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Two-Way Data Processing Technology for OPGW Line of Distribution Power Communication Networks

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Abstract

Promoted by information technology and scalable information systems, optical fiber composite overhead ground wire (OPGW) can not only improve the use efficiency of power towers, but also give full play to the dual role of communication optical cable and ground wire, due to the advantages of high reliability, excellent mechanical performance and low cost. The effective processing of the data from OPGW can effectively promote the wide application. In this paper, we study the two-way data processing technology for OPGW line of distribution power communication networks, where a single relay node assists the two-way data processing in time-division multiplexing mode. We evaluate the influence of the model parameters on the system data processing performance by investigating the outage probability, whereas the analytical and simulation results are demonstrated to show the effectiveness of two-way data processing for the OPGW communication. The results in this paper provides important reference for the development of OPGW communication and scalable information systems.

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Keywords: OPGW, two-way data technology, outage probability, simulation, analytical expression.

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1. Introduction

With the development of information technology [1–4], optical fiber composite overhead ground wire (OPGW) has been widely used in many areas including the smart grid networks. On the premise of ensuring the original electrical and mechanical performance of the overhead ground wire, it can transmit audio, video, data and other information [5, 6]. Compared with other types of optical cables, it has high reliability. It is suitable for erection on power lines of various voltage levels, with simple construction and installation. It can bear large stress and has strong bearing capacity to strong wind and ice. Protected by outer metal, it can effectively avoid the communication line fault caused by lightning strike and short-circuit current in the traditional power communication system. It can accommodate a large number of optical fiber cores. The service life is long, generally more than 25-30 years. Due to the above advantages, OPGW optical fiber communication has been widely used as an ideal communication means in the power system [7–9].

Power network refers to the part of the power system other than power generation equipment and power consumption equipment. The power network includes three links: power transformation, transmission and distribution. It integrates the power plants and power users distributed in a wide area, and sends the power produced in a centralized way to thousands of households with scattered power consumption. The power network is mainly composed of power lines, substations and converter stations (technical devices for realizing the mutual conversion of AC and DC power). According to functions, it can be divided into transmission lines, regional power grids, connecting lines and distribution networks. The connecting line in the power network is used to realize network interconnection, which can reasonably adjust the

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electric energy between regions, improve the reliability of power supply and the utilization rate of power generation equipment, and improve the economy and stability of power system operation. Although the realization of network interconnection has great social and economic benefits, it also puts forward higher requirements for the structure, control measures, communication facilities and operation dispatching of the power system.

Power network communication is the key to support the development of smart grid. The premise of building smart grid is the construction of power communication. Similarly, the development of power industry can not be separated from the effective operation of power communication. In general, synchronous digital hierarchy (SDH) is an optical fiber network structure in the smart grid system, which is used to solve the network requirements of data communication during the operation of the power grid. Nowadays, with the innovation and development of the power system, the operation volume of IP data transmission also increases year by year. In view of this phenomenon, people's conditions for power information communication are constantly changing, and their requirements are becoming higher and higher. Therefore, the power system bureau is also innovating, taking IP technology as the basis of the network and combining it with optical fiber technology to realize the development of smart grid communication.

In this paper, the two-way data processing technology is employed for enhancing the performance of OPGW line of distribution power communication networks, where a single relay node assists the two-way data processing in time-division multiplexing mode. We evaluate the influence of the model parameters on the system data processing performance by investigating the outage probability, whereas the analytical and simulation results are demonstrated to show the effectiveness of two-way data processing for the OPGW communication. The results in this paper provides important reference for the development of OPGW communication and scalable information systems.

