Proceedings of the Seventh International Conference on Research in Intelligent and Computing in Engineering pp. 267–271
DOI: 10.15439/2022R23
ISSN 2300-5963 ACSIS, Vol. 33

Performance Evaluation of Short-Packet Communications of Single-Hop System with Presence of Co-Channel Interference

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***Abstract*—An investigation of short-packet communications (SPCs) of a single hop system where there is a presence of co-channel interference at destination. The average block error rate (BLER) of the destination is derived in accurate as well as asymptotic closed-form expressions. The affects of some parameters like: the number of interference sources, the transmit power of the interference source on the system performance and the number of channel uses at the destination are considered. The results of the theory are evaluated by Monte Carlo simulation.**

***Index Terms*—average block error rate, short-packet communication, single-hop, co-channel interference**

I. INTRODUCTION

Recently, ultra-low latency and ultra-high reliability (URLL) is required in several operations serving as industrial automation, tele-surgery, tactile internet [1]. In order to meet the requirement, short-packet communications (SPCs) [2] is performed for the finite blocklength code transmission. Relied on the Shannon theory, in conventional communication systems, errors is dependent on both two parameters: the received signal-to-noise ratio (SNR), the coding rate. In the system deploying the short packet communication, in case of the coding rate is smaller the Shannon capacity, errors always exist; in addition, the packet blocklength affects the error rate. This leads to the classical Shannon theory not to be used to evaluate SPC systems, but to use another metric, which is BLER. Hence, SPC has attracted researchers and was investigated in different systems.

For single-hop system, an evaluation of the BLER of a non-orthogonal multiple access system with two users was presented in [3]. For dual-hop system, short packet communication were studied in [4], [5] in terms of BLER. The throughput and probability of coverage of SPC was evaluated for Multiple-input-multiple-output (MIMO) systems [6]. A performance for SPC in an unmanned-aerial-vehicle (UAV) system, where an UAV is a relay carrying out URLL connections between a user and a base station, was analyzed in [7]. The authors of [8] derived the BLERs of two destinations in an UAV system with presence of SPC. A solution to joint optimal power as well as blocklength was proposed to obtain max–min throughput for cooperative non-orthogonal multiple access [9]. The authors of [10] provided a deep-learning framework for predicting the BLERs for Internet of Things system. In [11], SPC was investigated in a cognitive radio network helped by an intelligent reflecting surface. However, these above works did not consider co-channel interference in the system. The authors in [12] study the affect of co-channel interference to the performance of the cooperative networks.

In this paper, the key contributions are listed as follows:

- We consider a single-hop system, where one source adopts short-packet communication to transmit the signal to its destination. In addition, we take into account co-channel interference in this system.
- Under setting, the BLERs of the destination are derived in closed-form and asymptotic expressions.
- The affects of some parameters, i.e., the number of interference sources, the transmission power of the interference source and the number of channel uses on the

performance also are evaluated.

- The simulation results are executed to validate the exact of our theory analysis. This simulation method is used effectively and widely in many studies [13]–[19]

A. Organization

In Section II, a description of the system model is presented. The performance of the system with regards to the BLER is analyzed in Section III. In Section IV, simulation and analysis results are discussed. Finally, a conclusion is provide in Section V.

II. SYSTEM MODEL

We considered a wireless system composed by one access point (i.e., S) and one Internet of Things (IoT) user (i.e., U) with presence of co-channel interference, as showed in Fig. 1

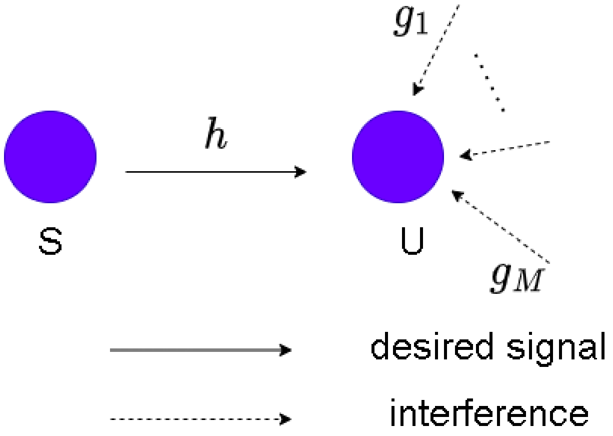

Fig. 1. System model of a single-hop communication system with the co-channel interference.

