


## Research Article

# Performance Analysis of Product Channel for Relaying-Assisted Edge Computing in IoT Networks

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In this paper, we analyze the typical product channel which is often encountered in wireless relaying channels, for relaying-assisted edge computing in Internet of Things (IoT) networks. Such analysis is of vital importance, as it is often encountered in wireless transmission. Specifically, we firstly derive a closed-form expression of the transmission outage probability in product channels, through solving involved complicated multivariate integral. We then simplify the expression through some approximation to the involved Bessel function, which can help obtain some meaningful findings to the system design. We finally provide some numerical results to verify that the presented analysis on the production channels is effective.

## 1. Introduction

Recently, Internet of Things (IoT) networks have been upgraded to a large extent [1, 2], thanks to the rapid progress in the wireless transmission and edge computing [3]. Moreover, the development of artificial intelligence also contributes to the upgraded IoT networks, such as the deep learning, transfer learning, and federated learning [4]. For these artificial intelligence algorithms, communication still plays an important role, since it can reduce the communication delay and power consumption, which can help speed up the intelligent algorithms and its convergence performance [5].

Moreover, an essential style in the MEC systems is the offloading strategy, which identifies the number of component of the jobs ought to be calculated by the CAPs. Essentially, offloading is actually to use the computational sources coming from the CAPs at the expense of communi-

cation [6, 7]. Many researches have been performed to accomplish a proper trade-off. Here, the authors in [8] examined the opportunistic CAP choice for the MEC connect with 2 CAPs and developed an optimal offloading strategy to enhance the outage efficiency in regard to latency as well as power usage. For multiuser multi-CAP MEC systems, the offloading might end up being rather complex [9, 10], as well as it is actually difficult to provide some logical services for the offloading. Within this particular situation, some smart formulas have actually been made a proposal to MEC systems, like deeper Q-network located formulas [11] as well as federated knowing located formulas [12, 13].

In further, the relaying technique has attracted a lot of attention from researchers including both the students and teachers. It has been widely applied in the IoT networks and edge computing. In particular, when the direct communication is poor due to the obstacles in the communication, the relaying can forward the signals and hence enhance the

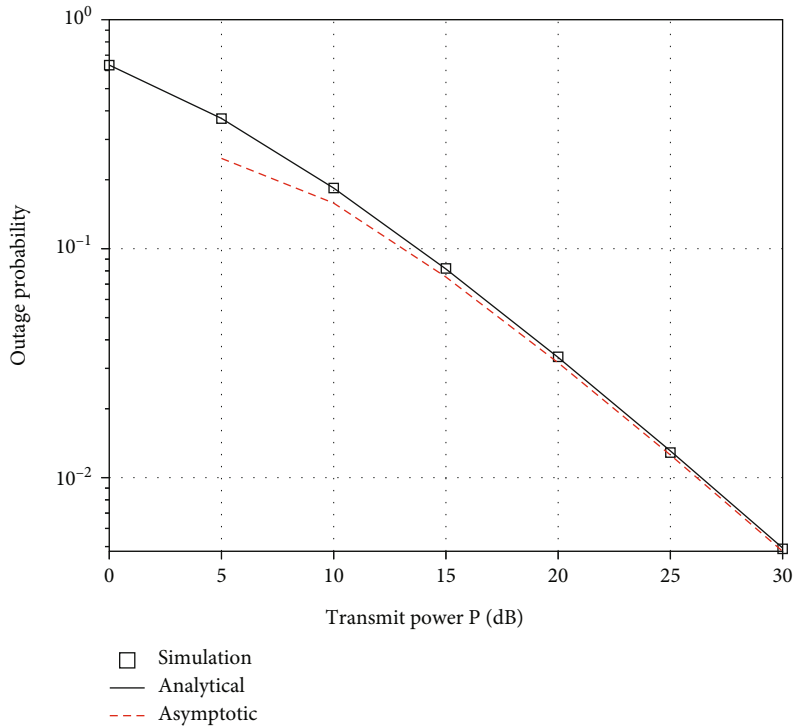


FIGURE 1: Comparison of three solutions versus the transmit power.

