Performance Analysis of P2P Networks Based on Queue with Bulk Service and Asynchronous Vacation

Yilin Liu, Zhanyou Ma, Yukang Zhang, and Boyu Zhang

Abstract—**With the widespread use of P2P network technology, the problem of its system energy consumption has become a topic of general interest. This paper studies how to lower the energy consumption of P2P networks, using queueing theory to analyze the problem of high system energy consumption in P2P networks. On the basis of the classical queueing model, an $\mathrm{M}/\mathrm{M}^d/c$ queue is established by introducing strategies such as asynchronous single vacation and bulk service. The steady-state distribution of the queueing model is solved using the matrix-geometric solution method to derive performance metrics. Finally, the problem of energy consumption in different states are studied, and the optimal parameters of the system are determined by constructing the benefit function, which provides a thought for the optimization of the hybrid P2P network.**

Index Terms—**P2P network, asynchronous vacation, bulk service, matrix-geometric solution, social optimal.**

I. Introduction

In order to eliminate servers network bottlenecks, utilize the resources of the network edge space as much as possible, and make the whole Internet load balanced, scholars have proposed the concept of P2P networks. The nodes in a P2P network are logical equivalence, and unlike the traditional C/S model, the nodes can communicate directly with each other. P2P networks have opened up a new era of Internet applications and attracted more and more users, meanwhile this situation has prompted higher demands on the performance of P2P networks. P2P computing technology emerged to make full use of the resources contained in the network, but with the increasing applications of P2P networks, it began to face problems such as inefficient routing, excessive maintenance overhead, and overmuch of requested data, which led to excessive system energy consumption, the poor system stability, the unguaranteed security, as well as the unreliable services. Therefore, further research is needed on how to boost the performance of P2P networks.

Owing to the resource transmission task is enormous and also consumes a lot of resources. In consideration of its service quality, it is also necessary to solve the problem of its high energy consumption. Lua et al.[1] summarized and compared various structured and unstructured P2P overlay networks, divided the various schemes into these two groups within the scope of the design, and discussed the network performance of each group. Lo et al.[2] described three general super nodes selection protocols: a tag-based structured overlay network protocol, a coordinate-based distributed overlay network protocol, and a negotiation-based unstructured overlay network protocol. Through the interaction and sharing of data between nodes, a comprehensive method to solve the super nodes selection problem was proposed. Zhang et al.[3] designed a three-layer architecture for a hybrid streaming system based on P2P networks and C/S to give a dynamic data distribution algorithm with minimum buffering delay. He et al.[4] compared P2P networks with traditional networks in terms of nodes equal, resource decentralization and management autonomy, and analyzed the challenges faced by P2P networks from the perspective of P2P system security. Meanwhile it explained that building a secure P2P network is an inevitable trend and certainly will have a broad future. Rawas et al.[5] measured the reasonable bandwidth allocation in P2P networks by establishing the utility maximization model. The successive approximation method was applied to solve the non-convex optimization problem of the model, and the resource allocation scheme was designed to achieve the optimal solution. Li et al.[6] proposed a new energy-efficient and bandwidth-aware workload allocation method. The experiment demonstrated that it is helpful to reduce the energy consumption of cloud DCs and communication network links delay. The assignment problem was expressed as a multi-objective optimization problem, and the approximate optimal solution of the problem was found through a meta-heuristic genetic algorithm.

To address the selfish behavior of some nodes in P2P networks that only request a large amount of existing resources instead of providing their own resources. Hales[7] proposed a measurement-based distributed approach to reduce free-rider behavior in unstructured P2P networks. The proposed scheme requires each node to monitor its neighboring nodes or adopt explicit incentives to inhibit the selfish behavior of nodes. Jin et al.[8] focused the different characteristics of the nodes and the diversity of the data objects, and combined with the working principle of delayed replication repair strategy in P2P storage systems, a three-dimensional Markov chain model was constructed. Moreover, the system performance was analyzed numerically. They optimized the system parameters by constructing the function of benefit. Lója et al.[9] constructed a P2P network model based on non-cooperative game theory, which focused on the bandwidth

Manuscript received November 23, 2022; revised July 3, 2023. This work was supported in part by the National Natural Science Foundation of China under Grant Nos. 61973261, 61872311, Natural Science Foundation of Hebei Province under Grant Nos. A2020203010, A2018203088.

Yilin Liu is a postgraduate student in the School of Science, Yanshan University, Qinhuangdao, Hebei 066004, China. (e-mail: lyl980504@163.com)

Zhanyou Ma is a professor in the School of Science, Yanshan University, Qinhuangdao, Hebei 066004, China. (e-mail:mzhy55@163.com)

Yukang Zhang is a postgraduate student in the School of Science, Yanshan University, Qinhuangdao, Hebei 066004, China. (e-mail: zyk980515@163.com)

Boyu Zhang is a postgraduate student in the School of Science, Yanshan University, Qinhuangdao, Hebei 066004, China. (e-mail: zbyzby202201@163.com)

allocation of nodes in the system. They came to the conclusion that the Nash equilibrium point exists and is efficient in terms of bandwidth utilization.

Since Neuts[10] invented the matrix-geometric solution method, the method has been widely utilized for the modeling and analysis of queueing systems, and made it possible to analyze the performance of complex queueing models. Vinod[11] analyzed a queueing system for servers that can take vacations the matrix-geometric solution method to acquire an approximation of the load-dependent performance metrics when the vacation period is independent of the customer waiting length. Wang[12] investigated a repairable queueing system in which the service time of two servers obeyed different distributions. Further, some performance metrics of the system and reliability metrics of the unreliable servers were given, and the results were analyzed numerically.

Vacation queueing system regarding strategies such as asynchronous vacation, synchronous vacation, single vacation and multiple vacation has been studied by most scholars with very important results. Tian et al.[13] analyzed the asynchronous vacation M/M/c queueing system and gave a unified solution for two types of models, including multiple vacation and single vacation. The concept of conditional stochastic decomposition was proposed to prove that both the number of queueing customers and the waiting time in a system can be decomposed into the sum of two independent random variables under the condition of fully busy servers. Liu et al.[14] introduced an asynchronous N-strategy multiple vacation strategy queueing model. Performance metrics such as the system steady-state queue length and the average customer waiting time were given, and compared with the classical model. Jain et al.[15] researched the queueing model with the asynchronous vacation strategy including two types of standby server and multiserver breakdown. Performance metrics such as the expected number of servers in different states were determined. Ling et al. [16] introduced standby servers into multiserver asynchronous vacation queueing, and solved the steady-state queue length of the system by using the matrix-geometric solution method. The conditional decompositions of the queue length and the waiting time under the fully busy condition of the servers were proved, and the generating function of the additional queue length and the Laplace transmission of the additional delay were given.

In real life, there are a large number of service systems serving in bulk. In order to analyze the complex queueing problem in this phenomenon, bulk service strategy was introduced based on the classical queueing model. Yi et al.[17] studied a discrete-time finite-capacity queue with Bernoulli arrivals and bulk services. The distribution of queue length after the service was completed by using the embedded Markov chain technology. Then the distribution of queue length for a random periods was obtained, along with important performance metrics such as the average queue length and the probability of loss. Zhang et al.[18] analyzed a class of bulk service work vacation queues, and discussed M/M/1 multiple or single work vacation queues for bulk services, this queueing model was modeled with a GI/M/1 type structured matrices. By solving the joint stationary distribution of this process, the detailed description of the stationary of the servers in the queueing system and the random decomposition results of the stationary queue length distribution were obtained. Most of the existing research on bulk services has been on single-server models. This paper extends single-server to a queueing system with multiserver.