In this paper, the channel state information are assumed to know at all nodes. The signal at U is received from S as

$$y_{\mathrm{U}} = \sqrt{P_{\mathrm{S}}} x_{\mathrm{U}} h + \sum_{m=1}^{M} \sqrt{P_{\mathrm{I_m}}} g_{\mathrm{I_m U}} x_{\mathrm{I_m}} + n_{\mathrm{U}}, \tag{1}$$

where P_{S}, $P_{\mathrm{I_m}} = P_{\mathrm{I}}$ denote transmission power of the S, interference source, respectively. h, g_m present the channel coefficients of S-U link, and interference source m-U link, respectively. $n_{\mathrm{U}} \sim \mathcal{CN}(0, \sigma^2)$ is the additive white Gaussian noise (AWGN) at U. Therefore, the signal-to-interference-plus-noise ratio (SINR) at U is obtained as

$$\Lambda_{\mathrm{U}} = \rho_{\mathrm{S}} |h|^2 / [\rho_{\mathrm{I}} \kappa + 1], \tag{2}$$

where $\kappa = \sum_{m=1}^{M} |g_{\mathrm{I_m U}}|^2$.

III. PERFORMANCE ANALYSIS

Assuming that S transmits to U with the amount of information bit $\mathcal{N}$ and blocklength l. Hence, the average BLER to decode signal of U can be calculated by [2]

$$\bar{e}_{\mathrm{U}}(\Lambda_{\mathrm{U}}, \mathcal{N}, l) \approx \int_0^\infty Q\left(\frac{C(\Lambda_{\mathrm{U}}) - r_{\mathrm{U}}}{\sqrt{V(\Lambda_{\mathrm{U}})/l}}\right) f_{\Lambda_{\mathrm{U}}}(x) dx, \tag{3}$$

where $r_{\mathrm{U}} \triangleq \mathcal{N}/l$. In order to reduce the complexity of (3), $Q(x)$ is approximated as follows

$$\Xi(\Lambda_{\mathrm{U}}) \approx \begin{cases} 1, & \Lambda_{\mathrm{U}} \le v_{\mathrm{U}}, \\ 0.5 - \chi_{\mathrm{U}} \left(\Lambda_{\mathrm{U}} - \tau_{\mathrm{U}}\right), & v_{\mathrm{U}} < \Lambda_{\mathrm{U}} < u_{\mathrm{U}}, \\ 0, & \Lambda_{\mathrm{U}} \ge u_{\mathrm{U}}. \end{cases} \tag{4}$$

where $\chi_{\mathrm{U}} = \left[2\pi(2^{2r_{\mathrm{U}}} - 1)/l\right]^{-1/2}$, $\tau_{\mathrm{U}} = 2^{r_{\mathrm{U}}} - 1$, $v_{\mathrm{U}} = \tau_{\mathrm{U}} - 1/(2\chi_{\mathrm{U}})$, and $u_{\mathrm{U}} = \tau_{\mathrm{U}} + 1/(2\chi_{\mathrm{U}})$. By replacing (4) into (3), $\bar{e}_{\mathrm{U}}$ can be obtained as

$$\bar{e}_{\mathrm{U}} \approx \int_0^\infty \Xi(\Lambda_{\mathrm{U}}) f_{\Lambda_{\mathrm{U}}}(x) dx \approx \chi_{\mathrm{U}} \int_{v_{\mathrm{U}}}^{u_{\mathrm{U}}} F_{\Lambda_{\mathrm{U}}}(x) dx. \tag{5}$$

The average BLER, e_{U} of the destination is derived as following

$$e_{\mathrm{U}} = \chi(u_{\mathrm{U}} - v_{\mathrm{U}} - \Psi H), \tag{6}$$

where $\Psi = \frac{\Omega_h \rho_{\mathrm{S}}}{\bar{\Omega}_g \rho_I}$,
$H = \exp(-v_{\mathrm{U}}/(\Omega_h \rho_{\mathrm{S}})) \sum_{k=1}^{M-1} \frac{(k-1)!(-1/\Omega_h \rho_{\mathrm{S}})^{M-k-1}}{(M-1)!(v_{\mathrm{U}}+\Psi)^k} - \frac{(-1/\Omega_h \rho_{\mathrm{S}})^{M-1} \exp \Psi \ (\Omega \rho_{\mathrm{S}})}{(M-1)!} Ei(-(v_{\mathrm{U}} + \Psi) \ (\Omega_h \rho_{\mathrm{S}})) - \exp(-u_{\mathrm{U}}/(\Omega_h \rho_{\mathrm{S}})) \sum_{k=1}^{M-1} \frac{(k-1)!(-1/\Omega_h \rho_{\mathrm{S}})^{M-k-1}}{(M-1)!(u_{\mathrm{U}}+\Psi)^k} - \frac{(-1/\Omega_h \rho_{\mathrm{S}})^{M-1} \exp \Psi \ (\Omega \rho_{\mathrm{S}})}{(M-1)!} Ei(-(u_{\mathrm{U}} + \Psi) \ (\Omega_h \rho_{\mathrm{S}}))$.

