International Journal of Autonomous and Adaptive Communications Systems

ISSN online: 1754-8640 - ISSN print: 1754-8632
https://www.inderscience.com/ijaacs

Network dynamic routing and spectrum allocation algorithm based on blockchain technology

Jue Ma

DOI: 10.1504/IJAACS.2023.10038427

Article History:

Received:	31 March 2020
Accepted:	01 September 2020
Published online:	17 March 2023

Network dynamic routing and spectrum allocation algorithm based on blockchain technology

Jue Ma

School of Information and Electromechanical Engineering,
Jiangsu Open University,
Nanjing 210017, China
Email: juema@mls.sinanet.com

Abstract: In order to overcome the problems of low resource utilisation rate and high bandwidth blocking rate of traditional network dynamic routing and spectrum allocation, a network dynamic routing and spectrum allocation algorithm based on blockchain technology is proposed. In this algorithm, a hybrid integer linear model of network dynamic routing and spectrum allocation is constructed to minimise spectrum consumption and frequency. Based on the extended static heuristic algorithm of blockchain, the link with the largest load is selected to optimise the spectrum allocation, and the linear model and extended static heuristic algorithm are combined to update the frequency gap state of the link where the path is located, so as to achieve the purpose of dynamic routing and spectrum allocation of the network. The experimental results show that the spectrum utilisation rate is as high as 99.66%, and the bandwidth blocking rate is as low as 0.

Keywords: blockchain technology; network dynamic routing; spectrum allocation; bandwidth blocking; hybrid integer linear model; spectrum utilisation rate; bandwidth blocking rate.

Reference to this paper should be made as follows: Ma, J. (2023) 'Network dynamic routing and spectrum allocation algorithm based on blockchain technology', *Int. J. Autonomous and Adaptive Communications Systems*, Vol. 16, No. 1, pp.17–30.

Biographical notes: Jue Ma received her Master degree in Computer Science from Hohai University in 2010. She visited University of Houston as a Visiting Scholar during 2013–2014. She is currently a Vice Professor in the School of Information and Electromechanical Engineering of Jiangsu Open University. Her research interests include network performance analysis, wireless sensor network and block chain technology.

1 Introduction

With the continuous rise of high bandwidth multicast services, the spectrum resources of the network at this stage cannot bear the linear growth of bandwidth demand (Wang and Zhu, 2016; Liu et al., 2016). Wireless spectrum resources are increasingly scarce. The traditional static spectrum allocation policy divides a fixed spectrum range for specific business planning, leaving limited spectrum resources for new systems and services. A considerable part of the authorised frequency band has not been fully utilised, which has great imbalance. At present, the network has provided huge network transmission bandwidth resources, but still can not meet the needs of network transmission (Liu and Jia, 2016). In the process of network dynamic routing and spectrum allocation, there is a large amount of data and the network chain is unbalanced. Therefore, blockchain technology can be selected as the allocation basis. Blockchain technology can make the whole network link balanced. It is characterised by decentralisation, openness and transparency. The blockchain records all the transaction information of the whole network through distributed recording, and the network spectrum data is jointly maintained by each node, so that the spectrum information can be traced and cannot be deleted, and the trust can be shared (Sun et al., 2016).

In Yu et al. (2019), a dynamic routing and spectrum allocation algorithm based on differentiated degradation service and adaptive modulation is proposed. A mixed integer linear programming model for RSA problem is established, which aims at minimising spectrum consumption and DS level and frequency. Considering the difference of service level, adaptive modulation and DS technology are integrated. The DS loss function and the DS window selection strategy are designed to distinguish the service level, and the ideal spectrum location and resources are allocated to the impending service. To achieve the efficient use of spectrum resources, the impact of degradation is reduced, and the network revenue is improved. However, there is a problem of low spectrum utilisation. In Wang et al. (2019), a routing and spectrum allocation algorithm based on node importance is proposed. Considering the type and size of the service, the key nodes in the network are found out to make the service allocation reach equilibrium. In the aspect of spectrum allocation, the algorithm considers the distribution of spectrum resources on the network link, combined with the number of frequency slots required by each service, it can reduce the spectrum fragments as much as possible. However, there is a problem of high bandwidth blocking rate. In Lu et al. (2018), a Nash equilibrium spectrum allocation method based on supply-demand balance and price discrimination algorithm is proposed. In this method, the supply-demand balance algorithm is used to balance the supply-demand contradiction in the spectrum market, and then the price discrimination algorithm is used to seek the best Nash equilibrium solution of spectrum allocation through continuous game. It can effectively allocate the free spectrum resources of the authorised network and improve the spectrum utilisation. However, there is a high delay in spectrum distribution.