By applying queueing theory to P2P networks, Jin et al.[19] used queueing theory combined with the online mechanism of nodes in P2P networks, a queueing model was established under the condition that the number of servers changes randomly. Then, the Nash equilibrium and the socially optimal strategies of the system nodes were analyzed by establishing the benefit function. Gray et al.[20] combined queueing theory to establish the model to analyze P2P networks, the expression for the expected value of the stationary queue length and the busy period distribution were obtained. When $R = 1$, the explicit expression of the stationary distribution of waiting time was determined. Ma[21] presented the maximum throughput that the system can carry under fixed parameter configuration and strategy deployment for P2P based media distribution network, and the queueing model was established. Zhang et al.[22] used queueing theory to allocate nodes with different resource requests in P2P networks. The steady-state distribution was solved and the expression of performance metrics was obtained, further through numerical analysis, the influence of different parameters on system performance was studied.

The above documents have studied the node online mechanism, throughput, system performance, bandwidth allocation and other aspects of P2P networks. But there is no literature that uses the matrix-geometric solution method and the GI/M/1 structure matrix to establish the queueing model of bulk service and asynchronous vacation of multiserver to analyze the energy consumption of P2P networks. In this paper, it is considered as a vacation mechanism when the server does not carry out resource transmission process such as update, repair, maintenance, etc., or when the multiplexer does not carry out this particular resource output and instead processes other data. The process of resource information transmission of ordinary nodes is regarded as a service process, and the node ends file downloading is regarded as a customer service completion process. An $\mathrm{M/M}^d/c$ queueing system with asynchronous single vacation strategy, bulk service strategy is built.

II. Hybrid P2P networks and modeling

A. Hybrid P2P network

The development of the P2P model has gone through three stages: centralized, distributed, and hybrid. This paper focuses on a hybrid P2P network, a useful alternative to pure system design, overcoming the limitations of the original approach, which refers to an architecture that presents a centralized structure locally, but exhibits a distributed structure overall. In a hybrid P2P network, a super node and multiple ordinary nodes form a star structure. Super nodes are generally powerful nodes that are responsible for resource finding and forwarding as well as collecting resource information stored by the ordinary nodes in the cluster. Ordinary nodes have simple functions compared to super nodes, they only need to store the resource information of their own nodes, and there is no direct neighbor relationship between ordinary nodes.

A node in a P2P network can either act as a "consumer" to request resources from other nodes or act as a "server" to provide services to other nodes. The requesting node can only choose one super node to send its search request at a given moment. In this paper, the nodes within a cluster in a hybrid P2P network are studied, the super node only needs to keep the information about the node in the cluster where it is located, and when the requesting node cannot find the required information in the cluster, it will continue to send requests to neighboring super nodes outside the cluster in a flooding manner through the super node.

B. Model description

In the hybrid P2P network, a large number of requesting nodes send resource requests, and it is necessary to set reasonable service rate and other parameters, otherwise it is easy to cause network congestion and generate more energy consumption. Therefore, the queueing model of servers bulk service and asynchronous vacation is established to solve the problem. Each requesting node is considered as a customer who needs to be served, and each ordinary node is considered as a server. The arrival interval, the service time and the vacation time are each independently, and they obey separately independently and identically distributed exponentially distributed random variables. It is assumed that the waiting space and the number of customers are infinite. Assuming the requesting nodes in the model enter the system and queue up for service on a first come first served rule, then enter the resource transmission phase and leaves the system when the resource transmission is completed.The P2P network operation mechanism is shown in Fig. 1.

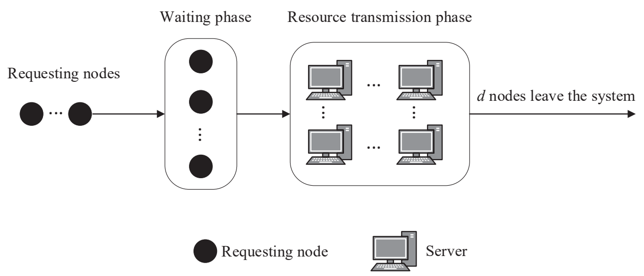

Fig. 1. P2P operation mechanism

1) The arrival interval of nodes requesting the download service follows an exponential distribution with parameter λ. The time of ordinary nodes resource transmission follows an exponential distribution with parameter μ, and the number of ordinary nodes is c.

2) There are usually three types of triggers for bulk service. The quantity trigger is that when the number of customers requesting service reaches the number of bulk service, the servers serve customers; Time trigger means that when a fixed time is reached, the system will serve customers when there are customers in the system; The compound trigger is the compound of the quantity trigger and the time trigger. The model in this paper mainly takes the form of the quantity trigger, i.e., an ordinary node can serve d requesting nodes at a time (d is a fixed constant). That is, the d requesting nodes are considered as a whole, and when the number of waiting requesting nodes reach d, the ordinary node serves them, where the requesting nodes within that bulk receive service and are served at the same time.

3) The model uses an asynchronous single vacation strategy, where each server can start and end vacation states individually. When an ordinary node has served d requesting nodes, it continues to serve the first d requesting nodes if the number of requesting nodes in the queue is greater than or equal to d; If the number of waiting requesting nodes is less than d, the ordinary node enters a vacation period of random length V. The vacation length V follows an exponential distribution with parameter θ ($\theta \geq 0$). When the vacation of an ordinary node is over, if the number of requesting nodes waiting in the queue is greater than or equal to d, this ordinary node immediately serves the first d requesting nodes in the queue and starts a new working period; If the number of waiting requesting nodes is less than d, this ordinary node enters the idle period until the number of waiting requesting nodes is equal to d. Then the node immediately ends the idle period and enters the working period to start serving these d requesting nodes, after that repeat the above process. Thus each ordinary node can be in one of three states (working, idle and vacation) within a busy cycle. The state change of ordinary nodes is shown in Fig. 2.

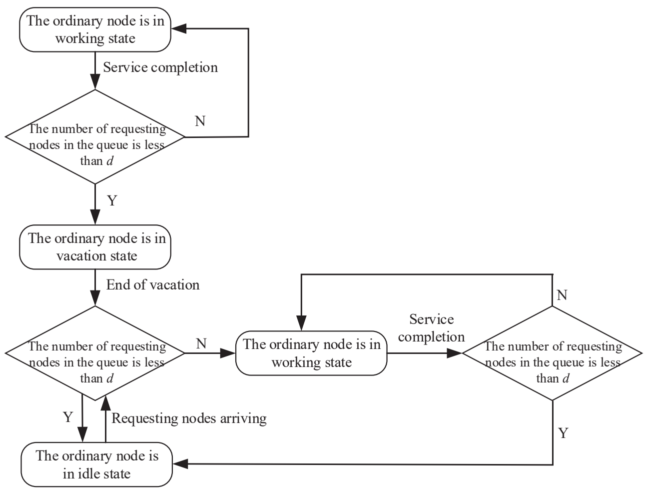

Fig. 2. State change of ordinary nodes

III. Model analysis

A. State transition rate matrix

Let $L(t)$ denotes the number of requesting nodes in the system at time t, $J(t)$ denotes the total number of ordinary nodes in the working and idle periods at time t. Then $\{(L(t), J(t)), t \geq 0\}$ indicates a two-dimensinal Markov process, which has the state space as follows

$$\Omega = \{(i, j), i \geq 0, 0 \leq j \leq c\} \tag{1}$$

where the state set $(i, 0), (i, 1), \cdots, (i, c)$ is called level $i(i \geq 0)$. Also, the meaning of each state is as follows:

$J(t) = 0$ indicates that there is 0 ordinary node in the working period or the idle period, i.e. all ordinary nodes are in the vacation period.