2. System model

In this section, a two-way data processing model is introduced and the overall architecture of the system model is shown in Fig. 1. As seen in Fig. 1, the system has two ways to deal with the data for the OPGW line of distribution power communication networks. One way is from B to A_n, where $n \in \{1, 2, ..., N\}$, and N is the number of receiving nodes [10–12]. The other way is from A_n to B. The channel from A_n to R is represented by h_n and the channel from R to B is represented by g. According to Shannon theorem, the received signal-to-noise ratio (SNR) at A_n can be expressed as [13, 14],

$$SNR_{A_n} = \frac{P^2 u_n v}{2Pu_n + Pv + 1}, \quad (1)$$

where

$$u_n = |h_n|^2, \quad (2)$$

$$v = |g|^2, \quad (3)$$

where P is the transmit power at the source. Moreover, the received SNR at B can be expressed as [15–17]

$$SNR_B = \frac{P^2 u_n v}{Pu_n + 2Pv + 1}. \quad (4)$$

In addition, the probability density functions (PDFs) of $u_n = |h_n|^2$ and $v = |g|^2$ are expressed as, [18–20]

$$f_{u_n}(x) = \frac{1}{\alpha} e^{\frac{-x}{\alpha}}, \quad (5)$$

$$f_v(y) = \frac{1}{\beta} e^{\frac{-y}{\beta}}. \quad (6)$$

Based on the following inequality [21, 22],

$$\frac{xy}{x+y+1} < \min(x, y), \quad (7)$$

we can obtain, [23, 24]

$$SNR_{A_n} < P \min\left(u_n, \frac{v}{2}\right), \quad (8)$$

and

$$SNR_B < P \min\left(\frac{u_n}{2}, v\right). \quad (9)$$

Subsequently, the outage probability from A_n to B can be expressed as,

$$P_{outA} = \Pr(\log_2(1 + SNR_{A_n}) < R_{th}), \quad (10)$$

$$= \Pr\left(SNR_{A_n} < 2^{R_{th}} - 1\right), \quad (11)$$

where R_{th} represents the threshold of the outage probability. Based on (8), P_{outA} can be further derived as

$$P_{outA} = 1 - \Pr\left(P \min\left(u_{n^*}, \frac{v}{2}\right)\right) \quad (12)$$

$$= 1 - \Pr\left(Pu_{n^*} > 2^{R_{th}} - 1\right) \Pr\left(P\frac{v}{2} > 2^{R_{th}} - 1\right) \quad (13)$$

$$= 1 - \underbrace{\left(1 - \Pr\left(Pu_{n^*} < 2^{R_{th}} - 1\right)\right)}_{K_1} \underbrace{\Pr\left(P\frac{v}{2} > 2^{R_{th}} - 1\right)}_{K_2}, \quad (14)$$

where

$$n^* = \arg\max_{1 \le n \le N} |h_n|^2, \quad (15)$$

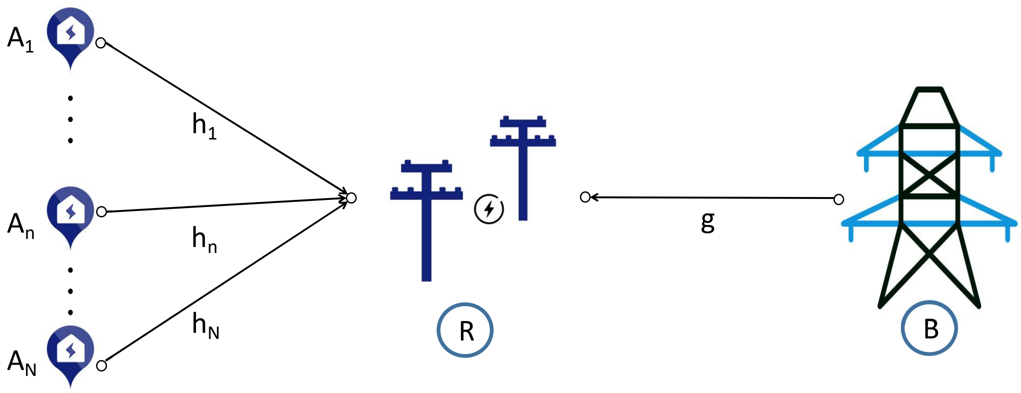

Figure 1. System model of the two-way data processing technology for OPGW line of distribution power communication networks.

and

$$SNR_{A_n} = \frac{P^2 u_{n^*} v}{2Pu_{n^*} + Pv + 1} < P \min\left(u_{n^*}, \frac{v}{2}\right). \tag{16}$$

