12, 194228–194239. <https://doi.org/10.1109/ACCESS.2024.3519323>
- Le, V.-D., Nguyen, H.-N., Nguyen, S. Q., Bui, T.-T., Hien, D. C., & Kim, B. S. (2025). Enabling D2D transmission mode of reconfigurable intelligent surfaces aided in wireless noma system. *Advances in Electrical and Electronic Engineering*, 23(1), 32–42. <https://doi.org/10.15598/aeee.v23i1.240809>
- Le Anh, U.-V., Nguyen, X.-P., & Nguyen, T.-T. (2025). Joint power control and relay selection with short packet communications under co-channel interference. *Advances in Electrical and Electronic Engineering*, 23(1), 52–60. <https://doi.org/10.15598/aeee.v23i1.240503>
- Linh, N. T. Y., Tu, N. H., Son, P. N., & Bao, V. N. Q. (2022). Dual-hop relaying networks for short-packet urllcs: Performance analysis and optimization. *Journal of Communications and Networks*, 24(4), 408–418. <https://doi.org/10.23919/JCN.2022.000020>
- Minh, B., Le, A., Phan, V., & Pham, T. (2024). Self-energy recycling in df full-duplex relay network: Security-reliability analysis. *Advances in Electrical and Electronic Engineering*, 22(1), 86–96. <https://doi.org/10.15598/aeee.v22i1.5528>
- Minh, B. V., Minh, T. H. Q., Phan, V. D., & Nguyen, H. T. (2024). D2D communication network with the assistance of power beacon under the impact of co-channel interferences and eavesdropper: Performance analysis. *Advances in Electrical and Electronic Engineering*, 21(4), 351–359.
- Minh, B. V., Nhan, N. H. K., Pham, T.-H. T., Tran, M., & Kim, S.-W. (2024). Physical layer security in wireless sensors networks with friendly jammer: Secrecy outage probability analysis. *Advances in Electrical and Electronic Engineering*, 22(4), 387–98. <https://doi.org/10.15598/aeee.v22i4.5840>
- Nguyen, A.-N., Nhan Vo, V., So-In, C., Ha, D.-B., Sanguanpong, S., & Baig, Z. A. (2019). On secure wireless sensor networks with cooperative energy harvesting relaying. *IEEE Access*, 7, 139212–139225. <https://doi.org/10.1109/ACCESS.2019.2941915>
- Nguyen, B. C., Hoang, T. M., Dung, L. T., & Kim, T. (2021). On performance of two-way full-duplex communication system with reconfigurable intelligent surface. *IEEE Access*, 9, 81274–81285. <https://doi.org/10.1109/ACCESS.2021.3086067>
- Nguyen, B. C., Hoang, T. M., Tran, P. T., Nguyen, T. N., Phan, V.-D., Minh, B. V., & Voznak, M. (2021). Cooperative communications for improving the performance of bidirectional full-duplex system with multiple reconfigurable intelligent surfaces. *IEEE Access*, 9, 134733–134742. <https://doi.org/10.1109/ACCESS.2021.3114713>
- Nguyen, Q.-S., Le Anh, U.-V., Nguyen, T. N., Nguyen, T.-T., & Voznak, M. (2024, May). Short packet communications for relay systems with co-channel interference at relay: Performance analysis and power control. *IEEE Access*, 12, 63452–63461. <https://doi.org/10.1109/ACCESS.2024.3396642>
- Nguyen, S. Q., Le, A.-T., Phan, V.-D., Thien, H. T., & Kharel, R. (2024). Outage performance analysis of star-ris-noma networks under imperfect csi. *Advances in Electrical and Electronic Engineering*, 22(3), 260–270. <https://doi.org/10.15598/aeee.v22i3.5546>
- Nguyen, T.-H., & Vu, T.-H. (2024, October). A generalized STAR-RIS-empowered ambient backscatter short-packet communication systems with partial NOMA. *IEEE Communications Letters*, 28(12), 2744–2748. <https://doi.org/10.1109/LCOMM.2024.3475569>
- Nguyen, T. L., Nguyen, T. L., Nguyen, V. V., & Phu, T. T. (2023). Outage performance of full-duplex unmanned aerial vehicle-aided cooperative non-orthogonal multiple access. *Advances in Electrical and Electronic Engineering*, 21(1), 1–8. <https://doi.org/10.15598/aeee.v21i1.4515>

- Nguyen, T. N., Duy, T. T., Tran, P. T., Voznak, M., Li, X., & Poor, H. V. (2022). Partial and full relay selection algorithms for af multi-relay full-duplex networks with self-energy recycling in non-identically distributed fading channels. *IEEE Transactions on Vehicular Technology*, 71(6), 6173–6188. <https://doi.org/10.1109/TVT.2022.3158340>