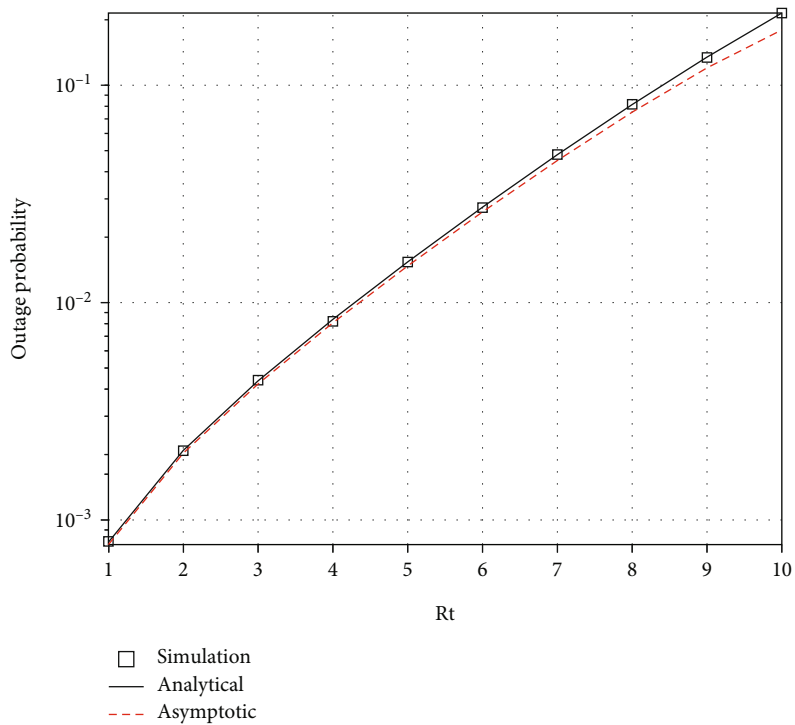


FIGURE 2: Comparison of three solutions versus  $R_t$ .

communication quality. Relaying technique has been also applied in the edge computing networks, whereas it can help assist the calculating tasks through relaying. However, the product channel is often encountered in the relaying trans-

mission, which needs some further and deeper research to solve the hanged problems.

In this paper, we analyze the typical product channel which is often encountered in relaying channels, for

TABLE 1: Outage probability values of three solutions versus the transmit power.

Transmit power $P$ (dB)	Simulation	Analytical	Asymptotic
0	$6.3339 \times 10^{-1}$	$6.3378 \times 10^{-1}$	0
5	$3.7149 \times 10^{-1}$	$3.7063 \times 10^{-1}$	$2.4797 \times 10^{-1}$
10	$1.8327 \times 10^{-1}$	$1.8390 \times 10^{-1}$	$1.5810 \times 10^{-1}$
15	$8.1029 \times 10^{-2}$	$8.1509 \times 10^{-2}$	$7.5192 \times 10^{-2}$
20	$3.3194 \times 10^{-2}$	$3.3502 \times 10^{-2}$	$3.1746 \times 10^{-2}$
25	$1.305 \times 10^{-2}$	$1.3084 \times 10^{-2}$	$1.2559 \times 10^{-2}$
30	$4.896 \times 10^{-3}$	$4.9308 \times 10^{-3}$	$4.7682 \times 10^{-3}$

TABLE 2: Outage probability values of three solutions versus  $R_t$ .