The cumulative density function (CDF) of u_{n^*} is expressed as,

$$F_{u_{n^*}}(x) = Pr(u_{n^*} < x), \tag{17}$$
$$= Pr(|h_1|^2 < x)Pr(|h_2|^2 < x) \cdots Pr(|h_N|^2 < x), \tag{18}$$
$$= \sum_{n=0}^{N} (-1)^n \binom{N}{n} e^{\frac{-nx}{\alpha}}. \tag{19}$$

Thus, we can obtain the analytical expressions of K_1 and K_2 as,

$$K_1 = 1 - \sum_{n=0}^{N} (-1)^n \binom{N}{n} e^{\frac{-n(2^{R_{th}}-1)}{P\alpha}}, \tag{20}$$

$$K_2 = e^{\frac{-2(2^{R_{th}}-1)}{P\beta}}. \tag{21}$$

Therefore, the analytical outage probability from A_n to B is derived as

$$P_{outA} = 1 - (1 - \sum_{n=0}^{N} (-1)^n \binom{N}{n} e^{\frac{-n(2^{R_{th}}-1)}{P\alpha}} e^{\frac{-2(2^{R_{th}}-1)}{P\beta}}. \tag{22}$$

In the meanwhile, we can obtain the analytical outage probability from B to A_n as,

$$P_{outB} = \Pr(log_2(1 + SNR_B) < R_{th}), \tag{23}$$
$$= 1 - \Pr\left(P\frac{u_{n^*}}{2} > 2^{R_{th}} - 1\right)\Pr\left(Pv > 2^{R_{th}} - 1\right), \tag{24}$$
$$= 1 - (1 - \sum_{n=0}^{N} (-1)^n \binom{N}{n} e^{\frac{-2n(2^{R_{th}}-1)}{P\alpha}} e^{\frac{-(2^{R_{th}}-1)}{P\beta}}. \tag{25}$$

In the next section, we will provide some simulation results to verify the derived analytical results on the two-way data processing.

3. Simulation

In this part, some simulation results are presented to verify the analytical results on two-way data processing. Specifically, the effects of the network parameters, such as P, R_{th}, α, β, and N will be analyzed in the following experiments to verify the analytical results. In this section, the experiments are divided into two parts: one is the experiment for data transmission from A_n to B, while the other is the experiment for channel from B to A_n.

3.1. Experimental Results and Analysis for Channel $A_n - R - B$

In order to illustrate the influence of the parameters for the system model from channel A_n to B, the control variable method is exploited to analyze the different parameters of the system, and the experimental results are shown from Table 1 to Table 4 and from Fig. 2 to Fig. 5. As seen in Table 1, there are two kinds of experimental result: one is the simulation experiment, and the other is the calculation results of the analytical expression. With different threshold R_{th}, the outage probabilities with a certain P value are different. For the simulation method with $P = 10$ dB, the outage probabilities are 0.1583 and 0.4307 when $R_{th} = 1.0$ and $R_{th} = 2.0$, respectively. It shows that R_{th} would affect the outage probability of the system model. In particular, a larger R_{th} would lead to a worse performance. In addition, the simulation results are close to the analytical results with the

Table 1. Numerical results of $A_n - R - B$ versus R_{th} and P.

Methods	R_{th}	P/dB				
		10	15	20	25	30
Simulation	1.0	0.1583	0.0472	0.0147	0.0047	0.0015
	2.0	0.4307	0.1457	0.0434	0.0140	0.0043
Analytic	1.0	0.1306	0.0433	0.0139	0.0044	0.0014
	2.0	0.3430	0.1244	0.0411	0.0132	0.0042

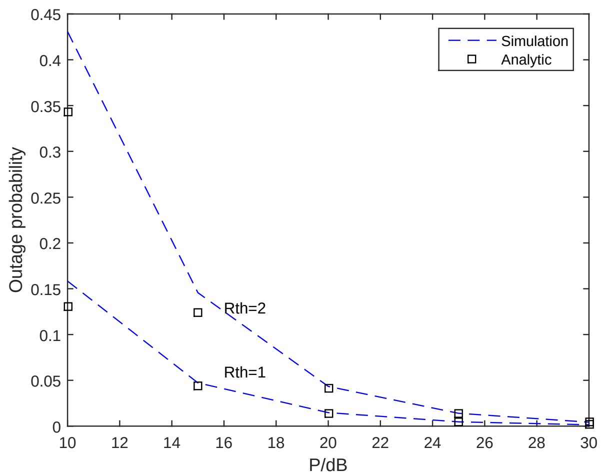

Figure 2. Outage probability of $A_n - R - B$ of OPGW line of distribution power communication networks versus P.