- Nguyen, T. N., Quang Minh, T. H., Tran, P. T., Voznak, M., Duy, T. T., Nguyen, T.-L., & Tin, P. T. (2019). Performance enhancement for energy harvesting based two-way relay protocols in wireless ad-hoc networks with partial and full relay selection methods. *Ad Hoc Networks*, 84, 178–187. <https://doi.org/10.1016/j.adhoc.2018.10.005>
- Nguyen, T. N., Tran, D.-H., Van Chien, T., Phan, V.-D., Voznak, M., & Chatzinotas, S. (2022). Security and reliability analysis of satellite-terrestrial multirelay networks with imperfect csi. *IEEE Systems Journal*, 17(2), 2824–2835. <https://doi.org/10.1109/JSYST.2022.3201128>
- Nguyen, T. N., Tran, M., Nguyen, T.-L., Ha, D.-H., & Voznak, M. (2019). Multisource power splitting energy harvesting relaying network in half-duplex system over block rayleigh fading channel: System performance analysis. *Electronics*, 8(1), 1–15. <https://doi.org/10.3390/electronics8010067>
- Nguyen, T.-T., Uyen, V. L.-A., & Sang, Q.-N. (2024, July). Short packet communication for dual-hop system under co-channel interference. In *Proceedings of the International Conference on Sustainable Energy Technologies* (pp. 739–745). Springer. [https://doi.org/10.1007/978-981-97-1868-9\\_73](https://doi.org/10.1007/978-981-97-1868-9_73)
- Nguyen, T.-T., Nguyen, A.-V., Nguyen, T.-L., & Le, V.-H. (2025). Noma-cognitive radio network-enabled iot systems with short packet communications: Block error rate analysis and blocklength optimization. *Arabian Journal for Science and Engineering*, 2025, 1–14.
- Nguyen, T.-T., Vu, T.-H., da Costa, D. B., Nguyen, P. X., & Ta, H. Q. (2022, September). Short-packet communications in iot-aided cellular cooperative networks with non-orthogonal multiple access. *IEEE Transactions on Vehicular Technology*, 72(1), 1296–1301. <https://doi.org/10.1109/TVT.2022.3204460>
- Nguyen, T.-V., Huynh-The, T., Nguyen, V.-D., Da Costa, D. B., R. Qingyang Hu, & An, B. (2022). An efficient deep CNN design for eh short-packet communications in multihop cognitive iot networks. In *ICC 2022 - IEEE International Conference on Communications* (pp. 2102–2107). IEEE. <https://doi.org/10.1109/ICC45855.2022.9839014>
- Park, J., Lee, B., Choi, J., Lee, H., Lee, N., Park, S.-H., Lee, K.-J., Choi, J., Chae, S. H., Jeon, S.-W., Kwak, K. S., Clerckx, B., & Shin, W. (2024). Rate-splitting multiple access for 6G networks: Ten promising scenarios and applications. *IEEE Network*, 38(3), 128–136. <https://doi.org/10.1109/MNET.2023.3321518>
- Phan, V. D., Nguyen, T. L., Phu, T. T., & Nguyen, V. V. (2023). Reliability-security in wireless-powered cooperative network with friendly jammer. *Advances in Electrical and Electronic Engineering*, 20(4), 584–591. <https://doi.org/10.15598/aeee.v20i4.4511>
- Phan, V.-D., Nguyen, T. N., Le, A. V., & Voznak, M. (2021). A study of physical layer security in swipt-based decode-and-forward relay networks with dynamic power splitting. *Sensors*, 21(17), 1–17. <https://doi.org/10.3390/s21175692>
- Polyanskiy, Y., Poor, H. V., & Verdú, S. (2010, April). Channel coding rate in the finite blocklength regime. *IEEE Transactions on Information Theory*, 56(5), 2307–2359. <https://doi.org/10.1109/TIT.2010.2043769>
- Ponnimbaduge Perera, T. D., Jayakody, D. N. K., Sharma, S. K., Chatzinotas, S., & Li, J. (2018). Simultaneous wireless information and power transfer (swipt): Recent advances and future challenges. *IEEE Communications Surveys & Tutorials*, 20(1), 264–302. <https://doi.org/10.1109/COMST.2017.2783901>
- Quang, P. M., Kien, N. T., Duy, T. T., An, N. H., Tung, N. T., & Le, A. V. (2024). Performance evaluation of reconfigurable intelligent surface aided multi-hop relaying schemes with short packet communication. *Advances in Electrical and Electronic Engineering*, 22(1), 97–106. <https://doi.org/10.15598/aeee.v22i1.5583>
- Raut, P., Sharma, P. K., Tsiftsis, T. A., & Zou, Y. (2020 May). Power-time splitting-based non-linear energy harvesting in FD short-packet communications. *IEEE Transactions on Vehicular Technology*, 69(8), 9146–9151. <https://doi.org/10.1109/TVT.2020.2998180>