$R_t$	Simulation	Analytical	Asymptotic
1	$8.15 \times 10^{-4}$	$7.9041 \times 10^{-4}$	$7.7047 \times 10^{-4}$
2	$2.118 \times 10^{-3}$	$2.0886 \times 10^{-3}$	$2.0285 \times 10^{-3}$
3	$4.374 \times 10^{-3}$	$4.3651 \times 10^{-3}$	$4.2241 \times 10^{-3}$
4	$8.484 \times 10^{-3}$	$8.3758 \times 10^{-3}$	$8.0706 \times 10^{-3}$
5	$1.5427 \times 10^{-2}$	$1.5391 \times 10^{-2}$	$1.4748 \times 10^{-2}$
6	$2.739 \times 10^{-2}$	$2.7487 \times 10^{-2}$	$2.6137 \times 10^{-2}$
7	$4.7893 \times 10^{-2}$	$4.7924 \times 10^{-2}$	$4.5047 \times 10^{-2}$
8	$8.134 \times 10^{-2}$	$8.151 \times 10^{-2}$	$7.519 \times 10^{-2}$
9	$1.3506 \times 10^{-1}$	$1.347 \times 10^{-1}$	$1.2019 \times 10^{-1}$
10	$2.1435 \times 10^{-1}$	$2.1486 \times 10^{-1}$	$1.7968 \times 10^{-1}$

relaying-assisted edge computing in Internet of Things (IoT) networks. Such analysis is of vital importance, as it is often encountered in wireless channels. Specifically, we firstly give a closed-form expression of the transmission outage in product channels, through solving the involved multivariate integral. We then simplify the expression through some approximation to the involved Bessel function, which can help obtain some meaningful finding to the system design. We finally provide some numerical results to verify that the presented analysis on the production channels is effective.

## 2. System Model

According to the definition of signal-to-noise ratio (SNR), we can obtain the SNR of a specific channel by

$$\text{SNR} = 10 \lg \left( \frac{Ph^2}{\sigma^2} \right), \quad (1)$$

where  $P$  is the transmit power,  $h \sim \mathcal{CN}(0, \varepsilon)$  is the instantaneous channel parameter of the wireless link, and  $\sigma^2$  is the variance of the additive white Gaussian noise (AWGN) at the receiver.

We write the probability that the SNR value of the channel composed of  $h_1$  and  $h_2$  that is less than  $R_t$  as follows:

$$P_{\text{out}} = \Pr \left( \frac{P}{\sigma^2} (|h_1||h_2|)^2 < R_t \right). \quad (2)$$

Then, we obtain

$$P_{\text{out}} = \Pr \left( |h_1||h_2| < \frac{\sigma^2 R_t}{P} \right). \quad (3)$$

For simplicity, we let  $|h_1|^2 = x_1$  and  $|h_2|^2 = x_2$ , thus

$$P_{\text{out}} = \Pr \left\{ x_1 x_2 < \frac{\sigma^2 R_t}{P} \right\} = \Pr \left\{ x_1 < \frac{\sigma^2 R_t}{P x_2} \right\}. \quad (4)$$

The probability density function of  $f_{|h_k|^2}(x_k)$ ,  $k \in \{1, 2\}$  is

$$f_{|h_k|^2}(x_k) = \frac{1}{\beta_k} e^{-x_k/\beta_k}. \quad (5)$$

Let  $H_1 = \sigma^2 R_t / P x_2$ , thus we can have

$$\int_0^{H_1} \mathbb{1} f_{|h_1|^2}(x_1) dx_1 = \int_0^{H_1} \mathbb{1} \frac{1}{\beta_1} e^{-x_1/\beta_1} dx_1 = 1 - e^{-H_1/\beta_1}. \quad (6)$$

We can write  $P_{\text{out}}$  as follows:

$$\begin{aligned} P_{\text{out}} &= \int_0^{+\infty} \left( 1 - e^{-H_1/\beta_1} \right) f_{|h_2|^2}(x_2) dx_2 \\ &= \frac{1}{\beta_2} \int_0^{+\infty} \left( 1 - e^{-(\sigma^2 R_t / P x_2) / \beta_1} \right) e^{-x_2/\beta_2} dx_2 \\ &= \frac{1}{\beta_2} \int_0^{+\infty} \left( 1 - e^{-\sigma^2 R_t / P \beta_1 x_2} \right) e^{-x_2/\beta_2} dx_2. \end{aligned} \quad (7)$$

