EAI Endorsed Transactions
on Scalable Information Systems
Research Article EAI.EU

Data Transmission of Digital Grid Assisted by Intelligent Relaying

Shuangbai He[1,*], Chun Yang[1], Yuda Li[1], Binyu Xie[1], and Jiaqi Zhao[1]

[1]Energy Development Research Institute of China Southern Power Grid, Guangzhou, China
(e-mail: shuangbaihe@hotmail.com, chunyang2022@hotmail.com,
yudali2022@hotmail.com, binyuxie@hotmail.com, jiaqizhaoCSG@hotmail.com).

Abstract

In this paper, we study the relaying and cache aided digital grid data transmission, where the relaying may be equipped by caching or not, depending on specific applications. For both cases, we evaluate the impact of relaying and caching on the system performance of digital grid data transmission through theoretical derivation. To this end, an analytical expression on the outage probability is firstly derived for the data transmission. We then provide an asymptotic expression on the system outage probability. Finally, some simulation results are provided to verify the correctness of the derived analysis on the system performance, and show the impact of relaying and caching on the data transmission of digital grid system. In particular, the usage of caching at the relaying can help strengthen the data transmission performance of the considered system effectively. The results in this paper could provide some reference to the development of wireless transmission and scalable information systems.

Received on 31 October 2022; accepted on 11 December 2022; published on 17 January 2023

Keywords: Digital grid, data transmission, outage probability, analytical expression, asymptotic expression.

Copyright © 2023 Shuangbai He *et al.*, licensed to EAI. This is an open access article distributed under the terms of the CC BY-NC-SA 4.0, which permits copying, redistributing, remixing, transformation, and building upon the material in any medium so long as the original work is properly cited.

doi:10.4108/eetsis.v10i3.2823

1. Introduction

Inspired by the information technology and scalable information systems [1–3], power transmission lines are generally called power lines, among which the lines from power plants to power load centers and the connecting lines between power systems are transmission lines, which are erected between substations (switchyards) and substations [4–6]. The power distribution line is the line that the power load center distributes power to each power user. In particular, the overhead distribution line is a distribution line that uses electric poles to suspend the conductors in the air and directly supplies power to users. The sectioning point of each overhead distribution line shall be equipped with a single switch (mostly on the column). In order to make effective use of overhead corridors, co tower is mainly adopted in urban areas. There are two circuits and four circuits on the same pole, and there are 10kV and 380V on the same pole. Overhead lines are divided into trunk lines and branch lines according to their locations in the network. In the middle of the trunk lines, they can be directly connected into branch lines (large branch lines), and in the middle of the branch lines, they can be directly connected and then formed into branch lines (small branch lines). Sectional switches shall be installed for trunk lines and large branch lines. The overhead line has the advantages of simple erection, low cost, sufficient material supply, and convenient maintenance. It is easy to find and remove faults and other advantages, but the disadvantage is that it is easy to be affected by external environments, and the power supply reliability is often poor in practice.

In the construction of traditional power distribution network, due to the limitation of technology and equipment, we may have to use wired communication for data transmission. The most obvious difference between wired communication and wireless communication is cost. Wired communication requires more cables and underground pipelines as the communication foundation. However, most ground construction of wireless

*Corresponding author. Email: shuangbaihe@hotmail.com

communication technology can often be avoided. Only when information receivers are reasonably installed at the receiving points, we can directly obtain the associated signals, which will certainly reduce the construction cost of communication systems more effectively. To realize the transformation from traditional distribution network to intelligent distribution network, we should rely on the construction of communication systems covering various forms. Under the background of significant improvement of social and economic level and scientific and technological level, wireless communication technology has developed rapidly in recent years, especially in the application of intelligent distribution network, which further enhances the intelligence of distribution network and effectively improves the security and stability of distribution network during operation.

Wireless communication utilizes the electromagnetic wave to convey information in free space, where users can flexibly exchange their information. In recent yeas, there have been great progress in the development of wireless communication techniques, and a lot of new applications have emerged [7]. There are many kinds of mobile communications, such as electromagnetic wave, satellite communication and near-field communication, which are the most frequently used technology in people's life. Wireless technology has become the most exciting field in telecommunications and networks. With the rapid growth of mobile phone use, various satellite services, wireless networks, wireless smartphones, tablets, 5G mobile phones, various applications, and Internet of Things have brought critical changes to the telecommunications and network design [8, 9].