Proof: The probability density functions (PDFs) of the random variables $X = |h|^2$ and $\kappa = \sum_{m=1}^{M} |g_{\mathrm{I_m U}}|^2$ are $f_X(x) = 1/(\Omega_h) \exp(-x/\Omega_h)$ and $f_\kappa(x) = (1/\bar{\Omega}_g) x^{M-1}/(M-1)! \exp(-x/\bar{\Omega}_g)$, respectively.

Firstly, the CDFs of Λ_{U} given in (2) can be expressed as

$$\begin{aligned} F_{\Lambda_{\mathrm{U}}}(z) &= \Pr\left(\frac{\rho_{\mathrm{S}} X}{\rho_{\mathrm{I}} \kappa + 1} \le z\right) \\ &= \int_0^\infty F_X\left(z\left(\frac{\rho_{\mathrm{I}} y + 1}{\rho_{\mathrm{S}}}\right)\right) f_\kappa(y) dy. \end{aligned} \tag{7}$$

With help of Eq. 3.351.3 in [20], we have

$$F_{\Lambda_{\mathrm{U}}}(z) = 1 - \left(\frac{\Psi}{z + \Psi}\right)^M \exp\left(\frac{-z}{\Omega_h \rho_{\mathrm{S}}}\right). \tag{8}$$

Then, putting (8) in (5) and using Eq. 3.353.1 in [20], we obtain the equation as in (6).

IV. SIMULATION AND NUMERICAL RESULTS

We set the parameters as following $\mathcal{N} = 80$(bits), $l = 100$ channel uses (CUs), $d_{\mathrm{SR}} = 40\,(\mathrm{m})$; $\nu = 2$ denotes the path loss exponent [21]. The interference sources are placed positions which have random distances between them and the destination and in range [50, 100 m].

Fig. 2 shows the average BLER of the destination changing with the the source's transmit power and with different transmit power at the interference source. It is clearly that the average BLER decreases as the transmit power of the source increases. The curses presenting theory match well

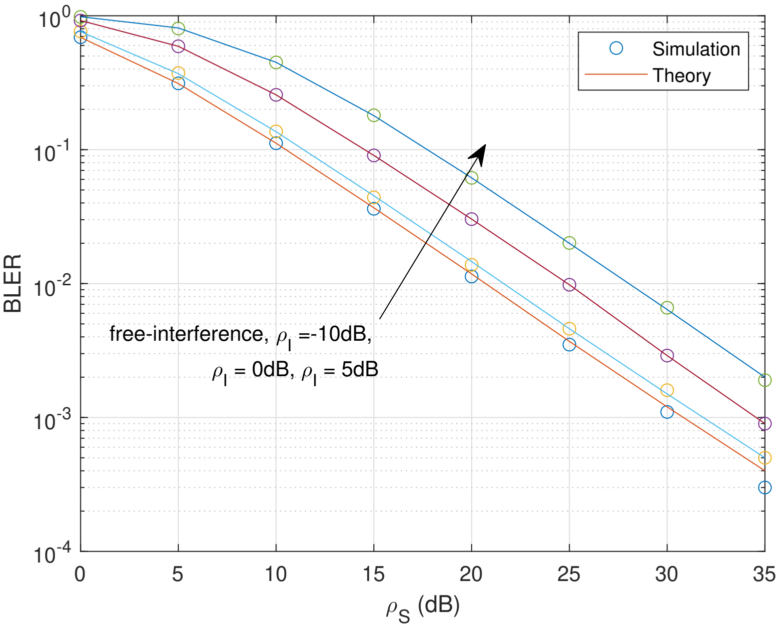

Fig. 2. Average BLER versus ρ_S with $M = 3$.

with that presenting simulation. Moreover, it is clear that the interference source's transmit powers affect significantly on the the performance of the system with regards to the BLER.