Let  $A = \sigma^2 R_t / P$ , we can obtain

$$P_{\text{out}} = \frac{1}{\beta_2} \int_0^{+\infty} \mathbb{1} \left( 1 - e^{-A/\beta_1 x_2} \right) e^{-x_2/\beta_2} dx_2. \quad (8)$$

By solving the integral formula, we can obtain

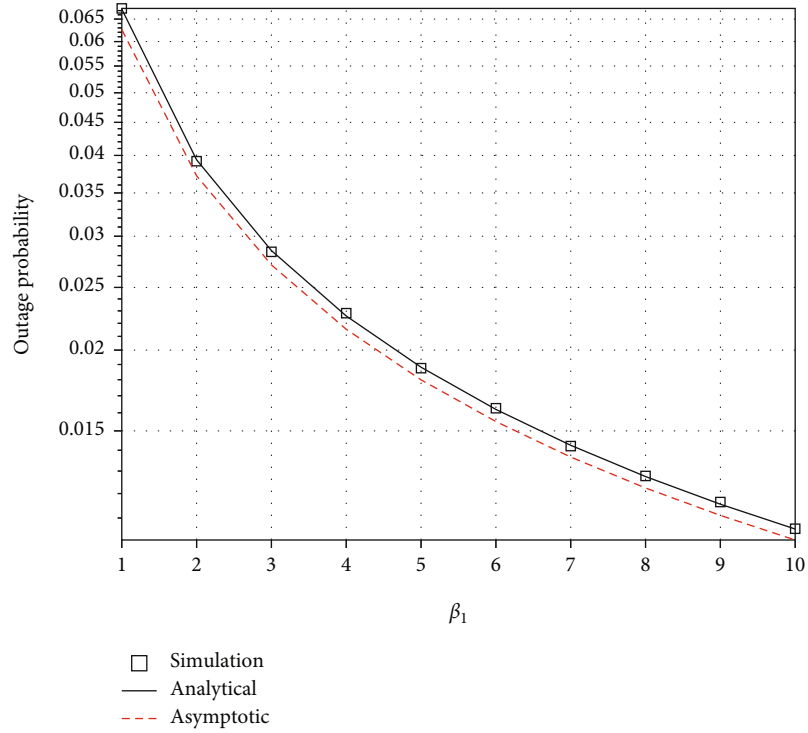
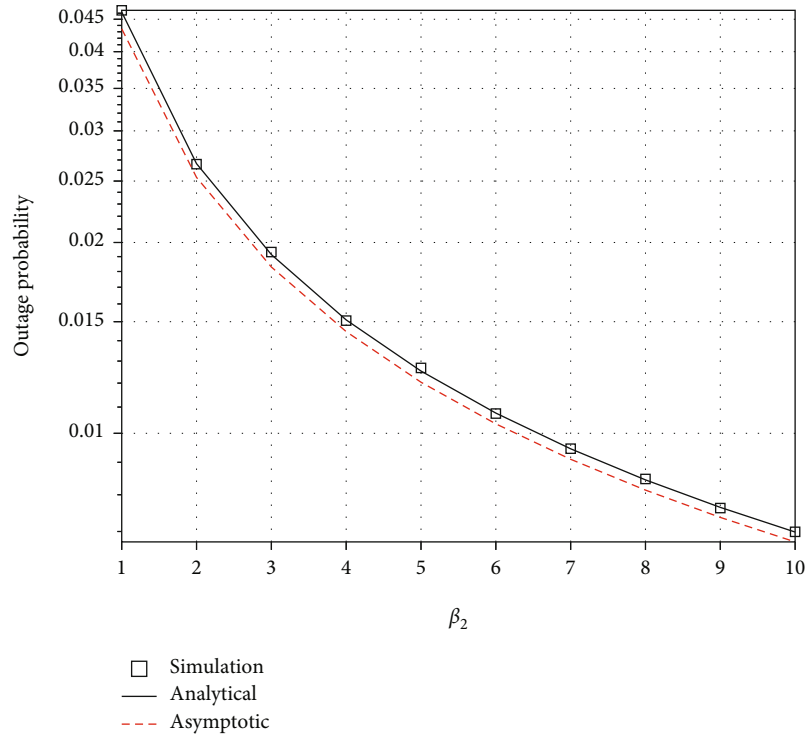
$$P_{\text{out}} = 1 - \frac{1}{\beta_2} \sqrt{4A} K_1(x) \left( \sqrt{\frac{4A}{\beta_1 \beta_2}} \right), \quad (9)$$