- Shafique, K., Khawaja, B. A., Sabir, F., Qazi, S., & Mustaqim, M. (2020, January). Internet of things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT scenarios. *IEEE Access*, 8, 23022–23040. <https://doi.org/10.1109/ACCESS.2020.2970118>
- Singh, S., Kumar, M., & Kumar, R. (2024). Powering the future: A survey of ambient rf-based communication systems for next-gen wireless networks. *IET Wireless Sensor Systems*, 14(6), 265–292. <https://doi.org/10.1049/wss2.v14.6>
- Ta, H. Q., Nguyen, N. B. T., Nguyen, T.-T., & Ho-Van, K. (2025). Zero-outage secrecy in short packet iot-aided cellular cooperative network with eh-noma. *IEEE Access*, 13, 75235–75245. <https://doi.org/10.1109/ACCESS.2025.3562392>
- Tin, P. T., Luan, N. T., Nguyen, T. N., Tran, M., & Duy, T. T. (2022). Throughput enhancement for multi-hop decode-and-forward protocol using interference cancellation with hardware imperfection. *Alexandria Engineering Journal*, 61(8), 5837–5849. <https://doi.org/10.1016/j.aej.2021.11.008>
- Tin, P. T., Nguyen, T. N., Tran, M., Trang, T. T., & Sevcik, L. (2020). Exploiting direct link in two-way half-duplex sensor network over block rayleigh fading channel: Upper bound ergodic capacity and exact ser analysis. *Sensors*, 20(4), 1–16. <https://doi.org/10.3390/s20041165>
- Tran, M., Tu, L.-T., Minh, B. V., Nguyen, Q.-S., Rejzek, L., & Lee, B. M. (2024). Security and reliability analysis of the power splitting-based relaying in wireless sensors network. *Sensors*, 24(4), 1–19. <https://doi.org/10.3390/s24041300>
- Tran Tin, P., The Hung, D., Nguyen, T. N., Duy, T. T., & Voznak, M. (2019). Secrecy performance enhancement for underlay cognitive radio networks employing cooperative multi-hop transmission with and without presence of hardware impairments. *Entropy*, 21(2), 1–16. <https://doi.org/10.3390/e21020217>
- Tu, N. H., Hoang, T.-D., & Lee, K. (2023). Short-packet urlcs for mimo underlay cognitive multihop relaying with imperfect csi. *IEEE Access*, 11, 81672–81689. <https://doi.org/10.1109/ACCESS.2023.3301139>
- Tu, N. H., & Lee, K. (2022). Performance analysis and optimization of multihop mimo relay networks in short-packet communications. *IEEE Transactions on Wireless Communications*, 21(6), 4549–4562. <https://doi.org/10.1109/TWC.2021.3131205>
- Tu, N. H., & Lee, K. (2024). Multihop mimo full-duplex relay networks with short-packet urlcs. *IEEE Systems Journal*, 18(4), 1975–1986. <https://doi.org/10.1109/JSYST.2024.3485690>
- Tu-Trinh, T. N., & Do, D.-T. (2021). Exploiting full-duplex and fixed power allocation approaches for dual-hop transmission in downlink noma. *Advances in Electrical and Electronic Engineering*, 19(3), 212–221.
- Van Nguyen, M. S., & Dang, H. P. (2021). Exploiting performance of ambient backscatter systems in presence of hardware impairment. *Advances in Electrical and Electronic Engineering*, 19(4), 313–321. <https://doi.org/10.15598/aeee.v19i4.4198>
- Vo, D.-T., Thi-Pham, T. H., Tran, M., Kim, B.-S., Kharel, R., & Voznak, M. (2025). Short packet communication in iot networks: Performance analysis. *Journal of Information and Telecommunication*, 1–14. <https://doi.org/10.1080/24751839.2025.2487353>
- Vu, T.-H., Nguyen, T.-V., Nguyen, T.-T., Vo-Nguyen, B., & Kim, S. (2022, February). Short-packet communications in NOMA-CDRT IoT networks with cochannel interference and imperfect SIC. *IEEE Transactions on Vehicular Technology*, 71(5), 5552–5557. <https://doi.org/10.1109/TVT.2022.3148988>
- Xia, C., Xiang, Z., Su, B., Liu, H., Meng, J., & Pan, G. (2024). Ris-noma-assisted short-packet communication with hardware impairments. *IEEE Internet of Things Journal*, 11(2), 2990–3002. <https://doi.org/10.1109/JIOT.2023.3294257>
- Xie, M., Jia, X., Yin, J., Wang, Q., & Zhou, M. (2023, June). Age of information for partial earliest relay aided short packet status update with energy harvesting. *IEEE Transactions on Wireless Communications*, 23(1), 699–719. <https://doi.org/10.1109/TWC.2023.3281736>
- Xu, D., & Zhu, H. (2024, July). Energy efficient resource allocation for wireless powered short packet communication networks. *IEEE Communications Letters*, 28(8), 1880–1884. <https://doi.org/10.1109/LCOMM.2024.3421561>