Due to the diversity of network service bandwidth, the number of fragments in the network link increases gradually, and the services with larger bandwidth are more difficult to find a suitable path for distribution. Therefore, this paper designs and proposes a network dynamic routing and spectrum allocation algorithm based on blockchain technology. Based on the blockchain technology, the occupancy of different link spectrum slots is analysed, and a mixed integer linear model is established. To complete the service request based on the mixed integer linear model, it is necessary to optimise the target to be allocated, select the link with the largest load to optimise the spectrum allocation, update the frequency gap state of the link where the path occupies, and complete the dynamic network routing and spectrum allocation. The effectiveness and superiority of the proposed algorithm are verified by the simulation experiment data.

2 Building mixed integer linear model

Due to the increasing number of fragments in the network link, it is more difficult for services with large bandwidth to find a suitable path for allocation. The throughput and data transmission security of the network can be improved by building an integer linear model, especially the bandwidth utilisation of the network can be improved, and the waste of network resources can be reduced. In order to explain the network scenario of anycast service more clearly and in detail, it is necessary to make a basic description and assumption for the network, and set the physical topology of the network as $G(V, E)$, where V represents the set of all nodes in the network; E represents the set of all links in the network; any two adjacent nodes in the network are connected by two links with opposite directions, that is, (a, b) represents the fibre link from node A to node B; (b, a) represents the fibre link from node B to node A. FS is used to represent the spectrum resources on different links, and the total number of spectrum resources on one fibre link is represented by F. For different anycast requests, it needs to start from the source node to all the selected destination nodes. It is assumed that the data is mainly routed by optical trees, and there is no spectrum conversion in each optical tree.

An example of the routing process for multicast service in the network is shown in Figure 1. The multicast request service can be expressed in the following forms:

$$\mathrm{R} = \{s, D, n\} \tag{1}$$

Where

$$D = \{d_1, d_2, \cdots, d_4\} \tag{2}$$

The introduction of blockchain technology into the network can effectively integrate network coding, further improve the throughput and data transmission security of the network, especially the bandwidth utilisation of the network, and reduce the waste of network resources.

$\left|U_k^r\right|_{H\times|C|}$ is formed by the occupation of spectrum slots of different links in the path. The specific calculation formula is as follows:

$$\sigma_k = C_s \cdot \log_2 M_k \tag{3}$$

$$\left|U_k^r\right|_{H\times|C|} = \begin{bmatrix} u_{1,1}^{r,k}, \cdots, u_{1,|C|}^{r,k} \\ u_{2,1}^{r,k}, \cdots, u_{2,|C|}^{r,k} \\ \vdots \\ u_{H,1}^{r,k}, \cdots, u_{H,|C|}^{r,k} \end{bmatrix} \tag{4}$$

$$\left|S_k^r\right|_{1\times|C|} = \prod_{l_{p\in p_k}}^{I=1} \left|U_k^r\right|_{H\times|C|} = \left[\mu_1^r, \cdots, \mu_{|C|}^r\right] \tag{5}$$

$$n_{b,e}^k = e - b + 1 \tag{6}$$

$$v_{b,e}^k = n_{b,e}^k \cdot \sigma_k \tag{7}$$

$$T_{b,e}^{k} = \left[V_r - v_{b,e}^{k}\right]_r^2 \cdot \sigma_k \tag{8}$$

Through comprehensive analysis of the above formula, we can obtain the spectrum occupancy results of each path (Liu et al., 2016; Ma et al., 2016), where $\left|S_k^r\right|_{1\times|C|}$ represents the occupancy of spectrum resources in the network.

The following formula is used to calculate the reduction rate of downgrading services in the adjacent area (Niu and Chen, 2016; Yang and Chen, 2016):

$$X_{r'} = V_{r'} \cdot \sigma_r \tag{9}$$

The following is the calculation formula of the number of free spectrum slots in different intervals, as shown in formula (10):

$$T_{b,e}^{l} = \min\left\{T_{b,e}^{l,1}, T_{b,e}^{l,2}, \cdots, T_{b,e}^{l,h}\right\}, \quad \forall B_{b,e}^{k} \in p_k, \forall p_k \tag{10}$$

$$T_{b,e}^{r} = \min\left\{T_{b,e}^{r,1}, T_{b,e}^{r,2}, \cdots, T_{b,e}^{r,h}\right\}, \quad \forall B_{b,e}^{k} \in p_k, \forall p_k \tag{11}$$