$J(t) = j(1 \leq j \leq c)$ indicates that there are j ordinary nodes in the working or the idle period, i.e. $(c - j)$ ordinary nodes are in the vacation period.

When $j = 0$, $i \geq 0$, state $(i, 0)$ indicates that the number of requesting nodes in the system is i, and all ordinary nodes are in the vacation period.

When $0 < j \leq c$, $0 \leq i < jd$, state (i, j) indicates that the number of requesting nodes in the system is i, $[i/d]$ (where the symbol $[\bullet]$ indicates rounding function) ordinary nodes are in the working period, $(j - [i/d])$ ordinary nodes are in the idle period, and $(c - j)$ ordinary nodes are in the vacation period.

When $0 < j \leq c$, $i \geq jd$, state (i, j) indicates that the number of requesting nodes in the system is i, j ordinary nodes are in the working period, no node is in the idle period and $(c - j)$ ordinary nodes are in the vacation period. Further, show some state transitions of the queueing model, as shown in Fig. 3.

The state transition rate matrix of the system can be written as follows

$$
\boldsymbol{Q} = \begin{bmatrix}
\boldsymbol{A}_0 & \boldsymbol{C} & & & & & & & & & & \\
\vdots & \ddots & \ddots & & & & & & & & & \\
\boldsymbol{0} & \cdots & \boldsymbol{A}_0 & \boldsymbol{C} & & & & & & & & \\
\boldsymbol{B}_1 & \boldsymbol{0} & \cdots & \boldsymbol{A}_1 & \boldsymbol{C} & & & & & & & \\
& \ddots & \ddots & \ddots & \ddots & & & & & & & \\
& & \boldsymbol{B}_1 & \boldsymbol{0} & \cdots & \boldsymbol{A}_1 & \boldsymbol{C} & & & & & \\
& & & \boldsymbol{B}_2 & \boldsymbol{0} & \cdots & \boldsymbol{A}_2 & \boldsymbol{C} & & & & \\
& & & & \ddots & \ddots & \ddots & \ddots & & & & \\
& & & & & \boldsymbol{B}_2 & \boldsymbol{0} & \cdots & \boldsymbol{A}_2 & \boldsymbol{C} & & \\
& & & & & & \ddots & \ddots & \ddots & \ddots & & \\
& & & & & & & \boldsymbol{B}_c & \boldsymbol{0} & \cdots & \boldsymbol{A}_c & \boldsymbol{C} \\
& & & & & & & & \ddots & \ddots & \ddots & \ddots \\
& & & & & & & & & \boldsymbol{B}_c & \boldsymbol{0} & \cdots & \boldsymbol{A}_c & \boldsymbol{C} \\
& & & & & & & & & & \boldsymbol{B} & \boldsymbol{0} & \cdots & \boldsymbol{A} & \boldsymbol{C} \\
& & & & & & & & & & & \ddots & \ddots & \cdots & \ddots & \ddots
\end{bmatrix}
$$

where $\boldsymbol{A}_0, \boldsymbol{A}_1, \boldsymbol{A}_2, \cdots, \boldsymbol{A}_c, \boldsymbol{A}, \boldsymbol{B}_1, \boldsymbol{B}_2, \cdots, \boldsymbol{B}_c, \boldsymbol{B}, \boldsymbol{C}$ indicate the state transition rate between corresponding levels, they are $c + 1$ dimensional square matrix. The block matrix of matrix $\boldsymbol{Q}$ is represented as follows

$$
\boldsymbol{C} = \begin{bmatrix}
\lambda & & & \\
& \lambda & & \\
& & \ddots & \\
& & & \lambda
\end{bmatrix},
$$

$$
\boldsymbol{B}_1 = \begin{bmatrix}
0 & & & & \\
\mu & 0 & & & \\
& \mu & 0 & & \\
& & \ddots & \ddots & \\
& & & \mu & 0
\end{bmatrix},
$$

$$
\boldsymbol{B} = \begin{bmatrix}
0 & & & & \\
& \mu & & & \\
& & 2\mu & & \\
& & & \ddots & \\
& & & & c\mu
\end{bmatrix},
$$

When $2 \leq k \leq c$, the following symbols are defined:

$$
\gamma_{k,i} = \begin{cases} i\mu, & 1 \leq i \leq k - 1, \\ k\mu, & k - 1 < i \leq c. \end{cases}
$$

$$
\boldsymbol{B}_k = \begin{bmatrix}
0 & & & & & & \\
0 & \gamma_{k,1} & & & & & \\
& 0 & \ddots & & & & \\
& & \ddots & \gamma_{k,k-1} & & & \\
& & & \gamma_{k,k} & 0 & & \\
& & & & \ddots & \ddots & \\
& & & & & \gamma_{k,c} & 0
\end{bmatrix}.
$$

And

$$
\boldsymbol{A}_0 = \begin{bmatrix}
\varphi_0 & c\theta & & & \\
& \varphi_1 & (c-1)\theta & & \\
& & \ddots & \ddots & \\
& & & \varphi_{c-1} & \theta \\
& & & & \varphi_c
\end{bmatrix},
$$

$$
\boldsymbol{A} = \begin{bmatrix}
\phi_0 & c\theta & & & \\
& \phi_1 & (c-1)\theta & & \\
& & \ddots & \ddots & \\
& & & \phi_{c-1} & \theta \\
& & & & \phi_c
\end{bmatrix},
$$

where $\varphi_i = -\lambda - (c - i)\theta$, $\phi_i = -\lambda - i\mu - (c - i)\theta$, $0 \leq i \leq c$.

When $1 \leq k \leq c$, the following symbols are defined:

$$
\omega_{k,i} = \begin{cases} -\lambda - i\mu - (c - i)\theta, & 0 \leq i \leq k - 1, \\ -\lambda - k\mu - (c - i)\theta, & k - 1 < i \leq c. \end{cases}
$$

$$
\boldsymbol{A}_k = \begin{bmatrix}
\omega_{k,0} & c\theta & & & \\
& \omega_{k,1} & (c-1)\theta & & \\
& & \ddots & \ddots & \\
& & & \omega_{k,c-1} & \theta \\
& & & & \omega_{k,c}
\end{bmatrix}.
$$

B. Steady-state analysis

From the structure of matrix $\boldsymbol{Q}$, it follows show that Markov process $\{(L(t), J(t)), t \geq 0\}$ is a GI/M/1 type structured matrice. When the Markov process is positive recurrent, the steady-state distribution is defined as follows

$$
\pi_{i,j} = \lim_{t \to \infty} P\{L(t) = i, J(t) = j\}, (i, j) \in \Omega \tag{2}
$$

$$
\boldsymbol{\pi}_i = (\pi_{i,0}, \pi_{i,2}, \cdots, \pi_{i,c}), i \geq 0 \tag{3}
$$

$$
\boldsymbol{\Pi} = (\boldsymbol{\pi}_0, \boldsymbol{\pi}_1, \boldsymbol{\pi}_2, \cdots) \tag{4}
$$

