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Performance Analysis of UAV Relay Assisted IoT Communication Network Enhanced With Energy Harvesting

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ABSTRACT This paper investigated the multiple unmanned aerial vehicle (UAV) relays' assisted network in the Internet of Things (IoT) systems enhanced with energy harvesting in order to overcome the large-scale fading between source and sink as well as achieve the green cooperative communications, where time switch (TS) and power splitting (PS) strategies were typically applied for UAV relays to implement energy harvesting transmission, which was also selected via signal to noise ratio (SNR) maximization criterion so that the terminal node can obtain the optimal signal. Meanwhile, it was worth noting that the terminal node may be disturbed by aggregated interference caused by dense network signaling interaction in the future 5G/B5G systems. Therefore, after TS and PS protocols designing and utilizing, the closed-form expressions of outage probability and bit error rate (BER) for UAV relay assisted IoT systems suffered from aggregated interference were derived in detail. In addition, the throughput and delay limited state of UAV relay assisted transmission were also analyzed thoroughly. The derivations and analysis results showed that the proposed multi-parameter joint optimization of transmitting power, scaling factor, and UAV relay selection could effectively improve the system throughput and reduce the system outage probability and BER. The simulation experiments verified the effectiveness of the proposed schemes and the correctness of theoretical analysis.

INDEX TERMS Unmanned aerial vehicles (UAV), relay assisted, IoT, energy harvesting, protocol design, aggregate interference.

I. INTRODUCTION

Rapid development of wireless communication technology and the dramatical innovation of UAV-based manufacturing technology make the cost of UAV continous decreasing. Therefore, many new UAV applications have recently appeared in the civilian market, including weather monitoring systems, forest fire prevention technology, man-v-machine areas and so on. This widespread application of UAV technology attracts extensive attention to explore the UAV relay assisted IoT communication network [1].

A. BACKGROUND

Recently, UAV assisted communications play an significant role in 5G/B5G networks, which is expected to achieve

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throughput transmission above 10Gbps, ultra density device connection and millisecond transmission delay [2], [3]. The stringent requirements of the future communications make the network coverage expand to 3D interconnection so as to overcome the large scale fading for the ultra speed transmission. Moreover, the construction of cellular stations in urban hotspots have excessive cost and can be extremely difficult to carry out. Therefore, the UAV relays assisted communication could provide solutions for the IoT network and have several advantages, such as its convenient deployment and lower cost, high-altitude assisted transmission and so on [4], [5]. It is mentioned that the UAV relay assisted communications can reduce the obstruction of buildings, mountains and other obstacles and obtain the higher line of sight (LoS) transmission effect [6], [7]. However, the UAV is a battery-powered terminal, which has limited battery life and its power consumption has a significant influence on the communication process [3], [8], so the transmission protocols should be designed to maximize the system throughput and minimize the transmitting power, therefore, the UAV relay assisted communication protocols in IoT system enhanced with energy harvesting are proposed and analyzed in this paper detailedly.

Due to the actual UAV circuit system is difficult to achieve energy harvesting and information processing simultaneously [9]–[11]. Therefore, the TS and PS schemes are typically applied for UAV relay assisted communication networks. The former strategy depends on the time slots seperation, one is used for energy harvesting and the other for information processing. The latter strategy depends on the power division, one part is utilized to energy harvesting and the other to information processing [7], [12]. The above two schemes can be implemented to realize energy harvesting and information processing by single antenna at the same time .

B. RELATED WORK

The traditional energy harvesting technologies were mostly solar energy or wind energy. With the development of new technology, RF energy harvesting has received widespread attention from academia and industry. Varshney *et al.* [13] studied amplify and forward (AF) relay network with energy harvesting function through the joint optimization of power control and the distribution of source, moreover, the average rate maximization of delay constraint under Rayleigh fading channel was investigated in detail. Dong *et al.* [14] derived the outage probability and system capacity of the energy harvesting relay with AF function under delay limited and delay tolerant transmission. Nasir *et al.* [15] analyzed a multiple sources to relay and destination node with energy harvesting transmission method. Ding *et al.* [16] investigated the performance of a two hop model for energy harvesting AF relays to transmit energy and information to two downlink sinks. Ji *et al.* [17] explored PS schemes for nonlinear energy harvesting AF relay systems with direct path and optimized system to maximize system capacity. Bai *et al.* [18] proposed a new hybrid EH protocol such as a combination of power splitting and time switching. In order to maximize the system throughput performance, Atapattu and Evans [19] analyzed the outage probability expression of a nonlinear energy harvesting and decoding system in the two-hop transmission relay network under the influence of interference through a multiple parameters joint optimization.

Kumar *et al.* [20] analyzed the average symbol error rate (SER) of a three nodes decode and forward (DF) relay system for energy harvesting in a Nakagami-*m* fading environment. Meanwhile, Li *et al.* [21] investigated the cooperative multiantenna protocols and analyzed the spectral efficiency of cellular networks. Gu and Sonia [22] studied the performance of two-hop DF systems to solve the optimal solution with aggregate interference. Chen [23] analyzed the outage probability and throughput of AF systems for energy harvesting under the interference of relay and destination nodes. Hussain *et al.* [24] studied the performance of a two-hop model system with multiple antennas in a κ-μ shadow fading channel. Badarneh *et al.* [25] showed the performance of energy harvesting DF systems in generalized η-μ and κ-μ mixed fading environments with multiple nodes cooperation. Chang *et al.* [26], [27] investigated the distributed resource allocation for energy efficiency in OFDMA(orthogonal frequency division multiple access) multi-cell networks with wireless power transfer systems in order to improve the system throughput via relays and mobile clouds cooperation.