In this paper, the digital grid data transmission assisted by relaying and caching is studied, where the relaying may be equipped by caching or not depending on the specific applications. For both cases, we study the system performance of digital grid by jointly taking into account the relaying and caching. Specifically, an analytical expression on the outage probability is firstly derived for the data transmission of digital grid system. We then provide an asymptotic expression for the outage probability on the data transmission for the digital grid system. Finally, some simulation results are presented to verify the effectiveness of the derived analysis on the system performance, and show the impact of both relaying and caching on the data transmission of digital grid system. In particular, the usage of caching at the relaying can help reduce the outage event for the considered system effectively. The results in this paper could provide some reference to the development of wireless transmission and scalable information systems.

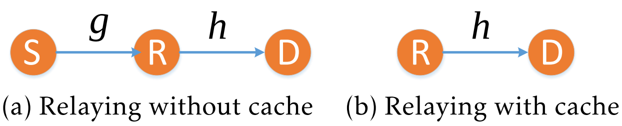

Figure 1. Two kinds of wireless transmission system model for digital grid data transmission.

2. System model and performance analysis

As to the relaying and caching aided digital grid data transmission, we provide Fig. 1 to show the structure of cache-aided wireless transmission model, where the relaying may be equipped by storage space due to specific needs and requirements [10–12]. To illustrate the characteristics of the cache-aided wireless transmission network, the cache-free model is also introduced in this work. In Fig. 1 (a), it shows that the signal transmitted from the source S to the destination D must go through two channels without the cache during the wireless path, where one is $S-R$ channel z_1 and the other is $R-D$ channel z_2. Once there is cache in R, the signal can be transmitted from R to D directly, as shown in Fig. 1 (b). From the above description, the received SNR at D without cache is calculated as [13–15]

$$\gamma_D = \frac{\rho^2 q_1 q_2}{\rho q_1 + \rho q_2 + 1}, \tag{1}$$

with

$$q_1 = |z_1|^2, \tag{2}$$

$$q_2 = |z_2|^2, \tag{3}$$

where ρ represents the transmit SNR, and the distributions of $q_1 = |z_1|^2$ and $q_2 = |z_2|^2$ are expressed as [16, 17]

$$f_{q_1}(q_1) = \frac{1}{\zeta} e^{\frac{-q_1}{\zeta}}, \tag{4}$$

$$f_{q_2}(q_2) = \frac{1}{\lambda} e^{\frac{-q_2}{\lambda}}. \tag{5}$$

Based on the following inequality [18, 19],

$$\frac{ab}{a+b+1} < \min(a, b), \tag{6}$$

we can obtain [20–22]

$$\gamma_D < \min(\rho q_1, \rho q_2) = \rho \min(q_1, q_2). \tag{7}$$

Then, the outage probability from S to D can be written as [23, 24]

$$P_{out_1} = \Pr\left(\frac{1}{2}\log_2(1+\gamma_D) < \xi\right), \tag{8}$$

$$= \Pr(\gamma_D < 2^{2\xi} - 1), \tag{9}$$

where ξ denotes a given threshold on the data rate. Based on the approximation of γ_D in (7), we can further write the lower bound (LB) on P_{out_1} as,

$$P_{out_1}^{LB} = 1 - \Pr(\rho \min(q_1, q_2) < 2^{2\xi} - 1), \quad (10)$$

$$= 1 - \Pr\left(\min(q_1, q_2) > \frac{2^{2\xi} - 1}{\rho}\right), \quad (11)$$

$$= 1 - \underbrace{\left(1 - \Pr\left(q_1 < \frac{2^{2\xi} - 1}{\rho}\right)\right)}_{K_1}\underbrace{\left(1 - \Pr\left(q_2 < \frac{2^{2\xi} - 1}{\rho}\right)\right)}_{K_2}. \quad (12)$$