Markov process $\{(L(t), J(t)), t \geq 0\}$ is positive recurrent, its sufficient necessary condition is the $d + 1$ dimensional matrix equation

$$
\boldsymbol{R}^{d+1}\boldsymbol{B} + \boldsymbol{R}\boldsymbol{A} + \boldsymbol{C} = \boldsymbol{0} \tag{5}
$$

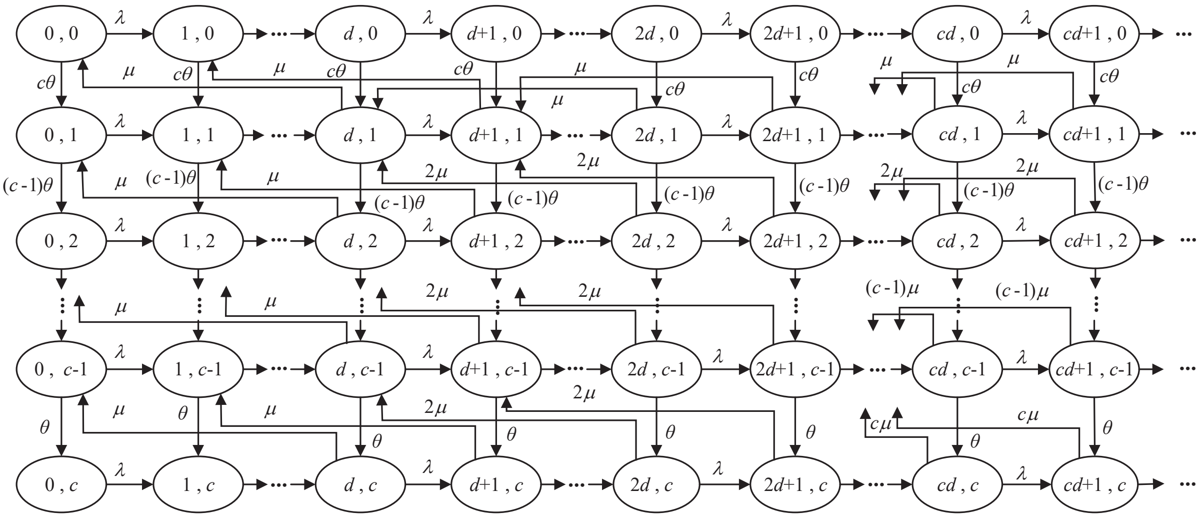

Fig. 3. State transition of queueing model

has a minimum non-negative solution, and the spectral radius $SP(\boldsymbol{R})<1$, the $(c+1)^2\times d$ dimensional stochastic matrix

$$
\mathrm{B}[\boldsymbol{R}]=\begin{bmatrix}
\boldsymbol{A}_0\,\boldsymbol{C} \\
\boldsymbol{0}\ \ \boldsymbol{A}_0\ \boldsymbol{C} \\
\vdots \qquad \ddots\ \ddots \\
\boldsymbol{0}\ \cdots\boldsymbol{0}\ \ \boldsymbol{A}_0\boldsymbol{C} \\
\boldsymbol{B}_1\boldsymbol{0}\ \ \cdots\boldsymbol{0}\ \ \boldsymbol{A}_1\ \boldsymbol{C} \\
\ddots\ \ddots \quad \ddots\ \ddots\ \ddots \\
\boldsymbol{B}_1\ \boldsymbol{0}\ \ \cdots\boldsymbol{0}\ \ \boldsymbol{A}_1\boldsymbol{C} \\
\boldsymbol{B}_2\boldsymbol{0}\ \ \cdots\boldsymbol{0}\ \ \boldsymbol{A}_2\ \boldsymbol{C} \\
\ddots\ \ddots \quad \ddots\ \ddots\ \ddots \\
\boldsymbol{B}_2\ \boldsymbol{0}\ \ \cdots\boldsymbol{0}\ \ \boldsymbol{A}_2\ \boldsymbol{C} \\
\ddots\ \ddots \quad \ddots\ \ddots\ \ddots \\
\boldsymbol{B}_c\ \boldsymbol{0}\ \ \cdots\boldsymbol{0}\ \ \boldsymbol{A}_c\ \boldsymbol{C} \\
\ddots\ \ddots \quad \ddots\ \ddots \quad \ddots \\
\boldsymbol{B}_c\ \boldsymbol{0}\ \ \cdots\boldsymbol{0}\quad \boldsymbol{A}_c\ \boldsymbol{C} \\
\boldsymbol{B}\ \ \boldsymbol{RB}\boldsymbol{R}^2\boldsymbol{B}\cdots\boldsymbol{R}^d\boldsymbol{B}+\boldsymbol{A}
\end{bmatrix}
$$

has left-zero vector, Markov process $\{(L(t),J(t)),t\geq 0\}$ is positive recurrent, the steady-state distribution satisfies the following equations

$$
\begin{cases}
\left(\boldsymbol{\pi}_0,\boldsymbol{\pi}_1,\cdots,\boldsymbol{\pi}_{(c+1)d}\right)B[\boldsymbol{R}]=\boldsymbol{0}, \\
\sum\limits_{i=0}^{(c+1)d-1}\boldsymbol{\pi}_i\boldsymbol{e}+\boldsymbol{\pi}_{(c+1)d}(\boldsymbol{I}-\boldsymbol{R})^{-1}\boldsymbol{e}=1, \\
\boldsymbol{\pi}_i=\boldsymbol{\pi}_{(c+1)d}\boldsymbol{R}^{i-(c+1)d}, \quad i\geq(c+1)d.
\end{cases} \tag{6}
$$

where $\boldsymbol{e}$ denotes a $c+1$ dimensional column vector, in which all elements are 1. $\boldsymbol{I}$ is a $c+1$ dimensional unit matrix. The above conclusion is proved mainly by using the matrix-geometric solution method. The literature written by Neuts contains the specific proof procedure of the method. The dimension of the matrix equation $\boldsymbol{R}^{d+1}\boldsymbol{B}+\boldsymbol{RA}+\boldsymbol{C}=\boldsymbol{0}$ is relatively large, so the display expression of $\boldsymbol{R}$ is difficult to obtain. Therefore, the Gauss-Seidel iterative method is used to solve this problem. The process of solving $\boldsymbol{R}$ by iterative algorithm is shown in the following Table I.

TABLE I
ITERATIVE ALGORITHM FOR RATE MATRIX $\boldsymbol{R}$

Step	Operation
Step 1	Initialize the error precision ε (for example, ε=10^{-3}), c,d,θ,λ,μ, and rate matrix $\boldsymbol{R}=\boldsymbol{0}$
Step 2	Input $\boldsymbol{A},\boldsymbol{B},\boldsymbol{C}$, $n=1$
Step 3	Define $\boldsymbol{R}=\boldsymbol{R}_n$
	$n=n+1$
	$\boldsymbol{R}=-(\boldsymbol{R}_{n-1}{}^{d+1}\boldsymbol{B}+\boldsymbol{C})\boldsymbol{A}^{-1}$
Step 4	If $\Vert\boldsymbol{R}_n-\boldsymbol{R}_{n-1}\Vert_\infty>\varepsilon$
	Go to Step3
	else
	Go to Step5
Step 5	$\boldsymbol{R}=\boldsymbol{R}_n$

C. Performance metrics

Based on the steady-state distribution of the queueing model, the expressions for the hybrid P2P network performance metrics are derived, and then the variation of the system performance metrics with parameters is investigated. Assuming that the average energy consumption of an ordinary node is y_1 during the vacation period, y_2 during the idle period, and y_3 during the working period, $y_1<y_2<y_3$.