Several researches have been explored for UAV relays assisted communications with RF energy harvesting. Hua *et al.* [28] analyzed the UAV AF relay networks using BS to implement the simultaneous wireless information and power transfer (SWIPT) and derived the multiple parameters joint optimization. Xie *et al.* [29] proposed the schemes for UAV uplink transmission energy harvesting systems, where the user adopted the harvested energy to send the information to the UAV. Yin *et al.* [30] established a typical single source and dual target system model and derived the solution of multiple parameters joint optimization with throughput maximization. Lu *et al.* [31] proposed an energy constrained UAV communication network protocol based on OFDM relay wireless power transmission. Yin *et al.* [32] gave several surveys for energy constrained UAV cellular network, which acts as a relay for all users to increase the uplink rate through cooperative communication.

C. INNOVATION AND STRUCTURE

The interference received by the terminal may be very common in the future ultra-dense wireless communication deployment of 5G/B5G environments. Therefore, this paper explores the multiple UAV relays assisted communication to complete the information transmission between the source and the IoT nodes enhanced with energy harvesting. In order to improve the performance of UAV relay assisted communication systems as well as reduce the power consumption, this paper proposes two methods of opportunistic UAV relay selection and partial UAV relay selection, meanwhile, TS and PS schemes are also utilized for UAV relay assisted energy harvesting protocols. Moreover, the derivations and analysis present the proposed multi-parameter joint optimization of transmitting power, scaling factor and UAV relay selection could effectively improve the system throughput and reduce the system outage probability and BER.

The main contributions of this paper can be seen as follows:

(1) The energy harvesting and information transmission schemes of UAV relay assisted DF networks is designed in detail together with TS and PS protocols;

(2) The closed-form expressions of system outage probability and BER via the Nagamai-*m* fading channel suffered from aggregate interference are derived thoroughly;

(3) The system throughput and delay limited state of UAV relay assisted system are analyzed and the joint optimization of multiple parameters is investigated detailedly.

The structure of this paper can be seen as follows: Section II introduces the system model of UAV relay assisted communication networks; Section III elaborates the PS and TS protocols of UAV energy harvesting; Section IV derives the closed form expressions of system outage probability and BER under aggregated interference environment; The simulations in section V verifies the proposed schemes and proves the correctness of theoretical analysis; Section VI concludes this paper.

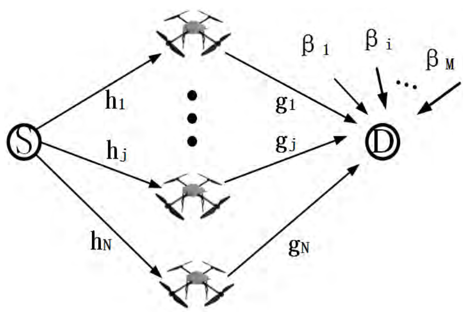

FIGURE 1. The system model.

II. SYSTEM MODEL

The two-hop energy harvesting UAV relay assisted communication model can be considered as shown in Figure 1. Where the UAV relays are half duplex and DF mode, one of the UAV relays are selected as the optimal relay to implement transmission for terminal IoT nodes. As shown in Figure 1, the system consists of source node S, multiple UAV relay nodes R(denoted as 1,2,...) and terminal node D. Typically, the communication between source and terminal node may be prevented or affected by the obstacles or blockage of urban buildings and mountains, then the UAV relays are required to realize assisted communication and the transmission process is divided into three phases. In the first phase, the source node S transmits signal s to the selected UAV relay node R_j. The channel h_j between the source node S and the selected UAV relay follows Nakagami-*m* distribution; In the second phase, the UAV relays may decode the signal with error free because of high communication quality between BS and UAV relays, meanwhile, the UAV relay also finishes the energy harvesting, which can be divided into two protocols, namely TS and PS. Moreover, the UAV relay R_j should be selected as the optimum through SNR maximization criterion; In the third phase, the terminal node decodes the signal and its channel from UAV relays is g_j, which also follows Nakagami-m distribution, namely, $h_j \sim \mathrm{CN}(0,\Omega_{hj})$ and $g_j \sim \mathrm{CN}(0,\Omega_{gj})$.

It is assumed that the signal transmission among each UAV relay link is independent identically distributed, the terminal node D may be suffered aggregate interference caused from multi-layer ultra dense network coverage in 5G/B5G environments. It can be denoted that the power of the *i*-th interference received on the terminal node is P_i, where i is an integer and satisfy $1 < i < M$. Each aggregate interference channel follows Nakagami-*m* distribution and its channel gain equals to β_i.