certain R_{th} and P. For example, when $R_{th} = 1$ and $P = 25$ dB, the experimental results for simulation experiment and analytical expression are 0.0047 and 0.0044, respectively. The difference between these two values is only 0.0003. It means that the simulation results identify the theoretical analysis of the OPGW line of distribution power communication networks with various values of R_{th} and P.

As seen in Fig. 2, the outage probability grows down as P grows up with a certain R_{th} for both simulation and analytical results. For example, as seen in the curves with $R_{th} = 1$ of simulation results in Fig. 2, the outage probability is larger than 0.4 with $P = 10$dB, but it is less than 0.05 when $P = 30$dB. It means that a larger P can improve the performance of the system. But after P reaches a certain high level, the system performance tends to be stable. It is because that a larger signal transmit power is helpful for the reliable two-way data transmission. Moreover, the curve with $R_{th} = 2$ is above the curve with $R_{th} = 1$, as a larger threshold corresponds to a higher data transmission standard, resulting in degradation of system performance.

As seen in Table 2 and Fig 3, we consider the influence of the number of the source N on the performance of the system model. In this experiment, the power $P = 20$ dB. As shown in Table 2, with different threshold R_{th}, different N results in different outage probability. For the analytical method with $N = 3$, the outage probabilities are 0.0040 and 0.0120 when $R_{th} = 1.0$ and $R_{th} = 2.0$, respectively. It shows that R_{th} would affect the outage probability of the system model. In particular, a larger R_{th} will lead to a worse performance. In addition, the simulation results are close to the analytical results with the certain R_{th} and N. For example, when $R_{th} = 1$ and $N = 4$, the experimental results for simulation experiment and analytical expression are 0.0037 and 0.0040, respectively. The difference between these two values is only 0.0003. It means that the simulation results identify the theoretical analysis of the OPGW line of distribution power communication networks with various values of R_{th} and N.

As seen in Fig. 3, the outage probability grows down as N grows up with a certain R_{th} for both simulation and analytical results. For example, as seen in the curves with $R_{th} = 1$ of simulation results in Fig. 3, the outage probability is larger than 0.04 with $N = 1$, but it is less than 0.02 when $N = 3$. It means that a larger N can improve the performance of the system. But after N reaches a certain high value, the system performance tends to be unchanged. Moreover, the curve with $R_{th} = 2$ is above the curve with $R_{th} = 1$, as a larger threshold corresponds to a higher data transmission standard, resulting in degradation of system performance.

Table 2. Numerical results of $A_n - R - B$ versus R_{th} and N.

Methods	R_{th}	N				
		1	2	3	4	5
Simulation	1.0	0.0145	0.0043	0.0041	0.0037	0.0039
	2.0	0.0432	0.0133	0.0121	0.0124	0.0125
Analytic	1.0	0.0139	0.0041	0.0040	0.0040	0.0040
	2.0	0.0411	0.0128	0.0120	0.0119	0.0119

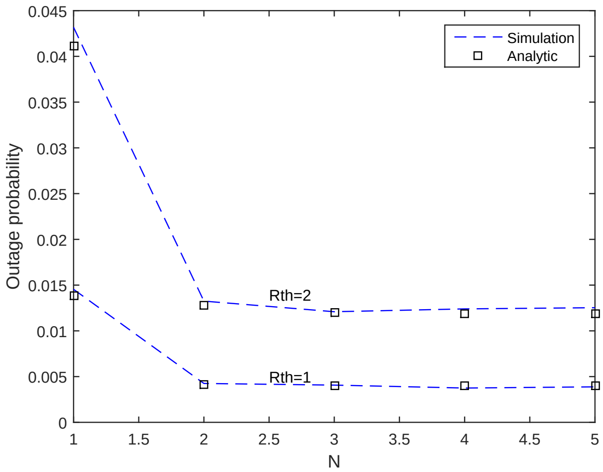

Figure 3. Outage probability of $A_n - R - B$ of OPGW line of distribution power communication networks versus N.