For simplicity, we use β_0 to denote,

$$\beta_0 = \frac{2^{2\xi} - 1}{\rho}. \quad (13)$$

According to the cumulative distribution function (CDF) of q_1 and q_2, K_1 and K_2 can be calculated as [8, 25, 26]

$$K_1 = 1 - \Pr(q_1 < \beta_0), \quad (14)$$

$$= 1 - \int_0^{\beta_0} \frac{1}{\zeta} e^{\frac{-q_1}{\zeta}} du, \quad (15)$$

$$= e^{-\frac{\beta_0}{\zeta}}. \quad (16)$$

$$K_2 = 1 - \Pr(q_2 < \beta_0), \quad (17)$$

$$= 1 - \int_0^{\beta_0} \frac{1}{\lambda} e^{\frac{-q_2}{\lambda}} dv, \quad (18)$$

$$= e^{-\frac{\beta_0}{\lambda}}. \quad (19)$$

Thus, one can obtain $P_{out_1}^{LB}$ as,

$$P_{out_1}^{LB} = 1 - e^{-\frac{\beta_0}{\zeta}} e^{-\frac{\beta_0}{\lambda}}, \quad (20)$$

$$= 1 - e^{-\frac{2^{2\xi}-1}{\rho\zeta}} e^{-\frac{2^{2\xi}-1}{\rho\lambda}}. \quad (21)$$

Different from the signal transmission model in Fig. 1 (a) without cache, the model in Fig. 1 (b) can convey signals from R to D directly. Therefore, the received SNR from R to D can be given by

$$\gamma_D = \rho q_2. \quad (22)$$

With the definition of SNR, the outage probability of the system with cache is

$$P_{out_2} = \Pr(\log_2(1 + \rho q_2) < \xi), \quad (23)$$

$$= \Pr\left(q_2 < \frac{2^{\xi-1}}{\rho}\right), \quad (24)$$

$$= 1 - e^{-\frac{2^{\xi}-1}{\rho\lambda}}. \quad (25)$$

Moreover, according to the Taylor expansion formula of exponential function e^b, when $|b|$ is small, we can approximate e^b as

$$e^b \simeq 1 + b. \quad (26)$$

Therefore, for a large ρ, the asymptotic expressions of $P_{out_1}^{LB}$ and P_{out_2} can be given by,

$$P_{out_1}^{LB} \simeq 1 - \left(1 - \frac{2^{2\xi} - 1}{\rho\zeta}\right)\left(1 - \frac{2^{2\xi} - 1}{\rho\lambda}\right), \quad (27)$$

$$\simeq 1 - \left(1 - \frac{2^{2\xi} - 1}{\rho\lambda} - \frac{2^{2\xi} - 1}{\rho\zeta} + \frac{2^{2\xi} - 1}{\rho\zeta}\frac{2^{2\xi} - 1}{\rho\lambda}\right), \quad (28)$$

$$\simeq \frac{2^{2\xi} - 1}{\rho\zeta} + \frac{2^{2\xi} - 1}{\rho\lambda}. \quad (29)$$

$$P_{out_2} \simeq 1 - \left(1 - \frac{2^{\xi} - 1}{\rho\lambda}\right), \quad (30)$$

$$\simeq \frac{2^{\xi} - 1}{\rho\lambda}. \quad (31)$$

From (29), the system performance without cache can be enhanced with the increase of ρ, indicating that a larger transmit SNR can help improve the link quality of wireless channels effectively. Moreover, the asymptotic $P_{out_1}^{LB}$ decreases with a larger value of ζ and λ, as the dual-hop relaying links are strengthened.

Similarly, from (31), the system performance with cache can be improved by the increasing ρ, as a larger transmit SNR leads to enhancing the wireless transmission effectively. Moreover, the asymptotic P_{out_2} becomes better with a larger value of λ, as the relaying link from R to D is strengthened. In further, the channel quality of the first-hop relaying has no impact on the system performance, due to the usage of caching at the relay.

3. Numerical and Simulation Results and Discussions

In this section, we provide a few experiments for the considered system aided by caching and relaying, to observe the effect of caching and relaying on the system, through which we find how to design and optimize the system. Specifically, the links in the system are subject to Rayleigh flat fading [27, 28], and note that the results in this paper can be readily extended to other fading channels, which will not lose the generality [29, 30]. We will observe the effect of the parameters such as ρ, ξ, and λ on the system outage probability, to show the effectiveness of the proposed studies in this work.