III. UAV RELAY ASSISTED COMMUNICATION PROTOCOL ENHANCED WITH ENERGY HARVESTING

The UAV relay assisted communication enhanced with energy harvesting can be designed through TS and PS protocols elaborated detailedly in this section as follows:

A. TS PROTOCOL

The TS protocol divides energy harvesting and information processing into three parts according to time intervals allocation, which can be seen as Figure 2, where T is the total time for energy harvesting and information processing. In the entire time block T, the duration of energy harvesting of the UAV relay node is αT, where α is time division scaling factor and the value range from 0 to 1, the remaining $(1-\alpha)T$ is used for information processing and the energy required during the transmission is all used to forward the signal to the terminal node D.

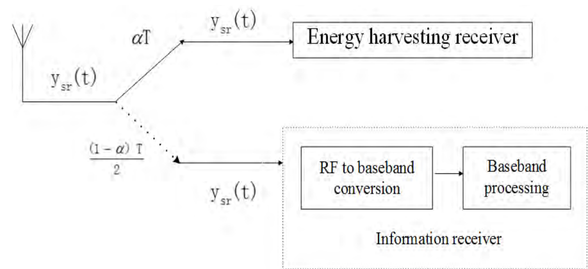

FIGURE 2. Schematic diagram of TS protocol.

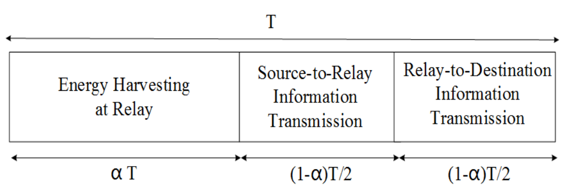

FIGURE 3. Schematic diagram of UAV relay time allocation for TS protocol.

The TS protocol of UAV relay time allocation scheme is shown in Figure 3. The source node S send signal s to the selected UAV relay node. Accordingly, the received signal of UAV relay can be expressed as:

$$y_{sr} = \sqrt{P_s} h_j s + n_j^r \tag{1}$$

where P_s is the transmit power of the source node S, which n_j^r is the additive white Gaussian noise (AWGN) between the source and the j-th UAV relay and $n_j^r \sim \mathrm{CN}(0,\sigma_j^2)$.

Therefore, the SNR of the UAV relay can be obtained as:

$$\gamma_{SR_j} = \frac{P_s \left\| h_j \right\|^2}{\sigma_R^2} \tag{2}$$

Then the energy harvesting by the UAV relay is:

$$Eh = \eta P_s \left\| h_j \right\|^2 \alpha T \tag{3}$$

where η is the energy conversion efficiency and the transmission time of the UAV relay transmission signal to the terminal node D is $(1-\alpha)T/2$, so the transmission power of the UAV relay can be expressed as:

$$P_r = \frac{Eh}{\frac{(1-\alpha)T}{2}} = \frac{\eta P_s \left\| h_j \right\|^2 \alpha T}{\frac{(1-\alpha)T}{2}} \tag{4}$$

Since the terminal node is affected by the aggregate interference caused from the dense network coverage in the environments, the signal received of terminal node can be indicated as:

$$y_{rd} = \sqrt{P_r} g_j s' + \sum_{i=1}^{M} \sqrt{P_i} \beta_i x_i + n_j^d \tag{5}$$

where s' is the UAV relay decoded signal and n_j^d is the AWGN between the j-th UAV relay and the terminal node, the Pi is the transmission power of the i-th interference, the total number of which is M, β_i is the channel between the i-th interference transmitter and the terminal node D, x_i is the i-th interference signal, and the SNR at the terminal node D is:

$$\gamma_{R_jD} = \frac{P_r \left\| g_j \right\|^2}{\sum_{i=1}^{M} P_i \|\beta_i\|^2 + \sigma_D^2} = \frac{2\eta P_s \left\| h_j \right\|^2 \alpha \left\| g_j \right\|^2}{(1-\alpha)(\sigma_D^2 + Id)} \tag{6}$$

It can be noted that the SNR needs to be greater than the threshold in the two-hop transmission. Otherwise, the transmission may be interrupted and the terminal node cannot achieve the correct signal.

B. PS PROTOCOLS

Unlike the TS protocol, the PS protocol can be mainly divided into two steps. In the first step, the source node S sends signal to the selected UAV relay node, In this process, the energy is divided into two parts according to the power split mode, θP_s is used for the UAV relay energy harvesting, and $(1-\theta)P_s$ is used for the source node transmitting information to the selected UAV relay. θ represents the scaling factor, which ranges from 0 to 1; In the second step, the UAV relay node uses the harvested energy to decode and transmit signal to the terminal node D. Figure 4 depicts the schematic diagram for UAV relay energy harvesting.

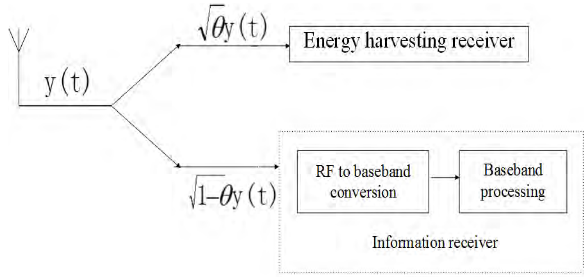

FIGURE 4. UAV relay PS protocol with energy harvesting.