Table 3. Numerical results of $A_n - R - B$ versus R_{th} and β.

Methods	R_{th}	β				
		1	2	3	4	5
Simulation	1.0	0.0312	0.0211	0.0174	0.0154	0.0145
	2.0	0.0982	0.0650	0.0534	0.0471	0.0437
Analytic	1.0	0.0296	0.0198	0.0165	0.0149	0.0139
	2.0	0.0861	0.0582	0.0488	0.0440	0.0411

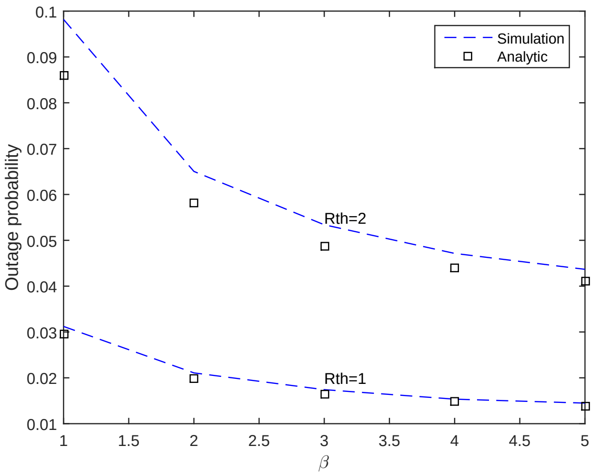

Figure 4. Outage probability of $A_n - R - B$ of OPGW line of distribution power communication networks versus β.

Table 4. Numerical results of $A_n - R - B$ versus R_{th} and α.

Methods	R_{th}	α 1	2	3	4	5
Simulation	1.0	0.0320	0.0257	0.0240	0.0226	0.0225
	2.0	0.0960	0.0778	0.0709	0.0677	0.0660
Analytic	1.0	0.0296	0.0247	0.0231	0.0222	0.0218
	2.0	0.0861	0.0723	0.0676	0.0653	0.0639

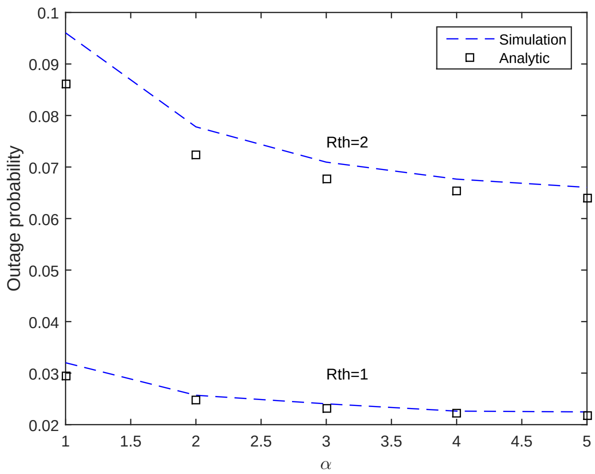

Figure 5. Outage probability of $A_n - R - B$ of OPGW line of distribution power communication networks versus α.

As seen in Table 3, Table 4, Fig. 4, and Fig. 5, we can analyze the influence of the channel parameters β and α on the performance of the considered system. In this experiment, the power $P = 20$ dB and $N = 1$ are set. In the experimental results of Table 3 and Fig. 4, the parameter α is set to 1 and parameter $\beta \in \{1, 2, 3, 4, 5\}$. Similarly, the parameter β is set to 1 and parameter $\alpha \in \{1, 2, 3, 4, 5\}$ in Table 4 and Fig. 5.

As seen in Table 3 and 4, the outage probabilities of simulation and analytical results are close to each other on the corresponding system parameters, which identifies the theoretical analysis of the OPGW line of distribution power communication networks versus the parameters β, α, and R_{th}. Moreover, as shown in Fig. 4, and Fig. 5, the outage probabilities of the simulation and analytical results both grow down as the parameters β and α grow up. It means that a larger β or α can improve the system performance.

