Evaluation and Optimization of Resource Allocation among Multiple Networks

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Abstract

Many telecommunication operators around the world have multiple networks. The networks run by each operator are always of different generations, such as 2G and 3G or even 4G systems. Each system has unique characters and specified requirements for optimal operation. It brings about resource allocation problem among these networks for the operator, because the budget of each operator is limited. However, the evaluation of resource allocation among various networks under each operator is missing for long, not to mention resource allocation optimization. The operators are dying for an algorithm to end their blind resource allocation, and the Resource Allocation Optimization Algorithm for Multi-network Operator (RAOAMO) proposed in this paper is what the operators want. RAOAMO evaluates and optimizes resource allocation in the view of overall cost for each operator. It outputs a resource distribution target and corresponding optimization suggestion. Evaluation results show that RAOAMO helps operator save overall cost in various cases.

Keywords: Resource allocation, multiple networks, cost evaluation

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1. Introduction

It has been several decades since the telecommunication age started. The very first generation telecommunication system, such like TACS, has been abandoned since the second generation system (2G system) represented by GSM came out. Telecommunication industry has been through many outbreak periods of new techniques. New generation telecommunications arrive so quickly that older systems are still in use. We have both 2G and 3G systems in service, and 4G system is being implemented and starts to serve as currently the most advanced telecommunication system in more and more countries. Wi-Fi, as another optional choice, is considered recently by some operators. Besides, 5G system has been a new topic in international standard study. New generations and novel techniques are regarded as the most advantage in competition among operators, and each operator peruses new generation networks. As the situation becomes a phenomenon, the problem of operating multiple networks turns out to be one of the problems that operators must solve.

Unfortunately, few studies have focused on this topic. Traditional network optimizations aim at maintaining best performance within a single network [1] - [10]. Represented by MIMO and OFDMA, many optimization schemes aiming at 4G system are brought about lately [1] - [4]. Load balancing and mobility optimization within single system are also well studied [5] - [7]. Optimization studies dedicated for TD-CDMA, CDMA, WiMAX and other existing systems have reached great height of skill [8] - [10]. For interoperation between two networks studied in our industry, smooth handover performance and such topics are concerned most, but the co-operation of more than two networks by one operator is left untouched [11] - [12].

The Resource Allocation Optimization Algorithm for Multi-network Operator (RAOAMO) is proposed in this paper to evaluate current resource allocation among different networks as well as providing optimization advices for operators. RAOAMO takes the overall cost for all the networks as an evaluation reference in optimizing resource allocation. Network capacity, terminal features, user habits, service types and network coverage etc. are involved in RAOAMO's evaluation. A performance evaluation model is proposed in RAOAMO to form a complete evaluation of all relevant effecting elements.

The rest of this paper is organized as follows. Sector 2 introduces the system model of RAOAMO. Sector 3 contains the compared algorithm as well as the evaluation parameter settings for different case studies. Evaluation results and performance analysis could be found in Sector 4. In Sector 5, the conclusion is drawn.

2. Resource Allocation Optimization Algorithm for Multi-network Operator (RAOAMO)

2.1 System Model

RAOAMO puts overall cost in the first place when evaluating resource allocation among multiple networks. For an operator, minimizing the overall cost is the very concern. Thus, overall cost minimization becomes the primary goal in RAOAMO, and the performance evaluation model for RAOAMO could be formed as follows.

Object:

$$\min\left(\sum_{m}\sum_{\omega} C_{\omega} \cdot g_{\omega m} \cdot x_{\omega}^{m}\right) \tag{1}$$

S.T.

$$\sum_{\omega} x_{\omega}^{m} = \sum_{\omega}\sum_{\sigma} \mu_{\sigma}^{m\omega} T_{\sigma}^{\omega} \tag{2}$$

$$\sum_{m} x_{\omega}^{m} \le E_{\omega} \tag{3}$$

$$x_{\omega}^{m} = 0 | v_{m} > V_{\omega} \tag{4}$$

Where, m stands for the m th type of services, ω is the ω th type of networks, σ represents σ th type of user terminals which could be cell phones or dongles, γ is the number of the types of user terminals, C_{ω} depicts capacity of ω th type of networks, $g_{\omega m}$ is defined as the radio resource used by ω th type of networks for m th type of services, x_{ω}^{m} refers to traffic volume of the m th kind of service in ω th type of networks, T_{σ}^{ω} denotes traffic generated by σ th type of user terminals served by ω th type of networks, $\mu_{\sigma}^{m\omega}$ is used as the ratio of traffic of the m th kind of service to the traffic generated by the σ th terminal type in the ω th network, network capacity is depicted by E_{ω}, v_{m} is the expected bandwidth of the m th kind of service, and V_{ω} stands for the maximum bandwidth that ω th type of network provides.