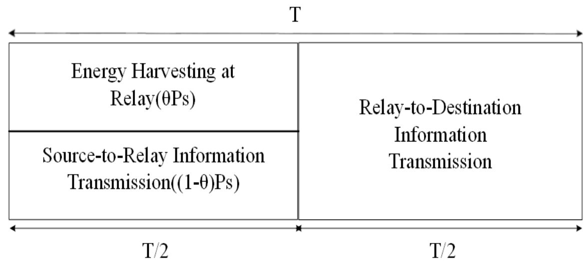

FIGURE 5. Schematic diagram of UAV relay power allocation for PS protocol.

The PS protocol of UAV relay power allocation can be shown as Figure 5. The signal received of UAV relay is:

$$y_{sr} = (1-\theta)\sqrt{P_s} h_j s + n_j^r \tag{7}$$

Therefore, the equation (7) shows that the SNR received by the UAV relay is:

$$\gamma_{SR_j} = \frac{(1-\theta) P_s \left\| h_j \right\|^2}{\sigma_R^2} \tag{8}$$

Since the energy harvesting time of UAV relay node for PS protocol is $T/2$, the energy harvesting of UAV relay can be given as:

$$Eh = \frac{\eta P_s \left\| h_j \right\|^2 \theta T}{2} \tag{9}$$

The energy harvesting process shall last for $T/2$ and the transmit power of the UAV relay could be indicated as:

$$P_r = \frac{Eh}{T/2} = \eta P_s \left\| h_j \right\|^2 \theta \tag{10}$$

The signal received of the terminal node is:

$$y_{rd} = \sqrt{P_r} g_j s' + \sum_{i=1}^{M} \sqrt{P_i} \beta_i x_i + n_j^d \tag{11}$$

So the SINR of the terminal node can be expressed as:

$$\gamma_{R_jD} = \frac{P_r \left\| g_j \right\|^2}{\sum_{i=1}^{M} P_i \|\beta_i\|^2 + \sigma_D^2} = \frac{\eta P_s \left\| h_j \right\|^2 \theta \left\| g_j \right\|^2}{\sigma_D^2 + Id} \tag{12}$$

IV. PERFORMANCE ANALYSIS

This section focuses on the performance analysis of the proposed UAV relay assisted communication protocols and derives the closed-form expressions of the system outage probability and BER.

A. OUTAGE PROBABILITY

The optimal UAV relay should be selected from the multiple UAV nodes and the SNR maximization selection criterion can be adopted as follows.

$$SNR_{R_j} = \max(\gamma_{R_jD}) \tag{13}$$

It is mentioned that the UAV relay assisted communication transmission may be interrupted if the SNR obtained of the terminal node is less than the threshold. Therefore, the outage probability of the terminal node can be derived in the following with threshold denoted as γ_{th}.

$$\begin{aligned} P_{out2} &= \Pr\left\{SNR_{R_j} < \gamma_{th}\right\} \\ &= \Pr(\max(\frac{P_r\left\|g_j\right\|^2}{\sum_{i=1}^{M} P_i\|\beta_i\|^2+\sigma_D^2}) < \gamma_{th}) \\ &= \prod_{j=1}^{N}\Pr(\frac{P_r\left\|g_j\right\|^2}{\sum_{i=1}^{M} P_i\|\beta_i\|^2+\sigma_D^2} < \gamma_{th}) \end{aligned} \tag{14}$$

Since the channel g_j follows Nakagami-m distribution, then the norm square of channel g_j, namely $\left\|g_j\right\|^2$ can follow Gamma distribution, so the probability density function (PDF) can be expressed as [33], [34]:

$$f_{P_r\|g\|^2}(x) = \frac{x^{\alpha-1}e^{-\frac{x}{\beta}}}{\beta^{a}\Gamma(\alpha)} \tag{15}$$

The parameters in equation (15) are as follows:

$$\Gamma(\alpha) = \int_0^\infty t^{\alpha-1}e^{-t}dt \tag{16}$$

$$\alpha = \frac{1}{e^{(\sigma_{dB}/8.686)^2}-1} \tag{17}$$

$$\beta = P_d\sqrt{\frac{\alpha+1}{\alpha^3}} \tag{18}$$

$\Gamma(\cdot)$ represents the Gamma function. σ_{dB} is a shadow spread parameter and expressed in decibels, which typically has a value range from 4 to 9. Pd is the average power of the signal received by the node [35].

Since the noise is negligible compared to interference at high SNR so that the noise variance is assumed to zero [36], [37]. The PDF of the aggregate interference I_d can be given as [38]:

$$f_{Id}(y) = \frac{y^{M-1}e^{-\frac{y}{\Omega}}}{\Omega^M\Gamma(M)} \tag{19}$$

M is the suffered interference number of terminal node D and Ω is the total SNR of the average interference signal,which can be indicated as:

$$\Omega = \frac{2P_{ave}}{M}(\frac{\Gamma(M+\frac{1}{2})}{\Gamma(\frac{1}{2})})^M \tag{20}$$

where P_{ave} is the average power of the interference signal. Therefore, the PDF expression of the terminal node according to equations (15) and (19) can be derived as:

$$\begin{aligned} f(z) &= \int_0^\infty f(y)f_x(zy)\,ydy \\ &= \int_0^\infty \frac{y^{M-1}e^{-\frac{y}{\Omega}}}{\Omega^M\Gamma(M)}\cdot\frac{(zy)^{\alpha-1}e^{-\frac{zy}{\beta}}}{\beta^\alpha\Gamma(\alpha)}ydy \\ &= \frac{z^{\alpha-1}\cdot\left(\frac{1}{\Omega}+\frac{z}{\beta}\right)^{-(M+\alpha)}\cdot\Gamma(M+\alpha)}{\Omega^M\Gamma(M)\,\beta^\alpha\Gamma(\alpha)} \end{aligned} \tag{21}$$