where  $K_1(x)$  is Bessel functions of the first order. In order to speed up the computation, we can approximate (9) as follows:

$$P_{\text{out}} \approx 1 - \frac{A}{\beta_1 \beta_2} \ln \left( \frac{4A}{e \beta_1 \beta_2} \right) + \beta_2. \quad (10)$$

## 3. Numerical and Simulation Results

In this part, we present some numerical and simulation results to verify the effect of outage probability analysis.

FIGURE 3: Comparison of three solutions versus  $\beta_1$ .FIGURE 4: Comparison of three solutions versus  $\beta_2$ .

We compare the effects of simulation solutions, analytical solutions, and asymptotic solutions with different transmit powers and upper limit values of SNR in Figures 1 and 2 and Tables 1 and 2. Moreover, we analyze the impact of dif-

ferent  $\beta_1$  and  $\beta_2$  on outage probability in Figures 3 and 4 and Tables 3 and 4.

Figure 1 shows comparison of three solutions versus the transmit power, and the three solutions gradually decline as

TABLE 3: Outage probability values of three solutions versus  $\beta_1$ .

$\beta_1$	Simulation	Analytical	Asymptotic
1	$6.7515 \times 10^{-2}$	$6.7346 \times 10^{-2}$	$6.2627 \times 10^{-2}$
2	$3.919 \times 10^{-2}$	$3.9384 \times 10^{-2}$	$3.7196 \times 10^{-2}$
3	$2.8379 \times 10^{-2}$	$2.8507 \times 10^{-2}$	$2.7091 \times 10^{-2}$
4	$2.281 \times 10^{-2}$	$2.2584 \times 10^{-2}$	$2.1539 \times 10^{-2}$
5	$1.8753 \times 10^{-2}$	$1.8817 \times 10^{-2}$	$1.7989 \times 10^{-2}$
6	$1.626 \times 10^{-2}$	$1.6191 \times 10^{-2}$	$1.5507 \times 10^{-2}$
7	$1.4209 \times 10^{-2}$	$1.4249 \times 10^{-2}$	$1.3665 \times 10^{-2}$
8	$1.2776 \times 10^{-2}$	$1.2749 \times 10^{-2}$	$1.2240 \times 10^{-2}$
9	$1.1643 \times 10^{-2}$	$1.1553 \times 10^{-2}$	$1.1102 \times 10^{-2}$
10	$1.0587 \times 10^{-2}$	$1.0576 \times 10^{-2}$	$1.0171 \times 10^{-2}$

TABLE 4: Outage probability values of three solutions versus  $\beta_2$ .

$\beta_2$	Simulation	Analytical	Asymptotic
1	$4.6547 \times 10^{-2}$	$4.6193 \times 10^{-2}$	$4.3462 \times 10^{-2}$
2	$2.6644 \times 10^{-2}$	$2.6630 \times 10^{-2}$	$2.5335 \times 10^{-2}$
3	$1.9154 \times 10^{-2}$	$1.9141 \times 10^{-2}$	$1.8295 \times 10^{-2}$
4	$1.4985 \times 10^{-2}$	$1.5097 \times 10^{-2}$	$1.4469 \times 10^{-2}$
5	$1.2491 \times 10^{-2}$	$1.2538 \times 10^{-2}$	$1.2039 \times 10^{-2}$
6	$1.0802 \times 10^{-2}$	$1.0762 \times 10^{-2}$	$1.0349 \times 10^{-2}$
7	$9.47 \times 10^{-3}$	$9.4525 \times 10^{-3}$	$9.0994 \times 10^{-3}$
8	$8.286 \times 10^{-3}$	$8.4437 \times 10^{-3}$	$8.1356 \times 10^{-3}$
9	$7.693 \times 10^{-3}$	$7.6410 \times 10^{-3}$	$7.3677 \times 10^{-3}$
10	$6.964 \times 10^{-3}$	$6.9860 \times 10^{-3}$	$6.7405 \times 10^{-3}$