3.1. Experimental Results and Analysis for Cache-Free Model

In Table 1 and Fig. 2, we depict the system outage probability without caching versus ρ and ξ, where

Table 1. Numerical outage probability of the system without caching versus ξ and ρ.

Methods	ξ	ρ/dB				
		20	25	30	35	40
Simulation	1.0	0.0376	0.0112	0.0035	0.0010	0.0004
	1.5	0.0864	0.0278	0.0082	0.0027	0.0008
Analysis	1.0	0.0360	0.0114	0.0036	0.0011	0.0004
	1.5	0.0840	0.0266	0.0084	0.0027	0.0008

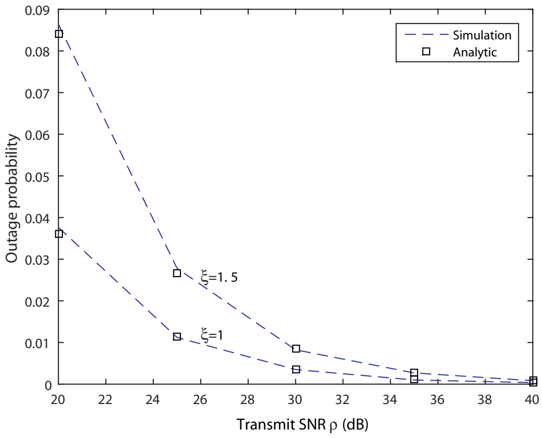

Figure 2. Outage probability of the system without caching versus ξ and ρ.

$\xi = 1$ or 1.5, and ρ varies from 20dB to 40dB. As observed from Table 1 and Fig. 2, the simulation result is quite near the analytical result. For example, when $\rho = 20$dB and $\xi = 1$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are 0.0376 and 0.0360, respectively. When $\rho = 40$dB and $\xi = 1$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are both 0.0004. When $\rho = 20$dB and $\xi = 1.5$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are 0.0864 and 0.0840, respectively. When $\rho = 40$dB and $\xi = 1.5$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are both 0.0008. These results can verify the correctness of the derived analysis on the system performance. Moreover, the outage probability improves when ρ increases, as a larger transmit power can help enhance the wireless transmission. In further, the system $P_{out,1}$ deteriorates with a higher ξ, due to a larger threshold on the data rate.

In Table 2 and Fig. 3, we show the system outage probability without caching versus ξ and λ, where $\rho = 30$dB, $\xi = 1$ or 1.5, and λ varies from 1 to 5. From Table 2 and Fig. 3, the simulation result is also close to the analytical one. For example, when $\lambda = 1$ and $\xi = 1$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are 0.0066 and 0.0060, respectively. When $\lambda = 5$ and $\xi = 1$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are 0.0037 and 0.0036, respectively. When $\lambda = 1$ and $\xi = 1.5$, the simulation $P_{out,1}$ and analytical $P_{out,1}$ are 0.0139 and 0.0140, respectively. When $\lambda = 5$ and $\xi = 1.5$, the simulation and analytical outage probabilities are 0.0081 and 0.0084, respectively. These results also show the correctness of the derived analysis on the system performance. Moreover, $P_{out,1}$ becomes smaller with a higher ρ or decreased value of ξ, which is similar to the results in Fig. 2.

3.2. Experimental Results and Analysis for Cache-Aided System

In Table 3 and Fig. 4, we illustrate the system outage probability with caching versus ρ and ξ, where $\xi = 1$ or 1.5, and ρ varies from 20dB to 40dB. From Table 3 and Fig. 4, we can see that the simulation result is also quite near the analytical result. For example, when $\rho = 20$dB and $\xi = 1$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are 0.0021 and 0.0020, respectively. When $\rho = 35$dB and $\xi = 1$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are both 0.0001. When $\rho = 20$dB and $\xi = 1.5$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are 0.0036 and 0.0037, respectively. When $\rho = 35$dB and $\xi = 1.5$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are both 0.0001. These results can verify the correctness of the derived analysis on the system performance. Moreover, the outage probability becomes better when ρ increases, as a larger transmit power can help enhance the wireless transmission. In further, $P_{out,2}$ becomes worse with a higher ξ, due to a higher data rate threshold.

