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Stackelberg Game Theory for Rectifying Mutual Interferences among Secondary Users of Cognitive Radio Network in Comparison with Cournot Game Theory

B. Bhavya Sree[1]; Dr.P. Shyamala Bharathi[2*]

[1]Research Scholar, Department of Electronics and Communication Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India.
[1]bhavya.sravani123@gmail.com

[2*]Project Guide, Department of Electronics and Communication Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India.
[2*]shyamalabharathip.sse@saveetha.com

Abstract

Aim: *The aim of the study is to solve the problem of mutual interference among SUs based on Stackelberg game theory.* ***Materials and Methods:*** *This paper proposes an innovative algorithm based on Stackelberg game theory to reduce interference among secondary users. MATLAB software is used to implement the algorithm. The algorithm is tested to find Signal to Interference noise ratio (SINR) of about 10 secondary users in CRN using novel Stackelberg game theory and compared with the SINR of Secondary users using Cournot game theory.* ***Results:*** *The Statistical analysis is done by performing Independent Variable test and T-test using SPSS software. The mean SINR is maximum for Stackelberg game theory (100.9±1 mdb), and the least SINR (13.11±1mdb) is seen for Cournot game theory.* ***Conclusion:*** *The algorithm based on Stackelberg game theory shows maximum SINR than the Cournot game theory. Since SINR is maximum Signal quality will be high and Interference will be less among the users due to which the network performance is improved.*

Key-words: Innovative Algorithm, Stackelberg Game, Cournot Game, Mutual Interferences, Cognitive Radio Networks, Primary User, Secondary User.

1. Introduction

In wireless sensor networks, multiple users use the same frequency band spectrum, it becomes more congested and it becomes one of the major problems (Liu et al. 2015), to overcome this problem Cognitive Radio Networks is introduced. The major functionality in CRN is spectrum sensing. spectrum sensing helps to identify the empty spaces in the licensed spectrum bands and to allocate the empty space to the unlicensed users (Liu et al. 2015; Bloem, Alpcan, and Basar 2007).In cognitive Radio Networks the users who have the legal access of spectrum are called as Primary users and those who rent the spectrum from other users are called as Secondary users (Liu et al. 2015; Bloem, Alpcan, and Basar 2007; Huang, Han, and Ansari 2015) (Rathika and Sophia 2017). The Secondary users should leave the channel whenever the respective primary users enter the channel. This type of networks finds many growing applications such as the internet of things, Surveillance, health monitoring.All these applications need a specific frequency bandwidth for effective functioning(Sun et al. 2016),(Rai, Ghose, and Sarma 2020) which is accessed by the users by Cognitive radio technology.

OLOFS game model reduced intercepts based on decode and forward method to protect from eavesdropping attacks, this game model improved network performance, energy efficiency and utility against eavesdropping attack.(Fang, Xu, and Choo 2017). Ilaria Malanchini et al proposed a framework based on game theory to analyze spectrum functionalities. This framework's main functionality is not to disturb the licensed spectrum and different mathematical calculations are made to evaluate bandwidth, efficiency and mobility of the spectrum (Malanchini, Cesana, and Gatti 2009). D. Sumithra Sophia et al worked on dynamic spectrum access and proposed an Auction mechanism approach, this approach enhances the spectral utilization by neglecting the mutual interferences. Auction mechanism approach allows the user to lease the spectrum from the licensed users and also increases the revenue of the primary users (Malanchini, Cesana, and Gatti 2009; Sofia, Sumithra Sofia, and Shirly Edward 2020).In Stackelberg game theory, by improving the follower's decision the leader can improve the utility using cost function as an effective tool(Kotobi and Bilén 2017). The best study is the Auction mechanism approach as it proposed a best solution to increase the revenue of Primary users by reducing Interferences.(Malanchini, Cesana, and Gatti 2009; Sofia, Sumithra Sofia, and Shirly Edward 2020).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S. R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

During spectrum allocation there is high probability for collisions, interferences, delay due to which the network performance reduces very drastically. So, to analyse the network functioning and to measure the QOS parameters game theory is the effective method. Based on the Studies, we found that Game theory to cognitive radio networks found solutions to many problems, this paper gives an efficient algorithm based on Stackelberg game theory. The interferences among secondary users typically SINR is related to the channel capacity and quality and to improve these resources an innovative algorithm based on Stackelberg game theory is proposed.