the transmit power gradually improves. The outage probability of the analytical solution reaches  $4.9308 \times 10^{-3}$  when the transmit power is 30 dB. Moreover, the simulation solutions almost coincide with the analytical solutions from transmit powers of 0 to 30 dB. The asymptotic solutions increasingly approximate the simulation solutions and the analytical solutions as the transmit power gradually improves. Specifically, when the transmit power is 30 dB, the outage probabilities of the analytical solution, the simulation solution, and the asymptotic solution are  $4.9308 \times 10^{-3}$ ,  $4.896 \times 10^{-3}$ , and  $4.7682 \times 10^{-3}$ , respectively. The specific values of the three solutions are shown in Table 1.

In Figure 2, the outage probabilities of the analytical solutions, the simulation solutions, and the asymptotic solutions improve as the target  $R_t$  raises. The analytical solutions, the simulation solutions, and the asymptotic solutions almost coincide when  $R_t$  versus from 1 to 5, but the asymptotic solutions begin to markedly lower than the two other curves as  $R_t$  raises. For instance, the outage probabilities of the analytical solution, the simulation solution, and the asymptotic solution are  $7.9041 \times 10^{-4}$ ,  $8.15 \times 10^{-4}$ , and  $7.7047 \times 10^{-4}$ , respectively, when  $R_t$  is 1, while the above

three are  $2.1486 \times 10^{-1}$ ,  $2.1435 \times 10^{-1}$ , and  $1.7968 \times 10^{-1}$ , respectively, when  $R_t$  is 10. The specific values of the three solutions are shown in Table 2.

Figures 3 and 4 demonstrate the effects of simulation solutions, analytical solutions, and asymptotic solutions with different  $\beta_1$  and  $\beta_2$ . The outage probabilities of the analytical solutions, the simulation solutions, and the asymptotic solutions decline as the values of  $\beta_1$  and  $\beta_2$  increase, in both Figures 3 and 4. In addition, the analytical solutions and the simulation solutions basically coincide when  $\beta_1$  and  $\beta_2$  vary from 1 to 10. The outage probability values of the asymptotic solutions are all less than the analytical solutions and the simulation solutions in both Figures 3 and 4. For instance, the outage probabilities of the analytical solution, the simulation solution, and the asymptotic solution are  $1.0576 \times 10^{-2}$ ,  $1.0587 \times 10^{-2}$ , and  $1.0171 \times 10^{-2}$ , respectively, when  $\beta_1$  is 10, while the above three are  $6.9860 \times 10^{-3}$ ,  $6.964 \times 10^{-3}$ , and  $6.7405 \times 10^{-3}$ , when  $\beta_2$  is 10, respectively. We present the detailed values of the three solutions in Tables 3 and 4.

## 4. Conclusions

In this paper, we analyzed the typical product channel which was often encountered in relaying channels, for relaying-assisted edge computing in Internet of Things (IoT) networks. Such analysis was of vital importance, as it was often encountered in wireless channels. Specifically, we firstly gave a closed-form expression of the transmission outage in product channels, through solving the multivariate integral. We then simplified the expression through some approximation to the involved Bessel function, which could help obtain some meaningful finding to the system design. We finally presented some numerical results to verify that the presented analysis on the production channels was effective.

## Data Availability

The data can be obtained through the email to the authors.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this work.

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