In Table 4 and Fig. 5, we show the system outage probability with caching versus ξ and λ, where $\rho = 30$dB, $\xi = 1$ or 1.5, and λ varies from 1 to 5. From Table 4 and Fig. 5, the simulation $P_{out,2}$ is still near

Table 2. Outage probability of the system without caching versus ξ and λ.

Methods	ξ	λ				
		1	2	3	4	5
Simulation	1.0	0.0066	0.0047	0.0041	0.0038	0.0037
	1.5	0.0139	0.0104	0.0087	0.0084	0.0081
Analysis	1.0	0.0060	0.0045	0.0040	0.0037	0.0036
	1.5	0.0140	0.0105	0.0093	0.0088	0.0084

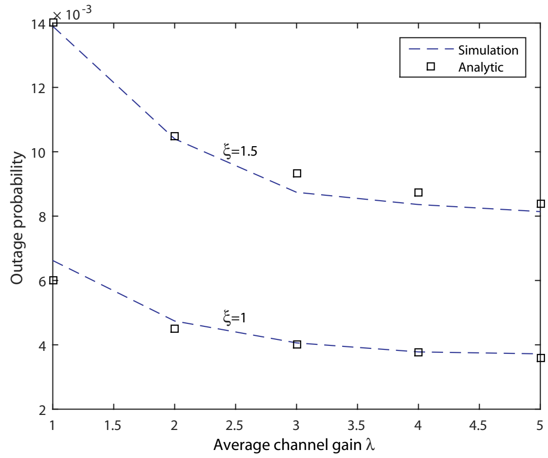

Figure 3. Outage probability of the system without caching versus ξ and λ.

Table 3. Numerical outage probability of the system with caching versus ξ and ρ.

Methods	ξ	ρ/dB				
		20	25	30	35	40
Simulation	1.0	0.0021	0.0006	0.0002	0.0001	0.0000
	1.5	0.0036	0.0012	0.0003	0.0001	0.0000
Analysis	1.0	0.0020	0.0006	0.0002	0.0001	0.0000
	1.5	0.0037	0.0012	0.0004	0.0001	0.0000

Table 4. Numerical outage probability of the system without caching versus ξ and λ.

Methods	ξ	λ				
		1	2	3	4	5
Simulation	1.0	0.0010	0.0006	0.0004	0.0002	0.0002
	1.5	0.0002	0.0012	0.0006	0.0005	0.0004
Analysis	1.0	0.0010	0.0005	0.0003	0.0003	0.0002
	1.5	0.0018	0.0009	0.0006	0.0005	0.0004

the analytical $P_{out,2}$. For example, when $\lambda = 1$ and $\xi = 1$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are both 0.0010. When $\lambda = 5$ and $\xi = 1$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are both 0.0002. When $\lambda = 1$ and $\xi = 1.5$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are 0.002 and 0.0018, respectively. When $\lambda = 5$ and $\xi = 1.5$, the simulation $P_{out,2}$ and analytical $P_{out,2}$ are both 0.0004. These results also show the correctness of the derived analysis on the system performance. Moreover, $P_{out,2}$ becomes smaller with a higher ρ or decreased value of ξ, which is similar to the results in Figs. 2-4.

4. Conclusions

In this paper, we studied the digital grid data transmission with the help of relaying and caching, where the relaying may be equipped by caching or not depending on the specific applications. For both cases, we evaluated the effect of relaying and caching on the system, by firstly providing an analytical outage probability for the data transmission. We then provided an asymptotic outage probability for the data transmission. Some simulation results were finally provided to show the correctness of the

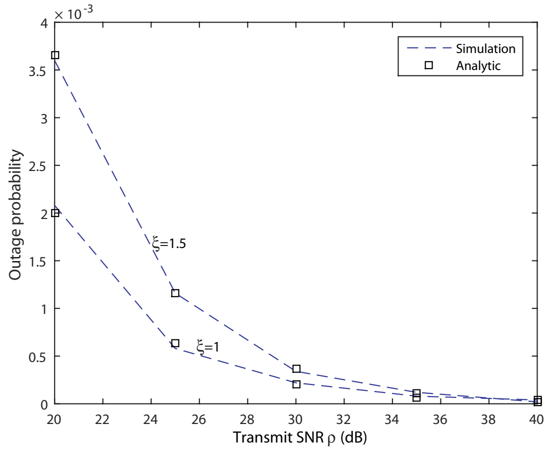

Figure 4. Outage probability of the system with caching versus ξ and ρ.