1) The average queue length $E(L)$ of the requesting nodes is given by

$$
E(L)=\sum_{i=0}^{\infty}iP(L=i)=\sum_{i=1}^{\infty}i\left(\sum_{j=0}^{c}\pi_{i,j}\right). \tag{7}
$$

2) The average waiting time $E(W)$ of the requesting nodes is given by

$$
E(W)=\frac{1}{\lambda}E(L)=\frac{1}{\lambda}\sum_{i=1}^{\infty}i\left(\sum_{j=0}^{c}\pi_{i,j}\right). \tag{8}
$$

3) The average energy consumption G_1 of the system during the vacation period is given by

$$
G_1=y_1\left(\sum_{i=0}^{\infty}\sum_{j=0}^{c-1}(c-j)\pi_{i,j}\right). \tag{9}
$$

4) The average energy consumption G_2 of the system during the idle period is given by

$$G_2 = y_2 \left(\sum_{j=1}^{c} \sum_{i=0}^{(j-1)d} \left(j - \left[\frac{i}{d} \right] \right) \pi_{i,j} \right). \tag{10}$$

5) The average energy consumption G_3 of the system during the working period is given by

$$G_3 = y_3 \left(\sum_{j=1}^{c} \sum_{i=0}^{jd} \left[\frac{i}{d} \right] \pi_{i,j} + \sum_{j=1}^{c} \sum_{i=jd+1}^{\infty} j\pi_{i,j} \right). \tag{11}$$

6) The total energy consumption G of the system is given by

$$G = G_1 + G_2 + G_3. \tag{12}$$

IV. Numerical experiments

Numerical analysis is performed using software programming to obtain images of system performance metrics with parameter variation, and then the trend of the indicators with the parameters is analyzed. Explain the meaning of each system parameter before analysis, as shown in Table II.

TABLE II
THE MEANING OF EACH SYSTEM PARAMETER

Symbol	Meaning
c	The number of ordinary nodes
d	The number of bulk services
λ	The arrival rate of requesting nodes
μ	The service rate of ordinary nodes
θ	The vacation parameter of ordinary nodes
y_1	Energy consumption during the vacation period
y_2	Energy consumption during the idle period
y_3	Energy consumption during the working period

A. *Effect of parameter on performance metrics*

Fig. 4 reflects the average queue length $E(L)$ of the resource requesting nodes changes with μ and λ, when $c = 10$, $d = 2$, $\theta = 1$. It can be seen from Fig. 4 that when λ is constant, along with the increase of μ, $E(L)$ has downward trend; When μ is constant, along with the increase of λ, $E(L)$ has ascendant trend. The main reason for the change in $E(L)$ is that the service rate of ordinary nodes in the system is larger, the faster the resources are transferred between nodes. Therefore, the number of requesting nodes that can complete the service leaving the system increases, and nodes waiting in the queue can enter the system to receive services faster, the smaller the average queue length is. As the number of requesting nodes increases, the number of nodes queued in the system increases, and thus the average queue length of the requesting nodes increases.

Assuming $c = 10$, $d = 2$, $\theta = 1$. Fig. 5 and Table III reflect the average waiting time $E(W)$ of the resource requesting nodes changes with λ and μ. When μ is constant, along with the increase of λ, $E(W)$ has downward trend and then ascendant trend; When λ is constant, along with the increase of μ, $E(W)$ has downward trend. The main reason for the change in $E(W)$ is that the more requesting nodes, the easier it is for the waiting nodes in the system to

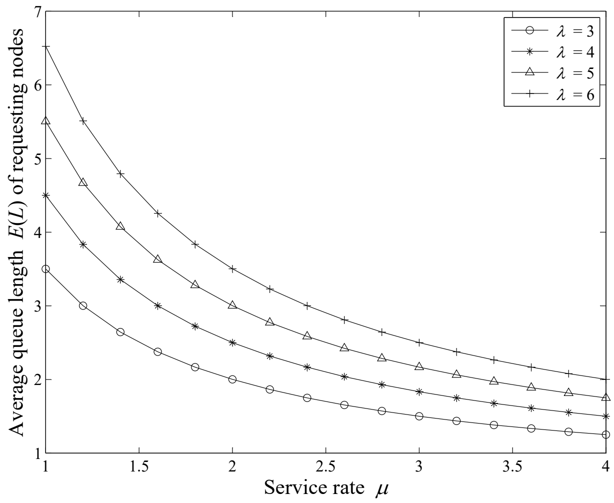

Fig. 4. Effect of λ and μ on average queue length $E(L)$

reach the start condition of the bulk service, therefore enters the system to receive the service. The more ordinary nodes in the idle period turn to the work period to serve them, the waiting time of requesting nodes decreases. However, as the increase of arrival rate makes most ordinary nodes in the system occupied to provide services, then with the increase of the number of requesting nodes, more requesting nodes are queued and their waiting time becomes longer. As the service rate of the ordinary nodes of the system increases, the transmission of resources between the nodes gets faster, so the service efficiency increases. The amount of requesting nodes departs from the system at the end of the service increases, thus the more requesting nodes waiting in line to enter the system to receive service, the waiting time of the requesting nodes shortening.

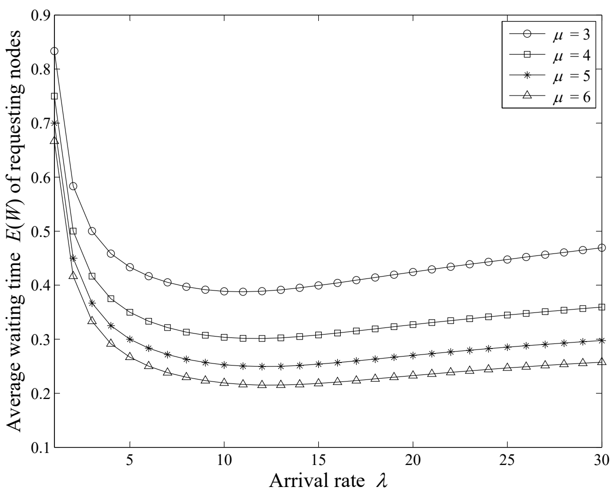

Fig. 5. Effect of λ and μ on average waiting time $E(W)$

It can be seen from the Table III that $E(W)_{min} = 0.215$ is minimum when $\mu = 6$, $\lambda = 13$ under the set conditions. According to the quantitative numerical results, the optimization effect of the arrival rate λ meeting the minimum average waiting time under different service rates is compared with that of $\lambda = 3$. When $\mu = 3$, the arrival rate corresponding to the minimum value of $E(W)$ is $\lambda = 11$, and $E(W)$ decreases by 22.36%; When $\mu = 4$, the arrival rate corresponding to the minimum value of $E(W)$ is $\lambda = 11$, and $E(W)$ decreases by 27.47%; When $\mu = 5$, the arrival rate corresponding to the minimum value of $E(W)$ is $\lambda = 13$, and $E(W)$ decreases by 32.47%; When $\mu = 6$, the arrival rate corresponding to the minimum value of $E(W)$ is $\lambda = 13$, and $E(W)$ decreases by 35.43%. It shows that proper arrival rate has obvious effect on shortening the average waiting time.