Combined with blockchain technology, a mixed integer linear model of network dynamic routing and spectrum allocation problem is established to minimise spectrum consumption and frequency (Li and Gao, 2017; Cui and Liu, 2016).

$$\Upsilon = \left\{B_{b,e}^{k} \left| T_{b,e}^{l,} > T_{b,e}^{k} \right|\right\}\left\{T_{b,e}^{k} \left| T_{b,e}^{l,} \geq T_{b,e}^{k} \right|\right\} \tag{12}$$

In the whole network, for the dynamic routing and spectrum allocation of multicast services, it is mainly the connection path established for each source node to any destination node in the multicast group, until all nodes in the multicast group realise the connection with the source node.

3 Dynamic routing and spectrum allocation algorithm based on blockchain technology

In the process of network dynamic routing and spectrum allocation, there is a large amount of data, and the network chain is unbalanced, so blockchain technology is chosen as the allocation basis. The link with the largest load is selected to optimise the spectrum allocation, in order to achieve the balanced state of the whole network link. It is characterised by decentralisation, openness and transparency, so that everyone can participate in the establishment of the database. The blockchain records all the transaction information of the whole network through the use of distribution, and the network spectrum data is jointly maintained by each node. Each participating maintenance node can copy and obtain a copy of the complete integer database. At the same time, it realises the traceability and non deletion of spectrum information, and realises trust sharing.

Based on the mixed integer linear model, to complete the service request, it needs to optimise the allocation target (Du et al., 2016; Zhou et al., 2016), in which the maximum index value of the whole link is Minimise *F*.

The maximum FS index value needs to be higher than the FS index value occupied by any request, that is:

$$F \geq f_i + b_f + F_G - 1 \tag{13}$$

Any anycast request can only be obtained from one data centre service, then there are

$$\sum_{p \in p_i^{(k)}} d_v^i = 1 \tag{14}$$

Each request can only select one path for service, and use the node data centre (Ren et al., 2016; Teng et al., 2016) corresponding to the path to provide corresponding computing services, namely:

$$\sum_{p \in p_i^{(k)}} x_p^i = d_v^i \tag{15}$$

In order to effectively compress the solution space and set the constraint relationship between different parameters, the following details are given:

$$\delta_{i,j} + \delta_{j,i} = 1 \tag{16}$$

$$f_i - f_j \leq F_{\max} \cdot \delta_{i,j} \tag{17}$$

$$f_i - f_j \leq F_{\max} \cdot \delta_{j,i} \tag{18}$$

The spectrum cannot overlap. When there is a common link between two transmission paths (Li et al., 2017; Zhang and Nie, 2016), the spectrum in the two transmission paths cannot be repeated, that is:

$$f_i + b_i + F_G - f_j \leq F_{\max} \cdot \left[\left(1 - \delta_{i,j}\right) + \left(2 - x_p^i - x_p^j\right) + \left(1 - y_{p,p}\right) \right] \tag{19}$$

$$f_j + b_j + F_G - f_j \leq F_{\max} \cdot \left[\left(1 - \delta_{j,t}\right) + \left(2 - x_p^i - x_p^j\right) + \left(1 - y_{p,p}\right) \right] \tag{20}$$

In order to meet the constraints of spectrum non overlapping and continuity, the calculation process needs to be simplified, then

$$f_i + b_i + F_G \leq f_j, \quad i \neq j \tag{21}$$

$$f_j + b_j + F_G \leq f_j + F_{\max}, \quad i \neq j \tag{22}$$

The operation process of the whole algorithm is very simple, but it will lead to uneven distribution of bandwidth resources, and this strategy needs to rely on the shortest path routing (He et al., 2019; Liang et al., 2017).

Let G_v represents all available computing resources $\left(v \in V_{DC}\right)$ connected to the data centre of destination node *v*, and give different measurement expressions as follows:

$$m_1\left(p_{s,v}^{(k)}\right) = \frac{BW\left(p_{s,v}^{(k)}\right) * \sqrt{C_v}}{\sqrt{hspa\left(p_{s,v}^{(k)}\right)}} \tag{23}$$