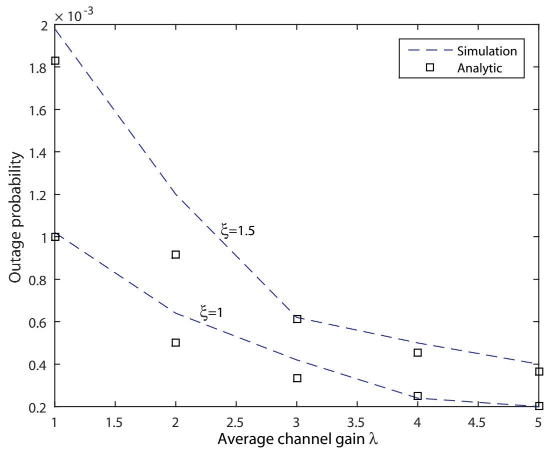

Figure 5. Outage probability of the system without caching versus ξ and λ.

derived analytical and asymptotic expressions of outage probability, which clearly show that the usage of caching at the relaying can help enhance the data transmission performance for the digital grid system effectively. The achievements in this paper could provide some important references to the development of information technology and scalable information systems.

The data of this work can be obtained through emails to Shuangbai He(shuangbaihe@hotmail.com), Chun Yang(chunyang2022@hotmail.com), Yuda Li(yudali2022@hotmail.com), Binyu Xie(binyuxie@hotmail.com), and Jiaqi Zhao(jiaqizhaoCSG@hotmail.com).

4.1. Copyright

The Copyright licensed to EAI.

References

[1] H. Wang and Z. Huang, "Guest editorial: WWWJ special issue of the 21th international conference on web information systems engineering (WISE 2020)," *World Wide Web*, vol. 25, no. 1, pp. 305–308, 2022.

[2] B. Wang, F. Gao, S. Jin, H. Lin, and G. Y. Li, "Spatial- and frequency-wideband effects in millimeter-wave massive MIMO systems," *IEEE Trans. Signal Processing*, vol. 66, no. 13, pp. 3393–3406, 2018.

[3] H. Wang, J. Cao, and Y. Zhang, *Access Control Management in Cloud Environments*. Springer, 2020. [Online]. Available: https://doi.org/10.1007/978-3-030-31729-4

[4] N. Dahlin and R. Jain, "Scheduling flexible nonpreemptive loads in smart-grid networks," *IEEE Trans. Control. Netw. Syst.*, vol. 9, no. 1, pp. 14–24, 2022.

[5] E. Z. Serper and A. Altin-Kayhan, "Coverage and connectivity based lifetime maximization with topology update for WSN in smart grid applications," *Comput. Networks*, vol. 209, p. 108940, 2022.

[6] Z. Alavikia and M. Shabro, "A comprehensive layered approach for implementing internet of things-enabled smart grid: A survey," *Digit. Commun. Networks*, vol. 8, no. 3, pp. 388–410, 2022.

[7] X. Hu, J. Wang, and C. Zhong, "Statistical CSI based design for intelligent reflecting surface assisted MISO systems," *Science China: Information Science*, vol. 63, no. 12, p. 222303, 2020.

[8] X. Lai, "Outdated access point selection for mobile edge computing with cochannel interference," *IEEE Trans. Vehic. Tech.*, vol. 71, no. 7, pp. 7445–7455, 2022.

[9] L. He and X. Tang, "Learning-based MIMO detection with dynamic spatial modulation," *IEEE Transactions on Cognitive Communications and Networking*, vol. PP, no. 99, pp. 1–12, 2023.

[10] J. Ling and C. Gao, "Dqn based resource allocation for NOMA-MEC aided multi-source data stream," *to appear in EURASIP J. Adv. Signal Process.*, vol. 2023, no. 1, 2023.

[11] L. Zhang and S. Tang, "Scoring aided federated learning on long-tailed data for time-varying IoMT based healthcare system," *IEEE Journal of Biomedical and Health Informatics*, vol. PP, no. 99, pp. 1–12, 2023.