Therefore, the system outage probability with aggregated interference suffered in the environment can be derived through some manipulations as follows:

$$\begin{aligned} P_{out2} &= \prod_{j=1}^{N}\Pr(\frac{P_r\left\|g_j\right\|^2}{\sum_{i=1}^{M}P_i\|\beta_i\|^2} < \gamma_{th}) \\ &= \left[\int_0^{\gamma_{th}}\frac{z^{\alpha-1}\cdot\Omega^\alpha\left(1+\frac{\Omega z}{\beta}\right)^{-(M+\alpha)}\cdot\Gamma(M+\alpha)}{\Gamma(M)\,\beta^\alpha\Gamma(\alpha)}\right]^N dz \\ &= [\frac{\Gamma(M+\alpha)\Omega^\alpha\cdot\eta^\alpha}{\Gamma(M)\,\beta^\alpha\Gamma(\alpha+1)}{}_2F_1(M+\alpha,\alpha;1+\alpha;-\frac{\Omega}{\beta}\eta)]^N \end{aligned} \tag{22}$$

So the outage probability of the UAV relay assisted communication system can be given as:

$$P_{out} = 1-(1-P_{out1})(1-P_{out2}) \tag{23}$$

where Pout1 is the system outage probability of the first hop and its value can be approximately closed to zero due to the DF mode and error free of UAV relays or depended on the allocated resources according to the scaling factor of TS or PS protocol.

B. BER ANALYSIS

This subsection presents the BER closed-form expression of the proposed UAV relay assisted communication systems as follows:

$$\begin{aligned} P_{BER} &= E\left\{Q\left(\sqrt{v\gamma}\right)\right\} \\ &= \frac{\sqrt{v}}{2\sqrt{2\pi}}\int_0^\infty\frac{e^{-\frac{v}{2}x}}{\sqrt{x}}[\frac{\Gamma(M+\alpha)\,\Omega^\alpha\cdot x^\alpha}{\Gamma(M)\,(\beta)^\alpha\Gamma(\alpha+1)}\cdot \\ &\quad\times{}_2F_1(M+\alpha,\alpha;1+\alpha;-\frac{\Omega}{\beta}x)]^N \\ &= \frac{\sqrt{v}}{2\sqrt{2\pi}}\left[\frac{\Gamma(M+\alpha)\,\Omega^\alpha}{\Gamma(M)\,(\beta)^\alpha\Gamma(\alpha+1)}\right]^N\cdot \\ &\quad\times\int_0^\infty\frac{x^{N\alpha-\frac{1}{2}}}{e^{\frac{v}{2}x}}\left[{}_2F_1\left(M+\alpha,\alpha;1+\alpha;-\frac{\Omega}{\beta}x\right)\right]^N dx \end{aligned} \tag{24}$$

The hypergeometric function can be written as [38]:

$$\left[{}_2F_1\left(M+\alpha,\alpha;1+\alpha;-\frac{\Omega}{\beta}x\right)\right]^N = \left[\sum_{k=0}^{\infty}\frac{(M+\alpha)_k(\alpha)_k}{(1+\alpha)_k}\right]^N\frac{\left(-\frac{\Omega}{\beta}\right)^{kN}}{[k!]^N}\cdot x^{kN} \tag{25}$$

where $(\cdot)k$ is a Pochhammer symbol and can be defined as

$$(q)_k = q(q+1)\ldots(q+k-1) = \frac{\Gamma(q+k)}{\Gamma(q)} \tag{26}$$

Therefore, the BER closed form expression can be achieved after substituting equation (25) into equation (24) as:

$$\begin{aligned} P_{BER} &= E\left\{Q\left(\sqrt{v\gamma}\right)\right\} \\ &= \frac{\sqrt{v}}{2\sqrt{2\pi}}\left[\frac{\Gamma(M+\alpha)\,\Omega^{\alpha}}{\Gamma(M)\,(\beta_r)^{\alpha}\,\Gamma(\alpha+1)}\right]^N\int_0^{\infty}e^{-\frac{v}{2}x}\cdot x^{N\alpha-\frac{1}{2}} \\ &\quad\cdot\left[\sum_{k=0}^{\infty}\frac{(M+\alpha)_k(\alpha)_k}{(1+\alpha)_k}\right]^N\cdot\frac{\left(-\frac{\Omega}{\beta}\right)^{kN}}{[k!]^N}\cdot x^{kN}dx \\ &= \left[\frac{\Gamma(M+\alpha)\,\Omega^{\alpha}}{\Gamma(M)\,(\beta)^{\alpha}\,\Gamma(\alpha+1)}\right]^N\left[\sum_{k=0}^{\infty}\frac{(M+\alpha)_k(\alpha)_k}{(1+\alpha)_k}\right]^N\cdot \\ &\quad\times\frac{2^{Nd+kN-1}}{\sqrt{\pi}v^{Nd+kN}}\cdot\frac{\left(-\frac{\Omega}{\beta}\right)^{kN}}{[k!]^N}\cdot\Gamma\left(N\alpha+kN+\frac{1}{2}\right) \end{aligned} \tag{27}$$