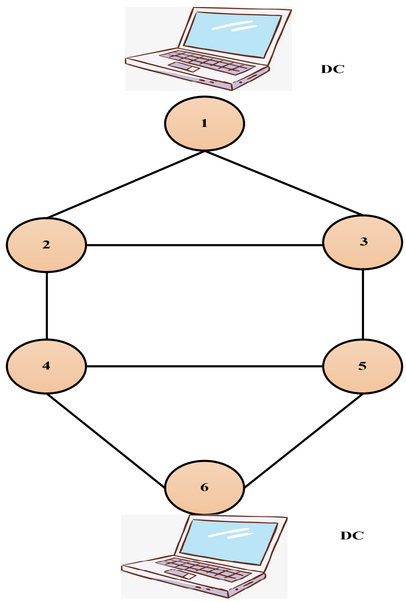
$$m_2\left(p_{s,v}^{(k)}\right) = \frac{BW\left(p_{s,v}^{(k)}\right) * C_v}{hspa\left(p_{s,v}^{(k)}\right)} \tag{24}$$

$$m_3\left(p_{s,v}^{(k)}\right)=BW\left(p_{s,v}^{(k)}\right)*C_v \tag{25}$$

$$m_4\left(p_{s,v}^{(k)}\right)=BW\left(p_{s,v}^{(k)}\right)*\sqrt{C_v} \tag{26}$$

In a six point topology network as shown in Figure 1, there are two data centre nodes in the network (Ou, 2017; Li et al., 2016). For any anycast request $R(s_i,b_i,c_i)$, it is necessary to select the corresponding equation to calculate the network resources.

Figure 1 Network topology of blockchain nodes (see online version for colours)



In dynamic network service, $BW\left(p_{s,v}^{(k)}\right)$ is needed to represent the bandwidth resources that can be used on the path $p_{s,v}^{(k)}$, where the unit is FS; based on the above analysis, $hspa\left(p_{s,v}^{(k)}\right)$ is used to represent the hops on the path $p_{s,v}^{(k)}$. The following needs to select the corresponding data centre for different requests, set it as the destination node, allocate resources according to the relevant requirements, and conduct RSA for different requests $\mathrm{R}(s,b,c)$, that is to find the path route to build the corresponding optical path, and distribute the corresponding spectrum resources on each optical path.

For any request, it is necessary to ensure that the allocated bandwidth on each path does not exceed the maximum bandwidth on this path, that is:

$$b_{u,v}^{(k)} \geq g \tag{27}$$

The following needs to ensure that each data centre does not allocate more computing resources than it has, namely:

$$c_v \leq C_v \tag{28}$$

The linear relationship between bandwidth resources and computing resources is given by formula (29), that is:

$$c = \sum_{v \in V_{DC}} c_v \tag{29}$$

In the process of running the whole network, each request will leave after the service arrives for a period of time. Among them, multicast request contains two very important parameters, which are service arrival time and service duration (Fu et al., 2016; Hu, 2018).

In the dynamic service request, the bandwidth blocking rate needs to be minimised

$$\text{Minimise } p_b = \lim_{i=1\ T \to \infty} N_b(T) * (N(T))^{-1} \tag{30}$$

In the actual process, it needs to select a data centre, set it as the destination node, and select a path to reach the data centre, and finally achieve spectrum allocation. On the basis of the above analysis, the static heuristic algorithm is extended, and the mixed integer linear model is solved by using the static heuristic algorithm, considering the computing resources and bandwidth resources, so as to achieve the purpose of dynamic network routing and spectrum allocation. The specific steps are as follows:

1 The network resources are initialised, and the network topology $G(V, E)$ is given.

2 The arrival of the service request $R(s, d, b, t_a, t_l)$ is to wait for. If it is a service connection request, go to step 3; if it is a service release request, go to step 9.

3 The number of free frequency slots is taken as the link cost, and the shortest path of source and destination nodes is calculated by static heuristic algorithm.

4 Through spectrum consistency, the continuously available frequency gap in the accessory path is screened out, and that the path that the continuously available frequency gap is larger than the service bandwidth is found. The link pair of p and its adjacent links are generated, and the total number of adjacent links in the path are calculated.

5 In the alternative path set F, the path with the least cost is selected to allocate services. If there are more than one identical minimum F_{cmht}, the path with the shortest hop number is selected;

6 Trying to use multi-path to establish service connection: the path whose continuous available frequency gap is larger than the bandwidth granularity limit g is selected, and whether the path set meets the conditions of differential delay is judged.

7 The state of the frequency gap occupied by the link where the path is located is updated, to complete the dynamic routing and spectrum allocation of the network.

To sum up, to complete the service request based on the mixed integer linear model, it is necessary to optimise the target to be allocated, select the link with the largest load to optimise the spectrum allocation, and update the frequency gap state of the frequency gap occupied by the link where the path is located, so as to complete the network dynamic routing and spectrum allocation.