[12] J. Lu and M. Tang, "IRS-UAV aided mobile edge computing networks with constrained latency: Analysis and optimization," *Physical Communication*, vol. 2023, p. 101869, 2023.

[13] S. Tang and X. Lei, "Collaborative cache-aided relaying networks: Performance evaluation and system optimization," *IEEE Journal on Selected Areas in Communications*, vol. PP, no. 99, pp. 1–12, 2022.

[14] W. Zhou and X. Lei, "Priority-aware resource scheduling for uav-mounted mobile edge computing networks," *IEEE Trans. Vehic. Tech.*, vol. PP, no. 99, pp. 1–6, 2023.

[15] L. Zhang and C. Gao, "Deep reinforcement learning based IRS-assisted mobile edge computing under physical-layer security," *Physical Communication*, vol. 55, p. 101896, 2022.

[16] Y. Wu and C. Gao, "Task offloading for vehicular edge computing with imperfect CSI: A deep reinforcement approach," *Physical Communication*, vol. 55, p. 101867,

2022.

[17] W. Zhou and F. Zhou, "Profit maximization for cache-enabled vehicular mobile edge computing networks," *IEEE Trans. Vehic. Tech.*, vol. PP, no. 99, pp. 1–6, 2023.

[18] S. Tang, "Dilated convolution based CSI feedback compression for massive MIMO systems," *IEEE Trans. Vehic. Tech.*, vol. 71, no. 5, pp. 211–216, 2022.

[19] S. Tang and L. Chen, "Computational intelligence and deep learning for next-generation edge-enabled industrial IoT," *IEEE Trans. Netw. Sci. Eng.*, vol. 9, no. 3, pp. 105–117, 2022.

[20] R. Zhao and M. Tang, "Profit maximization in cache-aided intelligent computing networks," *Physical Communication*, vol. PP, no. 99, pp. 1–10, 2022.

[21] L. Chen and X. Lei, "Relay-assisted federated edge learning:Performance analysis and system optimization," *IEEE Transactions on Communications*, vol. PP, no. 99, pp. 1–12, 2022.

[22] L. Chen, "Physical-layer security on mobile edge computing for emerging cyber physical systems," *Computer Communications*, vol. 194, no. 1, pp. 180–188, 2022.

[23] Y. Wu and C. Gao, "Intelligent resource allocation scheme for cloud-edge-end framework aided multi-source data stream," *to appear in EURASIP J. Adv. Signal Process.*, vol. 2023, no. 1, 2023.

[24] X. Zheng and C. Gao, "Intelligent computing for WPT-MEC aided multi-source data stream," *to appear in EURASIP J. Adv. Signal Process.*, vol. 2023, no. 1, 2023.

[25] R. Zhao, C. Fan, J. Ou, D. Fan, J. Ou, and M. Tang, "Impact of direct links on intelligent reflect surface-aided mec networks," *Physical Communication*, vol. 55, p. 101905, 2022.

[26] J. Lu and M. Tang, "Performance analysis for IRS-assisted MEC networks with unit selection," *Physical Communication*, vol. 55, p. 101869, 2022.

[27] Z. Na, C. Ji, B. Lin, and N. Zhang, "Joint optimization of trajectory and resource allocation in secure uav relaying communications for internet of things," *IEEE Internet of Things Journal*, 2022.

[28] W. Wu, F. Zhou, R. Q. Hu, and B. Wang, "Energy-efficient resource allocation for secure noma-enabled mobile edge computing networks," *IEEE Trans. Commun.*, vol. 68, no. 1, pp. 493–505, 2020.

[29] B. Li, Z. Na, and B. Lin, "Uav trajectory planning from a comprehensive energy efficiency perspective in harsh environments," *IEEE Network*, vol. 36, no. 4, pp. 62–68, 2022.

[30] W. Wu, Z. Wang, L. Yuan, F. Zhou, F. Lang, B. Wang, and Q. Wu, "Irs-enhanced energy detection for spectrum sensing in cognitive radio networks," *IEEE Wirel. Commun. Lett.*, vol. 10, no. 10, pp. 2254–2258, 2021.