The object is to minimize the overall cost among all the networks. The cost per bit and the traffic in bit are multiplied in each network, and the sum of cost for each network is expressed as the overall cost in Eq. (1). The boundary limits for Eq. (1) are illustrated in Eq. (2) to Eq. (4).

The limit condition in Eq. (2) is that all the traffic distributed among different networks via diverse terminals should be equal with the original traffic amount. So that the total traffic amount in the optimization is balanced. The boundary condition in Eq. (3) represents the capacity limit of each network to the traffic that a network carries. The optimized distributed traffic on one network should not be more than the capacity of the corresponding network. For Eq. (4), the service requirement is considered in expected bandwidth for each service. Only the network that could satisfy the expected bandwidth of one serve can carry the corresponding service.

To be noted that traffic of each type of terminals compose the parameter x_{ω}^{m}, so we could also express x_{ω}^{m} as

$$x_{\omega}^{m} = \sum_{\beta=1}^{\gamma} x_{\omega\sigma(\beta)}^{m} \Big|_{\omega\in\sigma(\beta)} \tag{5}$$

RAOAMO performance evaluation model above depicts the possible components of overall cost:

There are different kinds of user terminals which could be provided with various services running on different networks. One service could be generated by different kinds of terminals which are served by different networks. The radio resources required for the same service in different network would vary, and the costs for each network providing the same service are different. The traffic on one network is composed of the traffic with all kinds of services generated by different kinds of terminals, and the total traffic on one network could not exceed the capacity limit. Additionally, the traffic ratio borne on one network is restricted by the network coverage in the area. For different networks, services requiring a transmitting rate higher than one network could provide are not possible to be borne. For example, a video phone service is never borne by 2G systems. User habits, as another limit in the evaluation, affect the volume of traffic carried by one network. The manual switch between Wi-Fi and 2G/3G/4G on a cellphone is a good example to explain the importance of user habits.

2.2 Calculation for RAOAMO

Calculation is adopted to solve the optimization problem descripted by (1) to (4). The flow chart of the calculation is shown in **Fig. 1**.

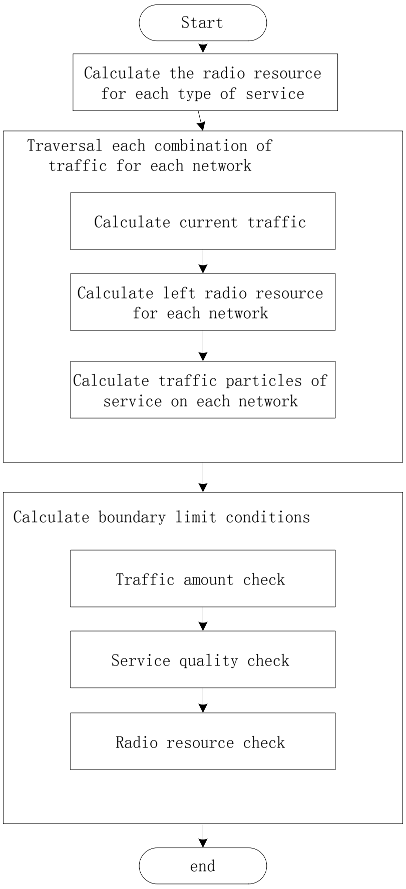

Fig. 1. The flow chart of RAOAMO

According to **Fig. 1**, the calculation follows the following steps:

(1) calculate the radio resource for each type of service

This step calculate the radio resource need for each service. For instant, the radio resource amount required by down loading in GSM, TD-SCDMA, etc. Referring to each type of network, the required radio resource for each service varies.

(2) traversal each combination of traffic for each network

This step needs to calculate each possible traffic distribution and compare the results to find the optimized result.