The value of v represents modulation scheme, when $v=1$ denotes the BPSK modulation, when $v=2$ denotes the QPSK modulation. In addition, the capacity of system under delay-limited conditions can be obtained as:

$$C_{out} = \frac{(1-P_{out})\log_2(1+\gamma_{th})}{2} \tag{28}$$

The acquisition of the optimal throughput depends on the effective time of information transmission in the UAV relay assisted communication system can be obtained into two cases, the system throughput of TS protocol can be given as:

$$T = C_{out}(1-\alpha) \tag{29}$$

The system throughput of the PS protocol can be expressed as:

$$T = C_{out} \tag{30}$$

V. SIMULATION AND ANALYSIS

This section simulates and analyzes the system performance of the proposed schemes and verifies the correctness of the theoretical analysis. The simulation parameters can be seen as follows: the number of UAV relays is N, the SNR maximization criterion is adopted for the UAV relays selection, the UAV relay energy harvesting of conversion efficiency $\eta = 1$, and the number of aggregate interference suffered by terminal node is M. In TS scheme, the scaling factor is α; In PS scheme, the scaling factor is θ, the SNR at the transmitter is γ_0 and the length of transmission data $L = 100$. Additionally, the channel fading follows Nakagami-m distribution.

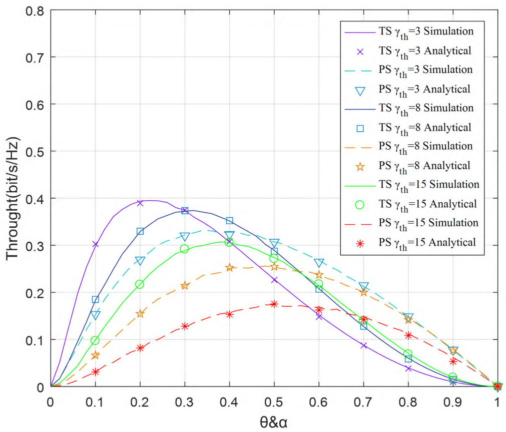

FIGURE 6. System throughput varies with different scaling factor under different thresholds.

The Figure 6 depicts the system throughput varies with different scaling factor and different thresholds under TS and PS schemes and the transmitting power is fixed. Moreover, the relay number $N = 3$, the interference number $M = 2$ and the interference transmission power is $P1 = 6W$, $P2 = 4W$ and $\gamma_0 = 20\ dB$ respectively. It can be observed from Figure 6 that the system throughput may decrease with the threshold γ_{th} growing, the reason is that the system outage probability will increase when the threshold γ_{th} is raising. The smaller the threshold value is, not only the maximum throughput of the system can be obtained, but also the smaller the scaling factor is. Moreover, the energy harvesting in the UAV relay is smaller and the transmit power is lower so as to the throughput is smaller. As the α and θ of the system increasing, the system performance can reach the optimal value. As can be seen in Figure 6, the system throughput of TS scheme is significantly better than that that of the PS scheme when the harvested energy is low. However, the system throughput of PS scheme is higher than that of TS scheme when information transmission is low.

Figure 7 depicts the curves of system outage probability varies with different scaling factor under different thresholds condition. It is obvious that the TS scheme is superior to PS scheme with the corresponding thresholds. The transmitting power required will be smaller with the threshold decreasing, the harvested energy for the UAV relays is smaller with parameters α and θ reducing, moreover, the harvested energy for the UAV relays is smaller and the transmitting power is lower so as to the outage probability could be higher consequently. The system can achieve the optimal outage probability performance with the value of α and θ increasing, after coming to the optimum, the system information

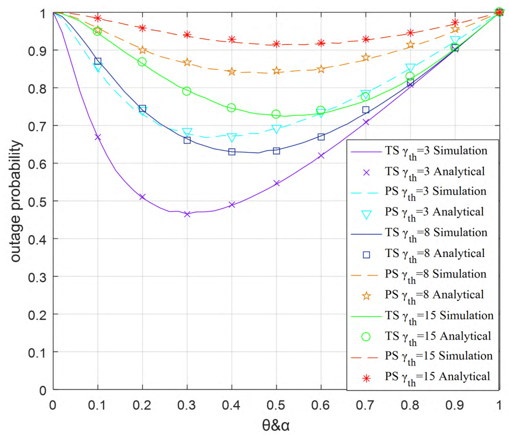

FIGURE 7. The curves of system outage probability varies with different scaling factor.

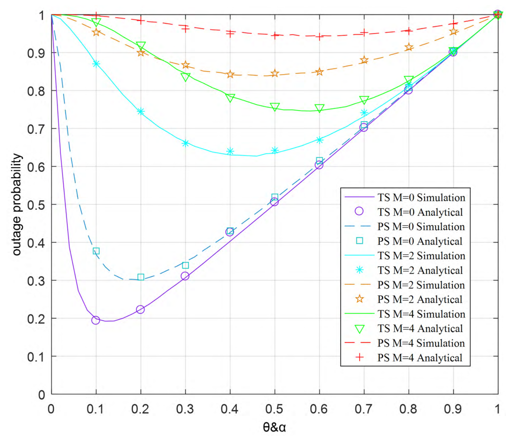

FIGURE 9. The system outage probability versus scaling factor with different number of interference.