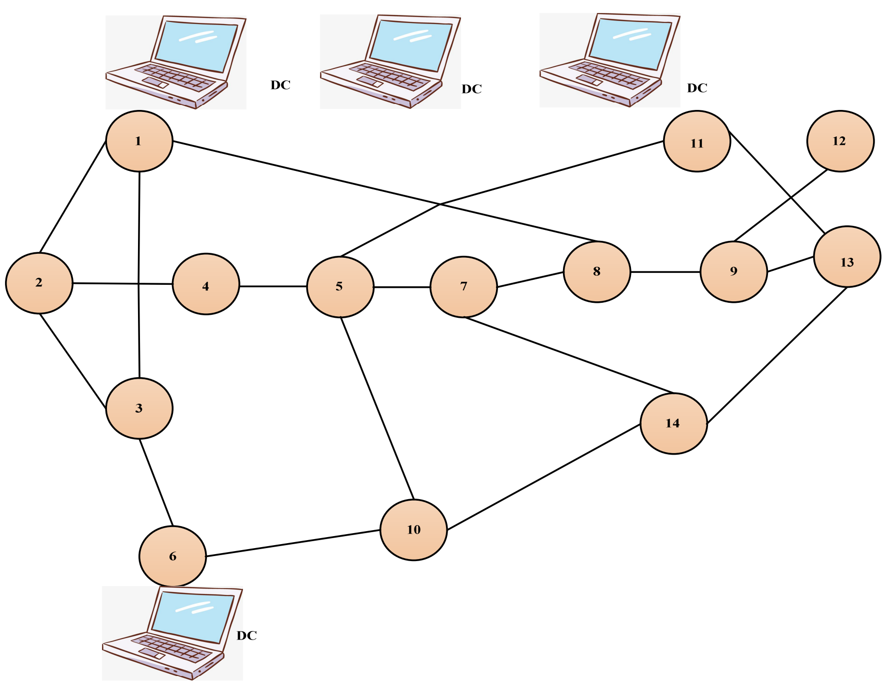
4 Simulation experiment

4.1 Experimental scheme

In order to verify the comprehensive effectiveness of the network dynamic routing and spectrum allocation algorithm based on blockchain technology, simulation experiments are needed. The experimental environment is: 2.0GHz Dell PC, slZMB memory, 80G hard disk and Windows XP operating system. All algorithms are implemented in C language. It is assumed that the number of secondary users in the PTI PRI communication route is ni. The allocation scheme of each time slot is as follows: the primary user sends the communication data to the first hop relay node in the first stage, and the time slot length in the first stage is Tni+1; the secondary user transmits the data of the primary user and the data of the secondary user in the second stage, and the time slot length in the second stage is niTni+1. It is set that the channel state among users is an independent Gaussian random variable. In each communication slot, the channel state does not change, but changes between slots. It is assumed that the transmitting power of the primary transmitter PTi transmitting data in the way of direct transmission is PSiDi, that is, the power of the user PTi-PRi transmitting data is PSiDi.

The network consists of 14 nodes and 21 links. Each fibre supports a link frequency gap capacity of 400, and the bandwidth of each spectrum slot is 12.5 GHz. The bandwidth requirements of the service are randomly distributed between one frequency gap and 10 frequency gaps. Figure 2 is used to show the specific usage of the two data centre resources of the topology:

Figure 2 Specific usage of two data centre resources in the topology (see online version for colours)



4.2 Research of performance index

- *Spectrum utilisation* (%): Refers to the ratio of the frequency gap used by the service to the total frequency gap. The spectrum utilisation is represented by S_u, which is defined as:

$$S_u = \frac{\sum_{e \epsilon E} \sum_{i=0}^{N_s} S(e)(i)}{N_v * N_s} \tag{31}$$

Where $S(e)(i)$ indicates the utilisation of the *i*th frequency slot on link *e*, and $S(e)(i)=1$ indicates that the frequency slot *i* is utilised, otherwise, it indicates that the frequency slot *i* is idle. The more the frequency gap is used, the larger the value of $\sum_{e \epsilon E} \sum_{i=0}^{N_s} S(e)(i)$ is, so the higher the spectrum utilisation is, the better the algorithm performance is.

- *Bandwidth blocking rate*/(%): Refers to under the dynamic traffic load, the ratio of the number of rejected service connection requests to the total number of service requests, namely:

$$BP = |S_b| / (|S| + |S_b|) \tag{32}$$

Where S is the set of business requests for successful connection establishment, S_b is the set of rejected business requests, $|S|$ is the number of business requests for successful connection establishment, and $|S_b|$ is the total number of rejected business requests. When the network reaches a dynamic stable state, the smaller the blocking rate is, the more traffic is successfully connected, the better the performance of the algorithm is.