For each traffic distribution, current traffic, left radio resource for each network and traffic particles used for each service on every network are calculated. These results are saved to find the best fit traffic distribution.

(3) calculate boundary limit conditions

This step is set for boundary limit condition check. According to (2) to (5), the optimization should satisfy all these boundary conditions so that the optimized result makes sense.

In this step, total traffic amount, service quality for each service, and radio resource used in each network are checked by sequence for the optimized result.

3. Compared Algorithm and the Evaluation Parameter Settings

3.1 Compared Algorithm

Load balancing has been widely accepted as one of the main considerations when allocating resource among networks. Current studies concern about the balance between two networks and few thesis mentions the balance among more than two networks [5] [11] - [12].

The Load Balancing Algorithm (LBA), whose primary optimization goal is to maintain each network similar load, is adopted in this paper for the ease of evaluating RAOAMO. The flow chart of LBA is represented in **Fig. 2**.

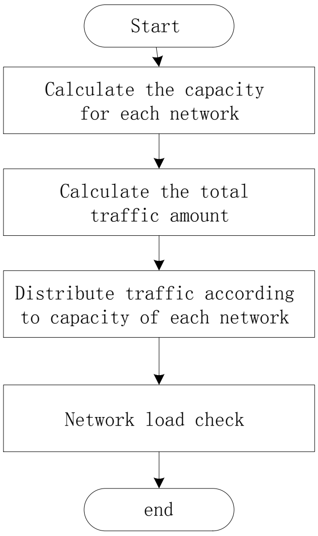

Fig. 2. The flow chart of LBA

Referring to **Fig. 2**, LBA first calculates capacity for each network and the total traffic amount. Then, LBA divides the traffic according to the capacity of each network. The traffic distributed to each network should keep the network load of each network even. After the traffic distribution, LBA double checks the network load for each network.

3.2 Evaluation Parameter Settings

Operators around the world are exploring different situations when running multiple networks. To better illustrate the discrepancy among operators, three case studies are represented.

Case Study I is set for the most advanced operators who already own a well-developed 4G system as well as a mature user community.

Case Study II is for the developing operators who newly start an advanced network (4G system is used as an example) while aiming at enhancing the network coverage and wining more users.

Case Study III is designed to simulate the less developed operators who have no 4G system but operate well developed 2G and 3G systems.

Additionally, Wi-Fi is considered in all three cases.

The parameter setting of each case study contains parameters of networks and traffic, parameters of service types and terminals, and user habits. Parameter settings for different case studies are listed in **Table 1** to **Table 9**.

4. Evaluation Results and Performance Analysis

MATLAB is used in the evaluation for the ease of matrix calculation. The optimization results and network load of LBA and RAOAMO are adopted to evaluate the proposed algorithm performance.

The optimization results of both algorithms are evaluated. Then network load for each algorithm is illustrated, for the ease of comparison with LBA. The overall cost for all networks and the cost for individual network are depicted to analyze the performance of RAOAMO against LBA.