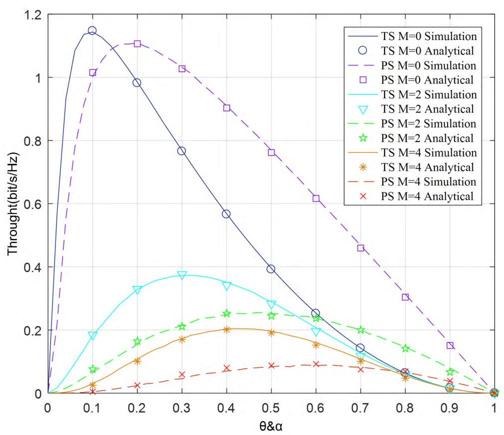

FIGURE 8. The system throughput versus scaling factor with different number of interference.

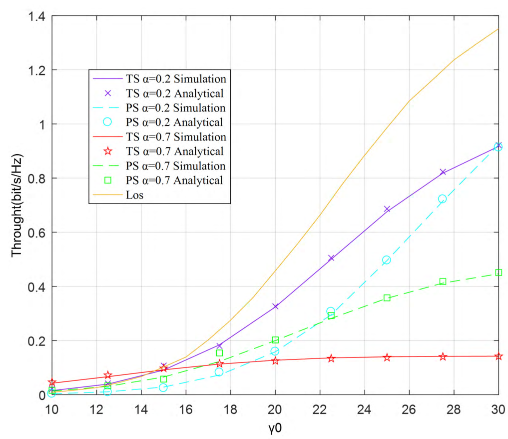

FIGURE 10. The System throughput varies with the transmitting power.

transmission rate becomes small and then the outage probability decrease gradually especially there is no data transmission when $\alpha = 1$ or $\theta = 1$.

Figure 8 displays the curves of system throughput versus scaling factor with different number of interference under TS and PS protocols. The UAV relay number $N = 3$, the interference number $M = [0, 2, 4]$, the interference transmission power $P1 = 6\ W, P2 = 4\ W, P3 = 6\ W, P4 = 4\ W$, the system transmitting power $\gamma_0 = 20\ dB$ and the threshold value $\gamma_{th} = 8\ W$. As shown in Figure 8, the system throughput reaches the ideal value when there is no interference, which is obviously higher than the case of 2 interference and 4 interference. In the case of the same number of interference, the α and θ corresponding to the intersection of TS and PS curves was 0.14, 0.55 and 0.76, respectively. It can be mentioned that when α and θ is less than the 0.14, 0.55 and 0.76, TS scheme is better than PS scheme. When Íż and ęÈ are greater than the 0.14, 0.55 and 0.76, the PS scheme is superior to the TS scheme.

In Figure 9 shows the system outage probability versus scaling factor α and θ with different number of interference. In order to achieve the minimum outage probability, the UAV relay needs to collect more energy to support information transmission. In the case of the same number of interference, TS scheme outage probability is always better than PS scheme. In the case of no interference, the performance of outage probability is obviously superior to the other cases.

In Figure 10, the system relay number $N = 3$, the interference number $M = 2$, the interference power is $P1 = 6\ W, P2 = 4\ W$ and the threshold $\gamma_{th} = 8\ W$, respectively. It can be assessed that the curves of throughput and outage probability of destination node D with the transmitting power growing under TS and PS schemes in different scaling factors, the α and $\theta = [0.2, 0.7]$. As shown the curves trend of Figure 10, Figure 10 depicts the throughput of TS scheme grows slowly and moves to an approximate line in the case of α and $\theta = 0.7$. The reason is that the system data transmission is fixed, Moreover, the transmitting power has little impact on the system throughput. In the case of α and $\theta = 0.7$, the throughput of PS scheme grows rapidly in the beginning and then increases slowly. In the case of α and $\theta = 0.2$, the throughput of TS scheme and PS scheme

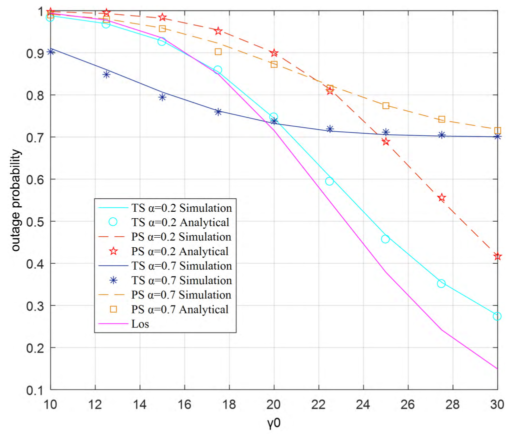

FIGURE 11. The system outage probability varies with the transmitting power.