Fig. 3 indicates the average BLER with a change of the number of interference sources. Obviously, increase in the number of interference sources results in a reduction of the BLER of the destination. This is because increase in co-channel interference makes decoding at the destination worse.

To evaluate affect of the number of channel use on the performance, we provide Fig. 4 where the BLER is changed with the number of channel uses. We can see that the increase in the amount of channel uses leads to better performance because the longer the length of blockcode is, the more successful the decoding at the destination is.

V. CONCLUSIONS

In this paper, an investigation SPC in a single-hop communication system with the presence of the co-channel interference was presented. The BLER of the destination for was derived. The results based on evaluating the transmit power of the inference source and the number of interference sources affecting on the system performance that the two parameters make the performance of the system worse. In the future works, some solutions such as deploying multiple antenna at the source or at the destination to reduce affect of the co-channel interference; and the number of hop with the assistance of relay nodes can be considered to improved the system performance.

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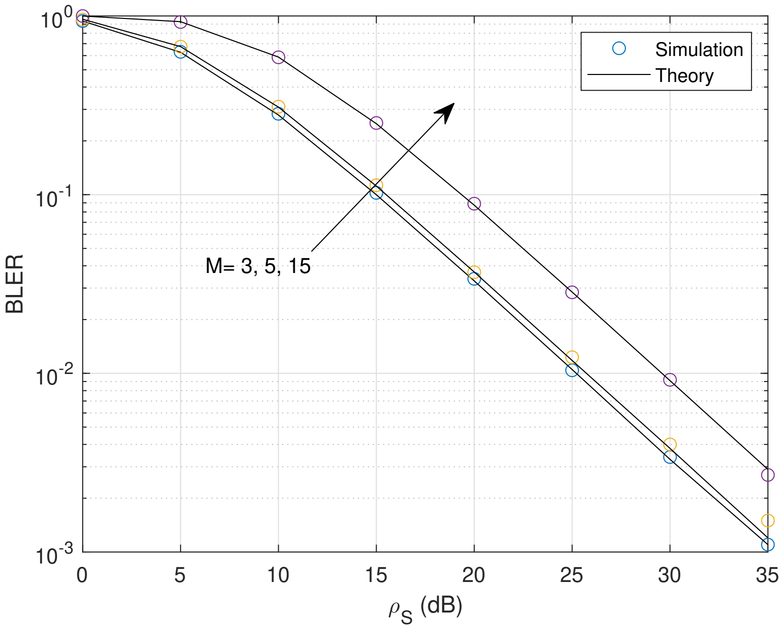

Fig. 3. Average BLER versus the number of interference sources with $\rho_{\mathrm{S}} = \{0, 35\}$ (dB), $\rho_{\mathrm{I}} = 0$dB.

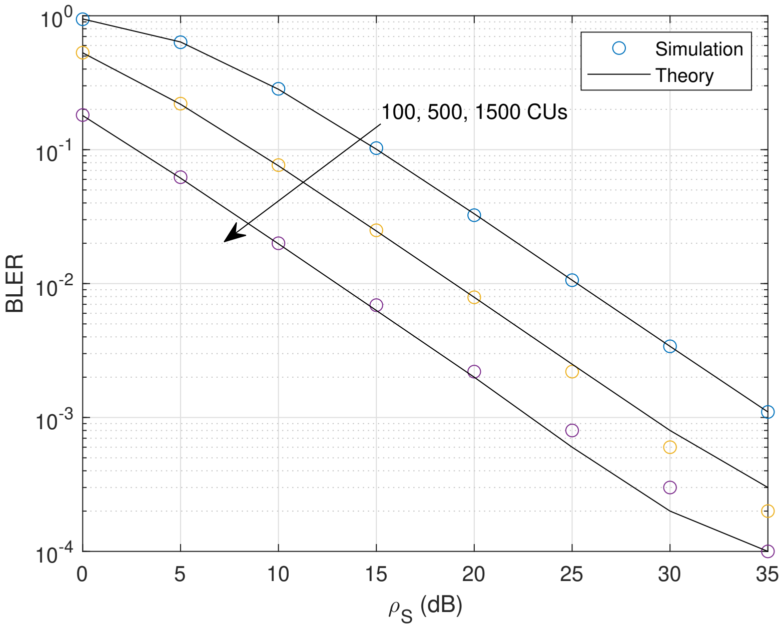

Fig. 4. Average BLER versus the number of channel uses with $M = 3$, $\rho_I = 0dB$.

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