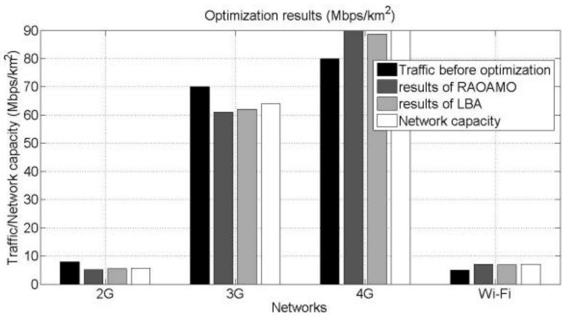

Fig. 3. The optimization results of case study I

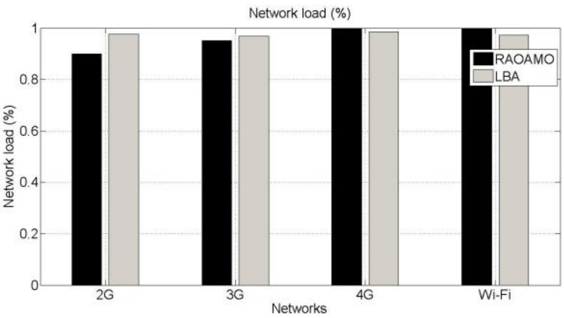

Fig. 4. The network load of case study I

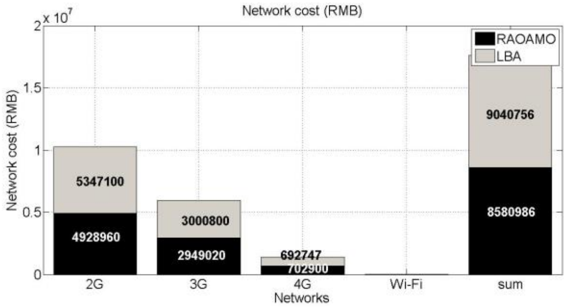

Fig. 5. The cost evaluation of case study I

For case study I, the developed operator's 4G network has good performance with high capacity per km2. At the same time, the user community of the developed operator is mature, and the expected user data services compose of tremendous data traffic per km2. Old systems such as 2G and 3G systems operated by the operator could not afford that much traffic. Since the operator also have 4G system and a Wi-Fi network, and both networks have capability to carry more traffic, the traffic migration to these two networks would be a must. The problem is that how much traffic from 2G and 3G systems would migrate to 4G system and Wi-Fi network, respectively.

LBA solves this problem by maintaining similar traffic load for each network so that all the networks are homogeneous in network load. We could not conclude that LBA's strategy is wrong, because the existing networks would be fully used. However, back to the problem of deciding how well each network would be used when facing so many networks with so much traffic, the solutions would consider the overall cost at the first place as RAOAMO does.

According to **Fig. 3** and **Fig. 4,** traffic migration is a must for case study I. Network load for each network is high, no matter taking RAOAMO or LBA. The load of each network in RAOAMO varies greater than that in LBA in **Fig. 4**. However, RAOAMO wins a lower overall cost against LBA, based on **Fig. 5**. For the aspect of overall cost, RAOAMO saves almost 460 thousand RMB from LBA, saving 5% cost for the operator. By using RAOAMO, current resource allocation is evaluated, and the result of RAOAMO could be considered as solution for operators.

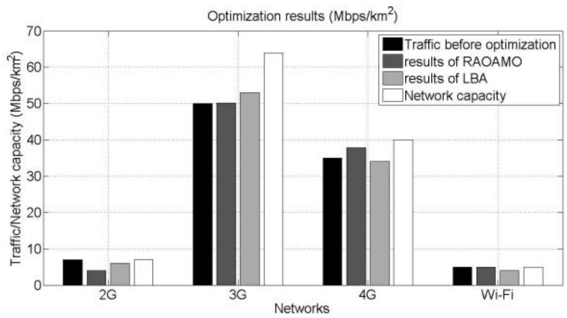

Fig. 6. The optimization results of case study II

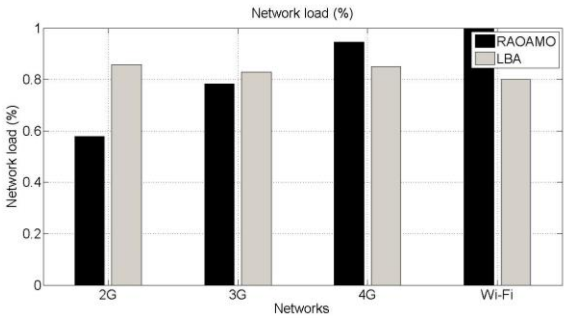

Fig. 7. The network load of case study II

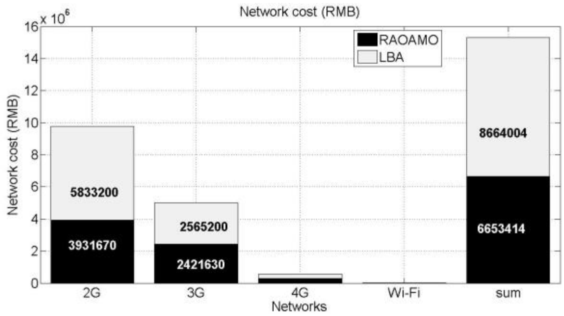

Fig. 8. The cost evaluation of case study II

In case study II, the developing operator does have a 4G system, but more investment is required if the operator wants more 4G system capacity per km2. Meanwhile, the total traffic in this case study is less than that in case study I, and much of the traffic is expected to be in 2G and 3G networks. The components of user terminal types in this case differ from those in case study I, being less "developed" according to Table V and Table VI.