2. Materials and Methods

Study Design

This study is on cognitive Radio Networks. The study was performed in the Department of Communication, Saveetha School of Engineering. A total of 10 samples were taken for each group of two groups and SINR is measured for both the groups using Stackelberg game and Cournot game respectively. The total sample size of the research work is taken as 20.The required samples for this research is taken using G power calculation(Du 2016).The minimum power taken for the analysis is 0.8 and the maximum error accepted is taken as 0.5.

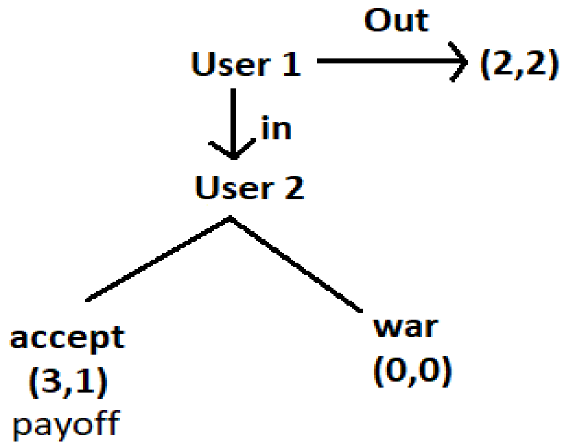
Sample preparation group 1: Created a Cognitive Radio Network environment a network with two base stations and five primary users 10 Secondary users were taken as an input. Ten samples are taken by changing the number of secondary users in the network each time by keeping frequency as constant. The group 1 is tested using Stackelberg game

Sample preparation group 2: Created a Cognitive Radio Network environment, A network with two base stations and five primary users 10 Secondary users were taken as an input. Ten samples are taken by changing the number of secondary users (Du 2016).The group 2 is tested using Cournot game.

Proposed Stackelberg Game Algorithm

A user decides whether to enter into the spectrum where another user currently has a Monopoly over. If the user enters into the spectrum where the user already in the spectrum space decides whether to accept or reject and declare a price war. The user wants to enter the spectrum only when the monopolist won't engage in a price war and this price war is unprofitable to the Monopolist as shown in Fig1.

Fig. 1 - Flow Chart Representing the Price War of User 1 and User 2



Backward Induction Method

A Backward induction is one of the techniques in game theories, this method tries to give a solution from the end of the problem. This method involves starting from the last stage of the game determining the last player's best action and tries to implement the best action replacing the information set with the payoffs from the outcome.

To attain pure strategy Nash equilibrium, Let us implement proposed game theory on the class of users. consider m players (j=1,2,3…….m) and q primary factors (k=1,2,3…….q).The j^{th} player's(j=1,2,3,4,5…..m) consists set of pure strategies and these pure strategies contains s_j elements($u_{j=}$ 1……..s_j).The cost for playing the u_j th pure strategy by the j^{th} player is equal to the sum of the costs of each selected primary factor. The cost for individual factors is given as P_k which are the functions of y_k. Thus, the cost to j^{th} player, if the strategy combination selected for $(u_1, u_2, u_3, \dots \dots . u_m)$ is π_j $(u_1, u_2, u_3 \dots\dots u_m) = \sum_{k=r_1}^{u_j} (P_k (y_k(u_1, u_2, \dots \dots u_m))$

In pure strategies the NE is is a pure strategy combination (u_1*, u_2*,….u_m^*) and it should satisfy the following condition π_j (u_1*, u_2*,….u_m^*) ≤ π_j (u_1^*,u_2^*,u_3^* ……. u_{j-1}^*, u_{j+1}^* …… u_m^*) Where $u_{j=}$ (1……..S_j) ; j=(1,2 ….m)

All games possess of taken class will consists at least one pure strategy Nash equilibrium, Let us consider y_{u_j} value be 1 if player j plays with strategy u_j, otherwise the value is considered as zero.