- *Spectrum allocation delay*/(min): When allocating the frequency gap, it needs to try to select the frequency gap with a small difference between the duration of new services and the remaining duration of adjacent services, that is to say, the less of the allocation delay, the better. The allocation delay is determined by the duration of the services to be allocated on the spectrum fragment and the remaining duration of the services on both sides.

$$T_{\text{fragment}} = \sum_{e \in p} |t_{lA} - t_l| + |t_{lB} - t_l| \tag{33}$$

t_{lA}, t_{lB} and t_l represent the time when the business leaves.

4.3 Analysis of experimental results

(1) Spectrum utilisation (%):

The utilisation rate of network resources is taken as an important index to evaluate the performance of the algorithm. The higher the utilisation rate of network resources is, the better the performance of the algorithm is. In the experiment, three different dynamic network routing and spectrum allocation algorithms are selected as comparison methods for simulation test. The specific comparison results are shown in Table 1.

Table 1 Spectrum utilisation change

Business load/ (Erlang)	*Utilisation rate of network resources* (%)			
	The proposed algorithm	*The algorithm in Yu et al. (2019)*	*The algorithm in Wang et al. (2019)*	*The algorithm in Lu et al. (2018)*
120	98.12	94.23	89.85	89.58
140	97.36	92.74	92.74	87.74
160	96.85	91.84	95.55	85.84
180	95.44	90.88	87.84	84.80
200	93.74	89.74	86.25	83.74
220	92.85	92.80	90.14	82.89
240	90.95	91.14	84.84	80.96
260	98.74	88.96	86.87	85.58
280	96.51	90.82	89.69	83.96
300	95.85	89.74	93.14	80.74
320	94.84	92.22	88.52	82.47
340	97.87	87.14	89.50	84..55
360	95.95	93.44	93.85	86.74
380	96.88	92.56	90.74	84.52
400	99.66	91.74	87.69	81.85

Analysis of the experimental data in Table 1 shows that when the traffic load continues to increase, the spectrum utilisation ratio of various network dynamic routing and spectrum allocation algorithms is also constantly changing. Among the four network dynamic routing and spectrum allocation algorithms, the spectrum utilisation ratio of the proposed algorithm is the highest, up to 99.66%. The main reason lies in the blockchain technology of the proposed algorithm, which updates the frequency gap state of the frequency gap occupied by the link where the path is located, and completes the dynamic network routing and spectrum allocation.

(2) Bandwidth blocking rate/(%):

In the following experiments, the bandwidth blocking rate is selected as the evaluation index for research, and the bandwidth blocking rate of four kinds of network dynamic routing and spectrum allocation algorithms are compared in detail as follows:

Analysis of the experimental data in Figure 3 shows that the bandwidth blocking rate of the proposed algorithm is the lowest among the four algorithms, no more than 2%. The bandwidth blocking rate of the algorithm in Niu and Chen (2016) is the highest among the four methods. The main reason is that the proposed algorithm analyses the occupancy of different link spectrum slots based on the blockchain technology, and builds a mixed integer linear model, to complete the service request based on the mixed integer linear model. It is necessary to optimise the target to be allocated, select the link with the largest load to optimise the spectrum allocation, and reduce the bandwidth blocking rate.