TABLE III
SPECIFIC NUMERICAL RESULTS VARYING WITH PARAMETERS λ AND μ

	$E(W)$					
	$\lambda = 3$	$\lambda = 5$	$\lambda = 7$	$\lambda = 9$	$\lambda = 11$	$\lambda = 13$
$\mu = 3$	0.5000	0.4332	0.4052	0.3925	0.3882	0.3911
$\mu = 4$	0.4172	0.3500	0.3223	0.3075	0.3026	0.3035
$\mu = 5$	0.3674	0.3000	0.2725	0.2573	0.2500	0.2490
$\mu = 6$	0.3333	0.2672	0.2382	0.2230	0.2167	0.2152

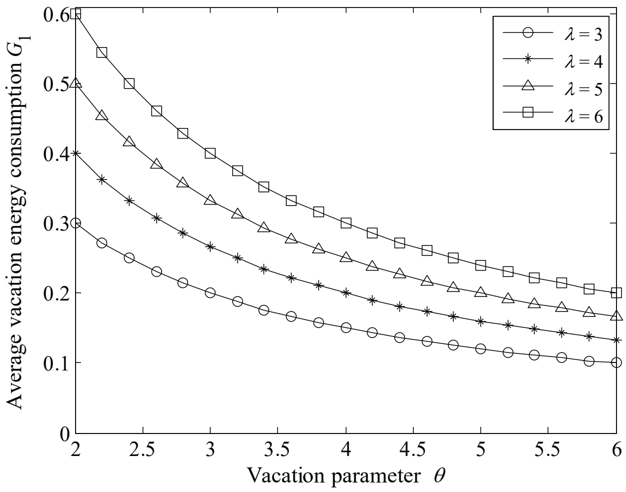

Fig. 6. Effect of θ and λ on energy consumption G_1

B. Energy consumption analysis

This paper mainly analyzes the energy consumption. Specifically according to a cluster in the system to study, and then analyzes the variation of system energy consumption with different parameter changes. Assuming $y_1 = 0.4$, $y_2 = 0.5$, $y_3 = 0.8$.

Assuming $c = 10$, $d = 2$, $\mu = 3$, Fig. 6 shows the effect of θ and λ on the average energy consumption G_1 during the vacation period. When λ is constant, along with the increase of θ, G_1 has downward trend; When θ is constant, along with the increase of λ, G_1 has ascendant trend. The main reason for the change in G_1 is that the vacation parameter increases, the average vacation time of each ordinary node decreases, and the ordinary node ends the vacation period quickly and enters the idle or working period, and thus the energy consumption during the vacation period decreases. As the arrival rate of the requesting nodes increases, it is easier to satisfy the bulk of d nodes entering the system to receive the service, so the more ordinary nodes are in the working period. The number of ordinary nodes that complete the transmission of resources into the vacation period increases, and thus the energy consumption of the system during the vacation period increases. Therefore, appropriate measures can be taken to increase the vacation parameters or reduce the arrival rate to achieve the goal of reducing the energy consumption of the system during the vacation period.

Assuming $c = 10$, $d = 2$, $\theta = 2$, Fig. 7 illustrates the effect of λ and μ on the average energy consumption G_2 during the idle period and the average energy consumption G_3 during the working period. When μ is constant, along with the increase of λ, G_2 has downward trend, and G_3 has ascendant trend; When λ is constant, along with the increase of μ, G_2 has ascendant trend, and G_3 has downward trend. The main reason for the change in G_2 and G_3 is that the arrival rate of requesting nodes increases, means that more nodes request resources, the easier it is to reach the number of bulk services to start the service and the more ordinary nodes enter the working period. As a result, the fewer ordinary nodes are in the idle period, the energy consumption during the idle period decreases, and the energy consumption during the working period increases. The service rate of ordinary nodes increases, the resource transmission between nodes get faster. So the more requesting nodes complete the service, and the ordinary nodes enter the idle period from the working period. Therefore, the energy consumption during the working period decreases and the energy consumption during the idle period increases. For the purpose of reducing the unnecessary energy consumption during the idle period, it is necessary to increase the arrival rate of the requesting nodes and reduce the service rate of the ordinary nodes, so that more ordinary nodes are in the working period.

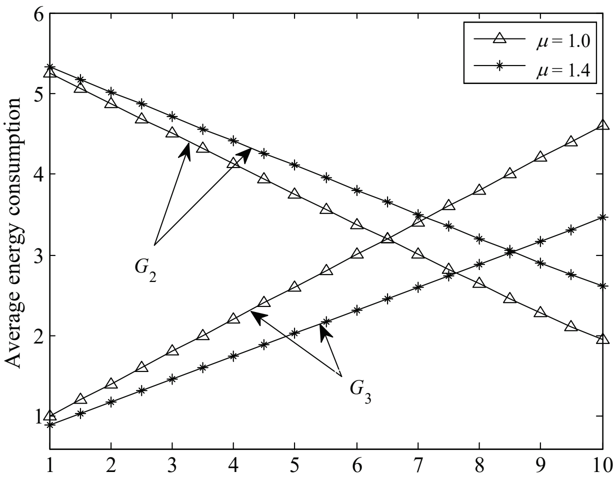

Fig. 7. Effect of λ and μ on energy consumption G_2 and G_3

According to the actual conditions, it is usually set the energy consumption during the working period is greater than that during the idle period or both are equal, i.e., $G_3 \geq G_2$. As can be seen from Table IV, when $\mu = 1.0$, $\lambda \geq 6.5$, the energy consumption during the working period is greater than that during the idle period. When $\mu = 1.4$, $\lambda \geq 9$, it have the same result.

Fig. 8 reflects the effect of θ, λ and μ changes on the total energy consumption G for the condition $c = 10$, $d = 2$. When λ and μ are constant, along with the increase of θ, G has ascendant trend; When λ and θ are constant, along with the increase of μ, G has downward trend; When μ and θ are constant, along with the increase of λ, G has

TABLE IV
SPECIFIC NUMERICAL RESULTS OF G_2 AND G_3 WITH λ AND μ

	G_2		G_3	
	$\mu = 1.0$	$\mu = 1.4$	$\mu = 1.0$	$\mu = 1.4$
$\lambda = 6.0$	3.3759	3.8037	3.0002	2.3143
$\lambda = 6.5$	3.1896	3.6521	3.2004	2.4572
$\lambda = 7.0$	3.0041	3.5006	3.4007	2.6001
$\lambda = 7.5$	2.8202	3.3495	3.6011	2.7431
$\lambda = 8.0$	2.6384	3.1988	3.8016	2.8861
$\lambda = 8.5$	2.4595	3.0489	4.0020	3.0292
$\lambda = 9.0$	2.2842	2.9001	4.2023	3.1724

ascendant trend. The main reason for the change in G is that that according to the actual $y_1 < y_2 < y_3$, the vacation parameter increases, the vacation time of ordinary nodes shorten, then the number of the ordinary nodes shift from the vacation period to the idle period or the working period increases, and the energy consumption during the vacation period decreases. The energy consumption during the working and the idle periods increases, consequently, the total system energy consumption is greater. The increase of the service rate of ordinary nodes indicates that the resource transmission between nodes is faster, the number of ordinary nodes at the end of the working period increases, and thus the decrease of the energy consumption during the working period affects the total energy consumption decreases. The increase of the arrival rate of requesting nodes indicates that more requesting nodes arrive, which means more ordinary nodes enter the working period, and the energy consumption during the working period increases, thus the total system energy consumption becomes larger and larger.