According to **Fig. 6** and **Fig. 7**, both RAOAMO and LBA realize the function of "allocation", but RAOAMO results in a less balanced network load among the four networks in **Fig. 7**. **Fig. 8** depicts the overall cost comparison. RAOAMO saves almost 2011 thousand RMB from LBA, saving 23.2% cost for the operator.

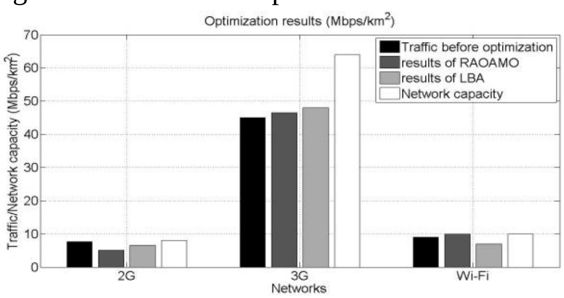

Fig. 9. The optimization results of case study III

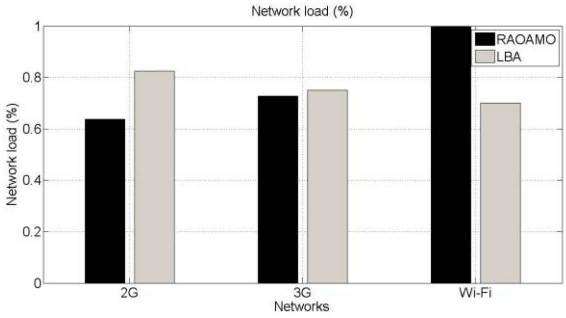

Fig. 10. The network load of case study III

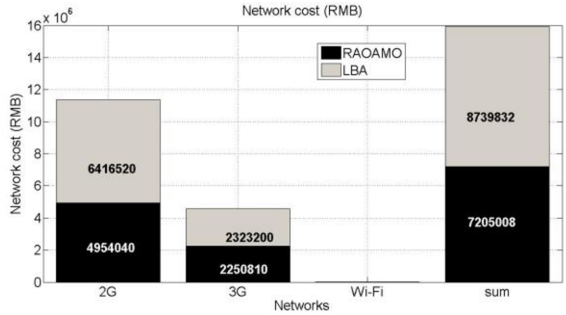

Fig. 11. The cost evaluation of case study III

Case study III is set for the less developed operators, with lower traffic amount and more undeveloped user terminals. In addition, this kind of operators would not have the most advanced techniques.

According to **Fig. 9** and **Fig. 10**, the results of RAOAMO and LBA are similar with those in case study II. Based on **Fig. 11**, RAOAMO saves almost 1535 thousand RMB from LBA, saving 17.6% cost for the operator.

5. Conclusion

Telecommunication technologies develop fast in recent years, while the data requirement grows much faster than the upgrade of communication networks. Operators have to face the problem of allocating limited resources to all operating networks and satisfying the growing data traffic. The Resource Allocation Optimization Algorithm for Multi-network Operator (RAOAMO) is proposed to solve this problem for operators. With evaluations in three different case studies, RAOAMO is proved to be effective solving this problem for developed operators, developing operators as well as less developed operators. By using RAOAMO, current resource allocation is evaluated, and the result of RAOAMO could be considered as solution for operators.

Table 1. Network and traffic parameters for case study i

Parameters	2G	3G	4G	Wi-Fi
Network cost forecast (RMB/Mbps)	972200	48400	7810	16
Network capacity forecast (Mbps/km^2)	5.63	64	90	7
Network coverage forecast (%)	100	100	100	50
Data traffic forecast (Mbps/km^2)	8[a]	70[a]	80	5
Supported service transmission rate (Mbps)	0.5	2	5[b]	5

a. According to the forecast, traffic demand based on 2G/3G users will exceed 2G/3G capacity if no traffic distribution is utilized.

b. Multi-user simultaneous transmission is considered.