The optimized constraint is

$$\text{minimize: } \sum_{k=1}^{q} \sum_{x=0}^{y_k} (P_k(x) \qquad (1)$$

$$\sum_{u_j=1}^{S\,j} y_{u\,j} = 1 \text{ (j=1,2,3....m)} \qquad (2)$$

$$y_k - \sum_{j=1}^{m} \sum_{u_i \in k} y_{u\,j} = 0 \text{ ; (k=1, 2,.....q) ; (3)}$$

$$y_{u\,j} = 0 \text{ or } 1 \text{ ; } u_{j=}(1........S_j), \text{ j=(1,2 ....m); (4)}$$

Any solution to the above problem will achieve equilibrium to the taken class and to explain it, Let us consider $\{y_{u_j}{}^0, y_k{}^0\}$ is the solution which is in Nash equilibrium. Then for some i the strategy is given as z_i such that

$$\sum_{k \in z_j\ k \notin u_j0} P_k(y_k{}^0 + 1) < \sum_{k \in u_j0\ k \notin z_j} P_k(Y_k{}^0) \text{ ; } u_j{}^0 \text{ is strategy used by j at } \{y_{u_j}{}^0\} \text{ (5)}$$

and every pure strategy equilibrium is not the solution for the problem and let us explain it with one example. The costs of six primary factors is given as follows:

$$P_a(y_a)= y_a^{2,}\ P_b(y_b)= y_b^2, P_c(y_c)= P_d(y_d)= P_e(y_e)= 0,\ P_f(y_f)= 1$$

The pure strategies of player 1 are {a, c} and {b, d}. The pure strategies of player 2 are {a,e} and {b,f}.The resultant normal form is represented as in fig(2).

Fig. 2 - Normal form Representation

	{a,e}	{b,f}
{a,c}	d,d	a,b
{b,d}	a,a	d,e

The normal form of six primary factors depicts that (d,d) and (a,a) achieve pure strategy equilibrium.(a,b) does not give solution to the problem, though it achieves equilibrium. Based on this game theory SINR is evaluated for different secondary users.

Consider N as the number of Secondary users, $\propto_n$ as interference cost, P_n as the power vector and g_n as the precoding vector of n user. H_n represents channel coefficients

$$SINR_n = \frac{P_n|g_n H_n|^2}{\sum_{j=1, j\neq n}^{n} P_j|g_j H_n|^2 + |g_n|^2 P_n + \sigma^2} \qquad (6)$$

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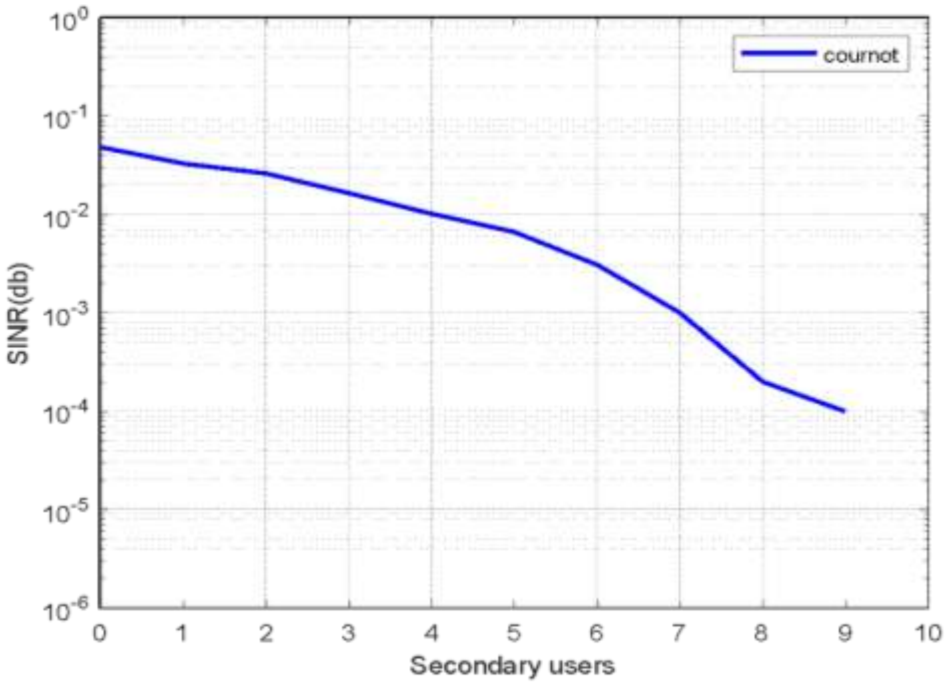
Where $\sum_{j=1,j\neq n}^{n} P_j|g_jH_j|^2$ represents mutual interferences from secondary users and $|g_n|^2P_n$represents interferences from primary nodes and σ^2 represents variance calculated for the noise.