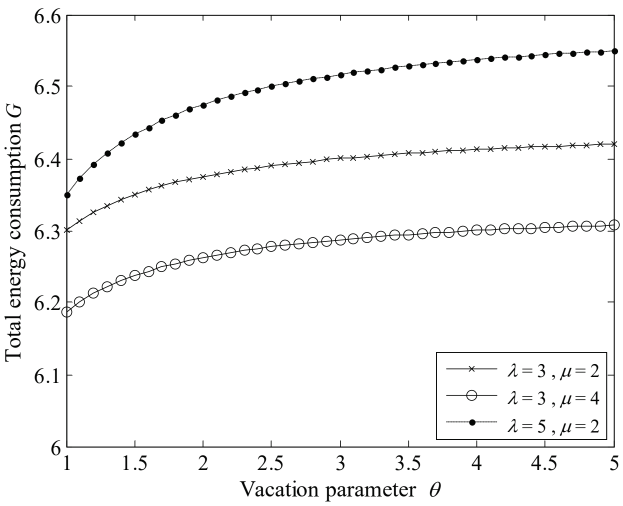

Fig. 8. Effect of θ, λ and μ on the total energy consumption G

TABLE V
SPECIFIC NUMERICAL RESULTS OF G_1, G_2 AND G WITH θ

	$\theta = 1.0$	$\theta = 1.5$	$\theta = 2.0$	$\theta = 2.5$	$\theta = 3.0$	$\theta = 3.5$
G_1	0.6000	0.4000	0.3000	0.2400	0.2000	0.1711
G_2	4.5000	4.7500	4.8751	4.9500	5.0000	5.0381
G	6.3000	6.3500	6.3752	6.3900	6.4000	6.4073

Through the above combined queueing model with bulk service and asynchronous vacation strategies analyzes the effect of different parameter changes on the system energy consumption. Combine with the actual problem, It is hoped that the energy consumption during the idle period and the energy consumption during the vacation period are relatively small. Accordingly, if we want to diminish the total energy consumption, the method of appropriately reducing the vacation parameter of the ordinary nodes can be used. Table V shows the specific values of G_1, G_2 and G as the vacation parameter increases when $c = 10$, $d = 2$, $\lambda = 3$, $\mu = 2$. From $\theta = 3.5$ to $\theta = 1.0$, G_2 is reduced by 10.68%, G is reduced by 1.67%.

C. Nash equilibrium strategy

P2P networks aggregate a large number of resources at a low cost, resulting in more nodes participating in them. In real life, most of them are unobservable queues. The requesting nodes has behavior of maximizing their own benefits, and there is a game behavior among requesting nodes. The vast majority of games have quantitative results themselves or can be quantified as quantitative results. So as to better prevent the performance and operation of P2P networks from being affected by too many requesting nodes pursuing their own benefits to the maximum, the benefit function were established.

Since customers' behavior of maximizing their own benefits often deviates from the overall benefit preference of the whole society. Therefore, this paper addresses the optimization problem of P2P networks and establishes a charging scheme in order to suppress the selfish behavior of requesting nodes, so that the behavior of customers and the social optimal decision behavior are aligned as much as possible. The following hypothesis is proposed:

1) The return available to the requesting nodes after accepting a resource transmission is r.

2) The activation cost for the requesting nodes to enter the system and start resource transmission is f_1.

3) The cost of the requesting node waiting is f_2.

The net benefit of individual requesting node is

$$U = r - f_1 - f_2 E(W). \tag{13}$$

As can be seen from Fig. 9 and Table VI, when $c = 10$, $d = 2$, $\theta = 1$, $r = 6$, $f_1 = 3$, $f_2 = 4.5$, the trend of the net benefit of individual requesting node U with λ and μ is reflected. When μ is constant, along with the increase of λ, U has ascendant trend; When λ is constant, along with the increase of μ, U has ascendant trend. The main reason for the change in U is that the number of requesting nodes increases, the easier it is to reach the number of bulk services, the shorter the time that the requesting nodes queue to receive the service, and thus the decrease in the cost of waiting affects the increase of the individual net benefit function. The service efficient of the ordinary node is higher, the requesting nodes leave the system after accepting the service are greater, as the same time the waiting time decreases and the net benefit of individual requesting node increases. As can be seen from the Fig. 9, the net benefit of individual requesting node gradually increases from negative to positive values in pace with the arrival rate goes up. There is a point in the middle where the net benefit of individual requesting node is 0. The point at which the net benefit equal 0 is regarded as the Nash equilibrium point. According to the analysis, so as to suppress the selfish behavior of nodes and increase the net benefit of individual requesting node, the arrival rate of requesting nodes can be appropriately increased and the service rate of ordinary nodes can be increased.

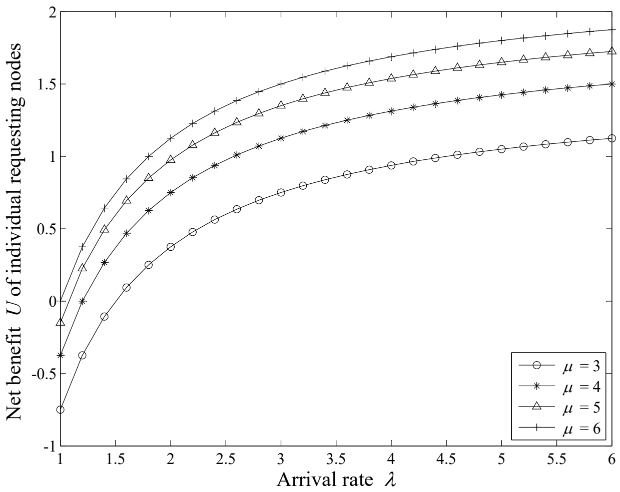

Fig. 9. Effect of λ and μ on the net benefit U

TABLE VI
SPECIFIC NUMERICAL RESULTS OF U WITH λ AND μ

	U				
	$\lambda = 1.0$	$\lambda = 1.2$	$\lambda = 1.4$	$\lambda = 1.6$	$\lambda = 1.8$
$\mu = 3$	-0.7500	-0.3750	-0.1071	0.0937	0.2500
$\mu = 4$	-0.3750	-0.2530	0.2679	0.4687	0.6250
$\mu = 5$	-0.1500	0.2250	0.4929	0.6937	0.8500
$\mu = 6$	-0.0875	0.3750	0.6429	1.0000	1.1250

D. Socially optimal strategy

Analysis of social optimal strategy for P2P networks, the average net benefit of nodes in the system at each moment is considered, and the social optimum aims to maximize the total benefit of all nodes.