Figure 3 Comparison results of bandwidth blocking rate

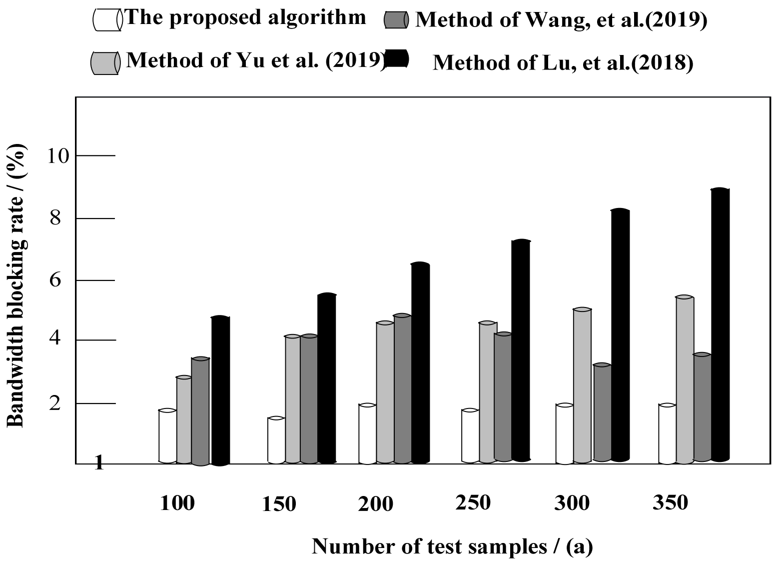


Table 2 Comparison results of spectrum allocation delay

Business load/ (Erlang)	*Spectrum distribution delay/*(min)			
	The proposed algorithm	*The algorithm in Yu et al. (2019)*	*The algorithm in Wang et al. (2019)*	*The algorithm in Lu et al. (2018)*
120	0.301	0.321	0.287	1.021
140	0.272	0.358	0.344	1.142
160	0.257	0.385	0.471	1.207
180	0.224	0.413	0.568	1.352
200	0.188	0.446	0.685	1.438
220	0.159	0.479	0.766	1.584
240	0.144	0.507	0.892	1.705
260	0.121	0.534	0.964	1.852
280	0.100	0.565	1.028	1.967
300	0.087	0.592	1.062	2.108
320	0.071	0.631	1.141	2.249
340	0.064	0.658	1.200	2.361
360	0.040	0.685	1.288	2.498
380	0.002	0.717	1.349	2.582
400	0.021	0.754	1.407	2.660
420	0.00	0.789	1.567	2.702
440	0.002	0.824	1.684	2.842
460	0.021	0.861	1.741	2.963

(3) Spectrum allocation delay/(min):

In order to further verify the effectiveness of the proposed algorithm, the spectrum allocation delay of the four algorithms are compared as follows, and the specific comparison results are shown in Table 2.

Analysis of the above experimental data shows that the spectrum allocation delay of the proposed algorithm has a significant downward trend compared with the other three methods, which fully shows the advantages of the proposed method. The main reason is that the proposed method is based on the blockchain technology to analyse the occupancy of different link spectrum slots, optimise the target to be allocated, and update the frequency slot state of the link where the path is located, so as to complete the dynamic network routing and spectrum allocation, ensuring the spectrum utilisation and bandwidth blocking rate, and then reducing the allocation delay.

5 Conclusions

This paper proposes a dynamic routing and spectrum allocation algorithm based on blockchain technology. Based on the block chain technology, the occupancy of spectrum slots in different links is analysed, a mixed integer linear model is established, and the service request is completed based on the mixed integer linear model. It is necessary to optimise the target to be allocated, select the link with the largest load for spectrum allocation optimisation, and update the frequency slot status of the link occupied by the path with the combination of linear model and extended static heuristic algorithm, in order to achieve the purpose of network dynamic routing and spectrum allocation, complete the network dynamic routing and spectrum allocation. The related research results show that the proposed algorithm can effectively improve the network resource utilisation rate to 99.66%, and reduce the bandwidth blocking rate, and effectively reduce the spectrum allocation delay to 0. In the future stage, the proposed algorithm will focus on the following aspects: the network request model of the data centre studied in this paper is linear. In the process of practical application, it may be in a variety of requests, but the actual network contains a variety of different resources. In the future stage, the research will focus on these resource fragments.

References

Cui, Y.F. and Liu, W. (2016) 'Grid network loop routing conflict shunt control algorithm', *Control Engineering*, Vol. 23, No. 10, pp.1523–1526.

Du, H.T., Li, Q., Ding, G.T., Wang, Y.G. and Zhu, L.J. (2016) 'Research on AODV routing algorithm based on link quality and node energy in WSN', *Journal of Transduction Technology*, Vol. 29, No. 7, pp.1042–1048.

Fu, C.M., Li, Y.M., Zhou, G.L., Yu, M.C., Tong, J.W. and Wang, X.P. (2016) 'A cooperative spectrum sensing algorithm based on energy detection', *Telecommunications Science*, Vol. 32, No. 9, pp.52–60.

He, R.X., Lei, T.Y. and Lin, Z.W. (2019) 'Multi-constrained energy-saving routing algorithm for software-defined data center networks', *Computer Research and Development*, Vol. 56, No. 6, pp.1219–1230.

Hu, C.L. (2018) 'Simulation of load balancing method for distributed internet network resources', *Computer Simulation*, Vol. 7, pp.241–244.

Li, X.C. and Gao, B.S. (2017) 'A WSN routing algorithm based on optimal cluster number and improved gravitational search', *Computer Applications*, Vol. 37, No. 12, pp.3374–3380.