3.2. Experimental Results and Analysis for Channel $B - R - A_n$

In order to illustrate the influence of the parameters on the system data transmission through channel B to A_n, we performed similar experiments as the experiments above, and the results are shown from Table 5 to Table 8 and from Fig. 6 to Fig. 9.

As seen in the Tables from 5 to 8, we can find that the same phenomenon is presented about that the experimental results of simulation method are close to the results of the analytical method. For example, in Table 6, when $R_{th} = 1$ and $N = 2$, the experimental results of simulation and analysis are 0.0027 and 0.0023, respectively. The difference between these two values is only 0.0004. Moreover, in Table 7, when $R_{th} = 1$ and $\beta = 3$, the experimental results of simulation and analysis are 0.0239 and 0.0231, respectively. The difference between these two values is only 0.0008. These experimental results identify the theoretical analysis of the OPGW line of distribution power communication networks versus the parameters β, α, and R_{th} of the channel $B - R - A_n$. As seen in the figures from Fig. 6 to Fig. 9, we can also draw a conclusion that the outage probability of the system decreases with the increase of parameters for a certain R_{th}. As shown in Fig. 7, the outage probability of the curve with $R_{th} = 2$ is larger than 0.06 when $N = 1$, but it is less than 0.02 when $N = 5$. In addition, in Fig. 8, the outage probability of the curve with $R_{th} = 2$ is larger than 0.09 when $\beta = 1$, but it is less than 0.07 when $\beta = 5$. It indicates that with the increase of parameters, the system performance has been continuously improved.

Table 5. Numerical results of $B - R - A_n$ versus R_{th} and P.

Methods	R_{th}	P/dB				
		10	15	20	25	30
Simulation	1.0	0.2225	0.0726	0.0223	0.0072	0.0022
	2.0	0.5531	0.2076	0.0670	0.0212	0.0070
Analytic	1.0	0.1975	0.0672	0.0218	0.0069	0.0022
	2.0	0.4831	0.1884	0.0639	0.0207	0.0066

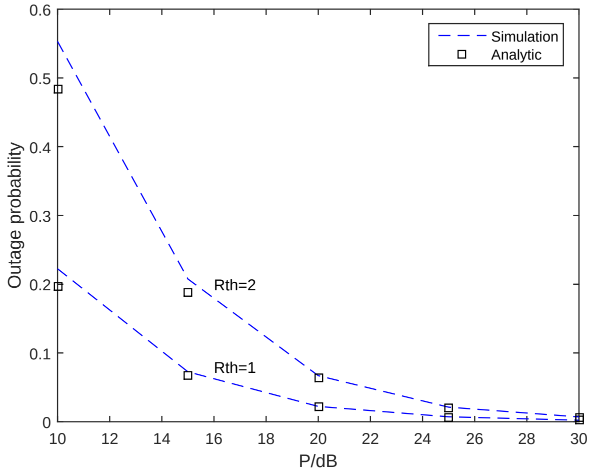

Figure 6. Outage probability of $B - R - A_n$ of OPGW line of distribution power communication networks versus P.

Table 6. Numerical results of $B - R - A_n$ versus R_{th} and N.

Methods	R_{th}	N				
		1	2	3	4	5
Simulation	1.0	0.0219	0.0027	0.0021	0.0018	0.0020
	2.0	0.0663	0.0098	0.0067	0.0067	0.0065
Analytic	1.0	0.0218	0.0024	0.0020	0.0020	0.0020
	2.0	0.0639	0.0094	0.0062	0.0060	0.0060

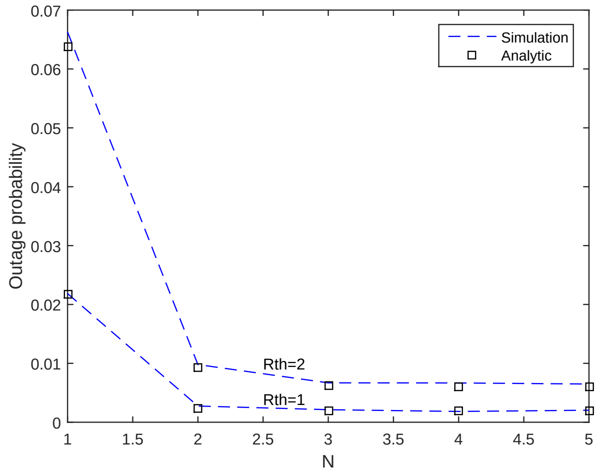

Figure 7. Outage probability of $B - R - A_n$ of OPGW line of distribution power communication networks versus N.