The average social net benefit function is defined as follows

$$U_s = \lambda(r - f_1 - f_2 E(W)) \ . \tag{14}$$

Assuming $c = 10$, $d = 2$, $\theta = 1$, $r = 6$, $f_1 = 3$, $f_2 = 4.5$, Fig. 10 allows to observe the magnitude of the average social net benefit U_s as μ and λ changes. When λ is constant, along with the increase of μ, U_s has ascendant trend; When μ is constant, along with the increase of λ, U_s has ascendant trend. The main reason for the change in U_s is that the service rate increases, then the service efficiency of ordinary nodes increases, the individual net benefit increases, and thus the average social net benefit increases. A larger arrival rate means more requesting nodes enter the system, the average net social benefit is inversely proportional to the arrival rate, so the average net social benefit increases accordingly. The maximum average social benefit is U_s=5.7375, and the optimal arrival rate at this point is λ=1.8 and the optimal service rate is μ=8.

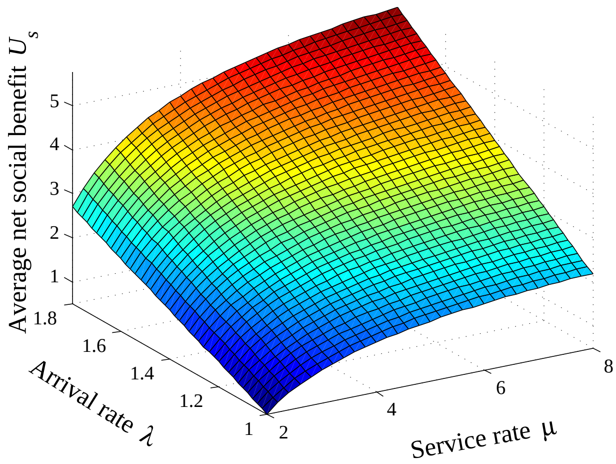

Fig. 10. Effect of λ and μ on the average social net benefit U_s

V. CONCLUSION

In this paper, the behavior of each node making resource requests in P2P network is analyzed and managed using queueing theory to enable the nodes to efficiently provide services to nodes and reduce system energy consumption. Introducing strategies such as asynchronous single vacation and bulk service to build $\mathrm{M/M}^d/c$ queueing model, the performance metrics such as the average queue length and the average waiting time are obtained by using the matrix-geometry solution method and the GI/M/1 type structured matrice. In addition, combined with the hybrid P2P network to study the energy consumption in different periods including vacation period, idle period and working period. Finally, considering that abundant requesting nodes enter the system and send resource requests, the problem of excessive system energy consumption is caused. The benefit function is constructed and the equilibrium analysis is carried out on the system. The results of this paper are helpful for the service provider to select the appropriate service rate, vacation parameter and other metrics under different conditions to make the system reach the optimal state.

REFERENCES

[1] E. K. Lua, J. Crowcroft, M. Pias, et al. "A survey and comparison of Peer-to-Peer overlay network schemes," IEEE Communications Surveys & Tutorials, vol. 7, no. 3, pp.72-93, 2005.
[2] V. M. Lo, D. Zhou, Y. Liu, et al. "Scalable super node selection in Peer-to-Peer overlay networks," Second International Workshop on Hot Topics in Peer-to-Peer Systems, pp.18-25, 2005.
[3] X. R. Zhang, T. B. Yang, Y. Z. Tan, et al. "Research on multi-sender data dispatching scheme based on P2P," Computer System Applications, vol. 30, no. 6, pp.46-49, 2007.
[4] W. H. He, H. Liu and J. S. He, "Research on the current situation and development of P2P network," Software Engineering, vol. 22, no. 4, pp.1-5, 2019.
[5] S. Rawas and A. Zekri, "EEBA: Energy-Efficient and Bandwidth-Aware Workload Allocation Method for Data-intensive Applications in Cloud Data Centers," IAENG International Journal of Computer Science, vol. 48, no.3, pp 703-715, 2021.
[6] S. Y. Li, K. Yuan, Y. Zhang and W. Sun, "A Novel Bandwidth Allocation Scheme for Elastic and Inelastic Services in Peer-to-peer Networks," IAENG International Journal of Computer Science, vol. 46, no.2, pp 163-169, 2019.
[7] D. Hales, "From selfish nodes to cooperative networks-emergent link-based incentives in Peer-to-Peer networks," Fourth International Conference on Peer-to-Peer Computing, Zurich, pp.151-158, 2004.

[8] S. F. Jin, Y. Zhao, W. Y. Yue, et al. “Performance analysis of a P2P storage system with a lazy replica repair policy,” Journal of Industrial & Management Optimization, vol. 10, no. 1, pp.151-166, 2014.
[9] K. Lója, and P. Giaccone, “Nash equilibria in bandwidth allocation for non-cooperative Peer-to-Peer networks,” Journal of Systems Architecture, vol. 54, no. 1-2, pp.81-96, 2008.
[10] M. F. Neuts, “Matrix-geometric solutions in stochastic models,” Johns Hopkins University Press, Baltimore, 1981.
[11] B. Vinod, “Exponential queues with server vacations,” Journal of the Operational Research Society, vol. 37, no. 10, pp.1007-1014, 1986.
[12] L. Wang, “Matrix-geometric solution of a repairable queueing system with two heterogeneous servers,” Yanshan University, 2010.
[13] N. S. Tian and Z. G. Zhang, “Vacation queueing models theory and applications,” Boston, Springer, 2006.
[14] M. X. Liu, Z. Y. Ma, X. L. Xu, et al. “The M/M/c queue with N-policy and asynchronous multiple vacation of partial servers,” Journal of Yanshan University, vol. 30, no. 3, pp.230-234, 2006.
[15] A. Jain and M. Jain, “Multi server machine repair problem with unreliable server and two types of spares under asynchronous vacation policy,” International Journal of Mathematics in Operational Research, vol. 10, no. 3, pp.286-315, 2017.
[16] T. T. Ling, B. L. Ding and Y. J. Zhu, “Asynchronous restricted vacation queue with two standby servers,” Journal of Taiyuan Normal College (Natural Science Edition), vol. 17, no. 4, pp.6-11, 2018.
[17] X. W. Yi, N. K. Kim, B. K. Yoon, et al. “Analysis of the queue-length distribution for the discrete-time batch-service Geo/G^{a,Y}/1/K queue,” European Journal of Operational Research, vol. 181, no. 2, pp.787-792, 2007.
[18] H. B. Zhang, H. W. Wang and D. H. Shi, “Analysis for a working vacation queue with batch service,” Acta Mathematicae Applicatae Sinica, vol. 43, no. 5, pp.781-791, 2020.
[19] S. F. Jin, Y. Li, J. P. Liu, et al. “Strategies of nash equilibrium and social optimization for online mechanisms of P2P nodes,” Journal of Jilin University (Engineering and Technology Edition), vol. 46, no. 1, pp.296-302, 2016.
[20] W. J. Gray and M. Scott, “A queueing model with bonus service for certain customers,” Applied Mathematical Modelling, vol. 10, no. 4, pp.241-245, 1986.
[21] X. F. Ma, “Performance analysis of P2P-based media delivery network,” University of Science and Technology of China, 2011.
[22] Y. Zhang, Z. Y. Ma, J. Q. Fan, ea al. “Research of queuing model based on request queue in P2P network system,” Radioelectronics and Communications Systems, vol. 64, no. 4, pp.174-188, 2021.