Li, Y.B., Guo, Z.H. and Xu, L.X. (2016) 'Joint resource allocation scheme for D2D communication based on interference control in cellular networks', *Firepower and Command Control*, Vol. 41, No. 1, pp.169–173.

Li, Z.N., Li, J.J., Wang, A.X. and Zhang, R.S. (2017) 'A novel top-chip network topology and its adaptive routing algorithm', *Journal of Northeastern University: Natural Science Edition*, Vol. 38, No. 9, pp.1217–1221.

Liang, J., Zhang, Z.H., Xiao, N., Liu, Y.L., Hu, M. and Zhuo, K. (2017) 'Opportunistic routing optimization algorithm for wireless mesh networks supporting QoS', *Journal of National University of Defense Technology*, Vol. 39, No. 6, pp.143–151.

Liu, J.F., Yang, J., Wang, J.X. and Hu, J. (2016) 'Spectrum allocation algorithm based on auction theory and Gaussian process regression learning', *Computer Engineering and Science*, Vol. 38, No. 5, pp.914–920.

Liu, J.X. and Jia, Z.H. (2016) 'A DABC cognitive radio spectrum allocation algorithm based on fitness prediction', *Computer Engineering and Applications*, Vol. 52, No. 18, pp.111–116.

Liu, S., Li, Z.W., Wu, Z.H., Wang, B. and Yang, Y.J. (2016) 'Routing algorithms for wireless sensor networks based on energy gradient', *Journal of Transduction Technology*, Vol. 29, No. 8, pp.1247–1252.

Lu, W.Q., Zhang, C.L., Tian, Y.H., Hu, J.X. and Qin, J.X. (2018) 'Spectrum allocation algorithm of cognitive radio based on game theory', *Electronic Measurement Technology*, Vol. 12, pp.58–63.

Ma, B., Bao, X.M. and Xie, X.Z. (2016) 'A review of spectrum switching algorithms in cognitive wireless networks', *Acta Electronica Sinica*, Vol. 44, No. 6, pp.1496–1503.

Niu, Y.G. and Chen, W.G. (2016) 'A grid-based WSN routing algorithm considering both congestion avoidance and energy balance', *Control and Decision*, Vol. 31, No. 11, pp.1985–1990.

Ou, Y.J. (2017) 'Research on physical layer secure transmission algorithms for green cognitive radio networks', *Journal of Nanjing University of Posts and Telecommunications: Natural Science Edition*, Vol. 37, No. 6, pp.29–35.

Ren, Z., Tan, Y.Y., Suo, J.W. and Li, X.F. (2016) 'An opportunistic network routing algorithm based on observation', *Application Research of Computers*, Vol. 33, No. 11, pp.3396–3400.

Sun, P.R., Wang, K.R. and Feng, H. (2016) 'Application of improved particle swarm optimization in spectrum power allocation', *Telecommunications Technology*, Vol. 56, No. 7, pp.788–793.

Teng, Z.J., Zhang, M.R. and Zhang, L. (2016) 'Energy-aware Zigbee network tree routing optimization algorithm from a cognitive perspective', *Journal of Harbin Institute of Technology*, Vol. 48, No. 11, pp.109–115.

Wang, D.W. and Zhu, F.F. (2016) 'Improved binary particle swarm algorithm and its application in spectrum allocation', *Computer Engineering and Applications*, Vol. 52, No. 21, pp.111–115.

Wang, P.H., Zhang, N. and Xiao, M.Mg. (2019) 'Routing and spectrum allocation algorithm based on node importance', *Computer Engineering and Application*, Vol. 55, No. 13, pp.106–111.

Yang, Y.Q. and Chen, Z.G. (2016) 'Resource saving minimum channel conflict value multicast routing algorithm in cognitive wireless mesh networks', *Journal of National University of Defense Technology*, Vol. 38, No. 4, pp.76–84.

Yu, C.Q., Zhang, L. and He, R.X. (2019) 'Dynamic routing and spectrum allocation algorithm based on differentiated degradation service and adaptive modulation in elastic optical networks', *Journal of Electronics and Information*, Vol. 41, No. 01, pp.38–45.

Zhang, L. and Nie, S.H. (2016) 'Mobile adhoc network routing algorithm based on particle filter walking length prediction', *Telecommunications Technology*, Vol. 56, No. 3, pp.331–336.

Zhou, C.R., Xu, X.Q., Ma, X.X. and Yang, L. (2016) 'Social selfishness routing algorithm in tolerant network', *Journal of University of Electronic Science and Technology of China*, Vol. 45, No. 3, pp.405–410.