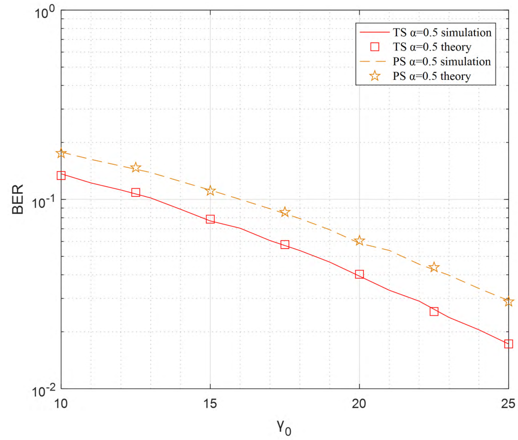

FIGURE 13. The BER performance varies with transmitting power.

have rapid growth. In terms of numerical results, TS and PS schemes approach intersect under the same scaling factor. When γ_0 is less than the intersection point, TS scheme is superior to PS scheme. When γ_0 is greater than the intersection point, PS scheme is better than TS scheme.

In Figure 11, it can be seen that when α and $\theta = 0.7$, the system outage probability of TS scheme decreases slowly and then tends to an approximation line. In the case of α and $\theta = 0.7$, the outage probability of PS scheme decreases rapidly at the start and then reduces slowly. In the case of α and $\theta = 0.2$, the system outage in TS and PS schemes keep decreasing rapidly.

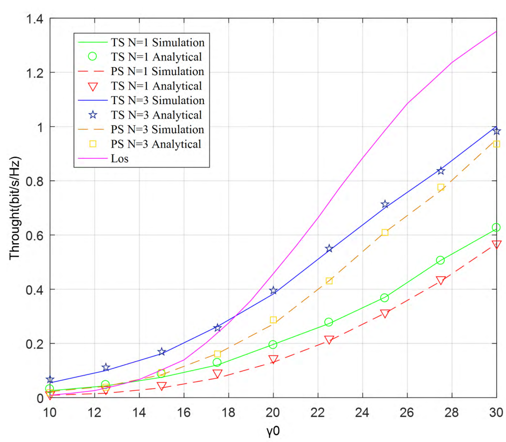

FIGURE 12. The system optimal throughput curves varies with the transmitting power.

Figure 12 displays that the system optimal throughput curves when the interference number $M = 2$ and the relay number $N = [0, 3]$. The interference power $P1 = 6\ W$ and $P2 = 4\ W$, respectively. The curves of the system optimal throughput varies with the change of transmitting power can be expressed as Figure 12. Furthermore, the UAV relay number can have significantly effect on the system throughput, which results from that the different UAV relay number can have different diversity order, the more the UAV relay number, the larger the system diversity gains.

Figure 13 displays the curves of the system BER performance. The system interference number $M = 2$, the relay number $N = 3$, the interference power $P1 = 6\ W, P2 = 4\ W$, the threshold $\gamma_{th} = 8\ W$ and the scaling factor α and $\theta = 0.5$. It can be seen that the system BER keeps decreasing with the transmitting power growing. Furthermore, the BER of PS scheme is less than TS scheme. The reason is that the remaining power of TS protocol can be used overall to information transmission and processing, however, the power harvested in PS protocol may have a significant impact on the information transmission and processing. Therefore, the TS scheme can be superior to the PS scheme in the aspect of BER performance.

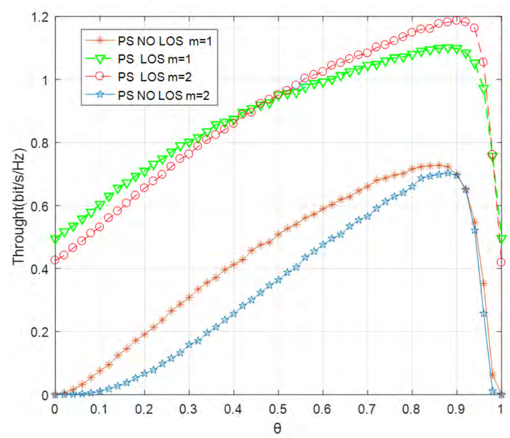

FIGURE 14. The system throughput of PS protocol versus scaling factor with LoS.

As can be seen from Figure 14, it is worth noting that the parameter m represents the effect of line of sight. The larger the m is, the better the LoS effect have, then the system performance can be better. Moreover, the system performance of LoS can be superior to the non LoS case.

VI. CONCLUSION

The paper proposed multi-UAV relay assisted network in Internet of Things (IoT) systems enhanced with energy harvesting, which effectively overcome the large scale fading between source and sink node and reduce the transmitting power to the required minimum value. Moreover, the proposed TS and PS schemes strategies were typically applied for UAV relays and achieved the energy harvesting with information transmission, where the multiple UAV assisted relays were selected via SNR maximization criterion so that the terminal node can obtain the optimal signal. Meanwhile, the outage probability and BER closed expressions were derived with the terminal node disturbed by aggregate interference caused from dense network signaling interaction in the future 5G/B5G systems. Additionally, the throughput and delay limited state of UAV relay assisted transmission were also analyzed thoroughly. The derivations and analysis results showed that the proposed multiple parameters joint optimization can effectively improve the system throughput and reduce the system outage probability and BER. Simulation experiments verified the effectiveness of the proposed schemes and the correctness of theoretical analysis.

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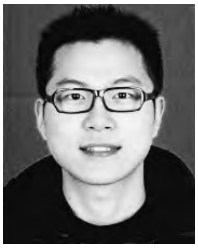

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