Table 2. Network and traffic parameters for case study ii

Parameters	2G	3G	4G	Wi-Fi
Network cost forecast (RMB/Mbps)	972200	48400	7810	16
Network capacity forecast (Mbps/km^2)	7	64	40	5
Network coverage forecast (%)	100	100	80	50
Data traffic forecast (Mbps/km^2)	7	50	35	5
Supported service transmission rate (Mbps)	0.5	2	5	5

Table 3. Network and traffic parameters for case study iii

Parameters	2G	3G	4G	Wi-Fi
Network cost forecast (RMB/Mbps)	972200	48400	7810	16
Network capacity forecast (Mbps/km^2)	8	64	0	10
Network coverage forecast (%)	100	100	0	50
Data traffic forecast (Mbps/km^2)	7.6	45	0	9

Supported service transmission rate (Mbps)	0.5	2	5	5

Table 4. Service type parameters for all case studies

Service type	**Expected bandwidth (kbps)**
Web browsing	100
Down loading	200
Instant messaging	50
Mobile games	300
Streaming media I	200
Streaming media II	1000
MMS	100
Other	60

The penetration ratio in Table 5 and Table 6 is used to represent the percentage of users using one kind of terminal among all the users. For instance, penetration ratio 5% for 2G cell phone means that there is 5% percent cell phone users using 2G cell phones.

Table 5. Terminal parameters for case study i

	No.	**Terminal type (supported networks)**	**Penetration ratio (%)**
Cell phone	1	2G	5
	2	2G, Wi-Fi	15
	3	2G, 3G	20
	4	2G, 3G, Wi-Fi	25
	5	2G, 3G, 4G, Wi-Fi	35
Dongle	6	2G	9
	7	3G	21
	8	4G	30
	9	Wi-Fi	40

Table 6. Terminal parameters for case study ii

	No.	**Terminal type (supported networks)**	**Penetration ratio (%)**
Cell phone	1	2G	5
	2	2G, Wi-Fi	15

	3	2G, 3G	35
	4	2G, 3G, Wi-Fi	35
	5	2G, 3G, 4G, Wi-Fi	10
Dongle	6	2G	15
	7	3G	30
	8	4G	15
	9	Wi-Fi	40

Table 7. Terminal parameters for case study iii

	No.	**Terminal type (supported networks)**	**Penetrati on ratio (%)**
Cell phone	1	2G	15
	2	2G, Wi-Fi	20
	3	2G, 3G	30
	4	2G, 3G, Wi-Fi	35
	5	2G, 3G, 4G, Wi-Fi	0
Dongle	6	2G	15
	7	3G	45
	8	4G	0
	9	Wi-Fi	40

Table 8. User habit parameters for case study i and case study ii

No.	**Distribution direction (based on terminal mark)**	**Target network**	**Migration percentage (%)**
1	A->W	W	20
2	W->A	A	0
3	A->B	B	70
4	B->A	A	30
5	A->BW	B	80
6	A->BW	W	20
7	B->AW	A	1
8	B->AW	W	20
9	W->AB	A	0
10	W->AB	B	0
11	A->BCW	B	30
12	A-> BCW	W	20
13	A-> BCW	C	90

14	B->ACW	A	0
15	B->ACW	W	20
16	B->ACW	C	90
17	W->ABC	B	30
18	W-> ABC	A	1
19	W-> ABC	C	90
20	C->ABW	A	0
21	C-> ABW	B	0
22	C-> ABW	W	0

Note: W, A, B and C are short for Wi-Fi, 2G, 3G and 4G.

Table 9. User habit parameters for case study iii

No.	**Distribution direction** (based on terminal mark)	**Target network**	**Migration percentage** (%)
1	A->W	W	20
2	W->A	A	0
3	A->B	B	70
4	B->A	A	30
5	A->BW	B	80
6	A->BW	W	20
7	B->AW	A	1
8	B->AW	W	20
9	W->AB	A	0
10	W->AB	B	0
11	A->BCW	B	0
12	A-> BCW	W	0
13	A-> BCW	C	0
14	B->ACW	A	0
15	B->ACW	W	0
16	B->ACW	C	0
17	W->ABC	B	0
18	W-> ABC	A	0
19	W-> ABC	C	0
20	C->ABW	A	0
21	C-> ABW	B	0
22	C-> ABW	W	0

Note: W, A, B and C are short for Wi-Fi, 2G, 3G and 4G.

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