Table 7. Numerical results of $B-R-A_n$ versus R_{th} and β.

Methods	R_{th}	β				
		1	2	3	4	5
Simulation	1.0	0.0317	0.0261	0.0239	0.0229	0.0223
	2.0	0.0975	0.0784	0.0721	0.0678	0.0661
Analytic	1.0	0.0296	0.0247	0.0231	0.0222	0.0218
	2.0	0.0861	0.0723	0.0676	0.0653	0.0639

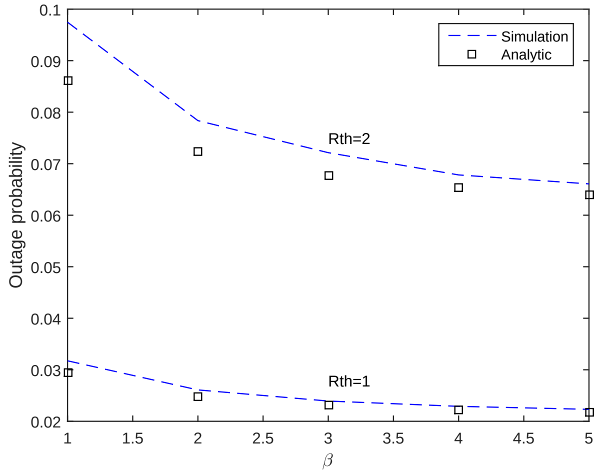

Figure 8. Outage probability of $B-R-A_n$ of OPGW line of distribution power communication networks versus β.

Table 8. Numerical results of $B-R-A_n$ versus R_{th} and α.

Methods	R_{th}	α				
		1	2	3	4	5
Simulation	1.0	0.0320	0.0212	0.0175	0.0156	0.0149
	2.0	0.0971	0.0649	0.0529	0.0473	0.0440
Analytic	1.0	0.0296	0.0198	0.0165	0.0149	0.0139
	2.0	0.0861	0.0582	0.0488	0.0440	0.0411

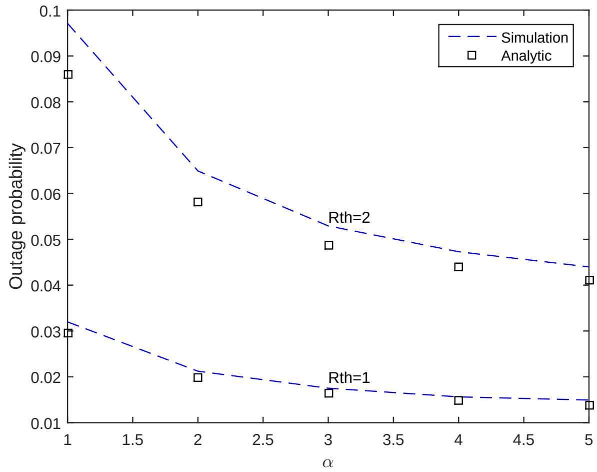

Figure 9. Outage probability of $B-R-A_n$ of OPGW line of distribution power communication networks versus α.

4. Conclusions

This paper investigated the two-way data processing technology for enhancing the performance of OPGW line of distribution power communication networks, where the relay node R was assisted the two-way data processing between A_n and B, in time-division multiplexing mode. Specifically, one way is from A_n to B with the help of R, while the other is from B to A_n assisted by R. The data processing performance of the considered system was investigated, where we derived analytical expressions on the outage probability, from which we obtain some important and meaningful insights on the two-way data processing. Finally, we presented some simulation results which agree with the analytical ones and verify the proposed studies on the two-way data process of OPGW line of distribution power communication networks.

4.1. Data Availability Statement

The data of this work can be obtained through the email to the authors: Xinzhan Liu (XinzhanLiu2022@hotmail.com), Zhengfeng Zhang (zhengfengzhang2022@hotmail.com), and Bin Du (bindu2022@hotmail.com).

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