3. Results

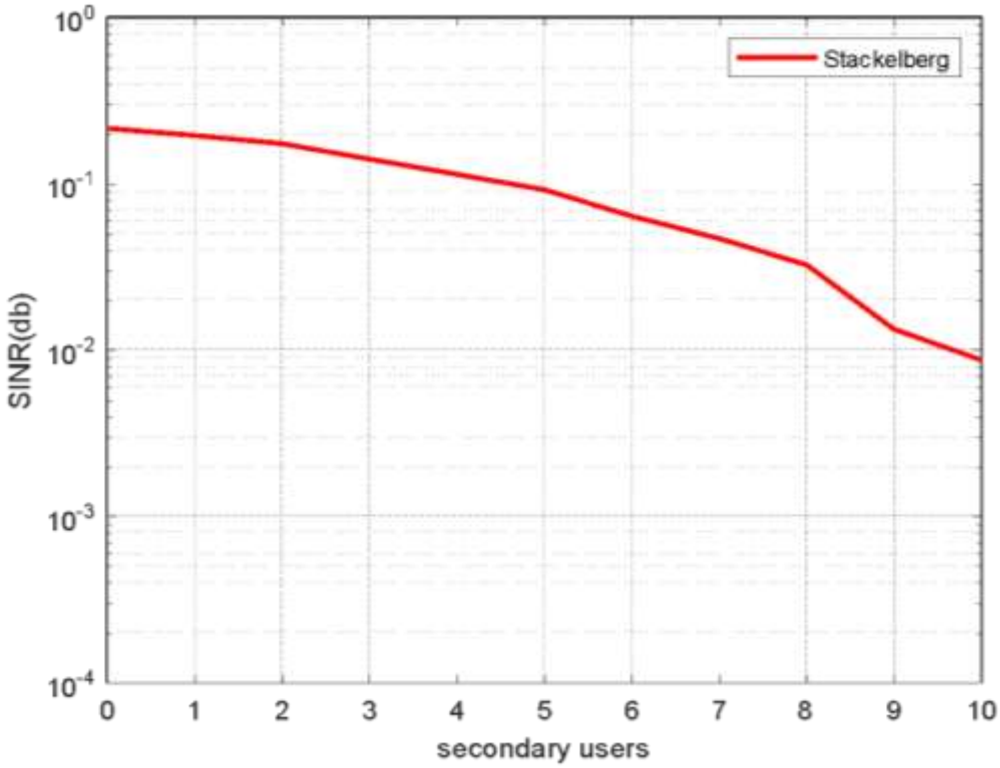
From Figure 3 it was observed that an increase in the number of secondary users decreases the SINR(db).it was found that as secondary users increased interferences also increased so SINR value is decreased. These are the results obtained from algorithms based on Cournot game theory. In Cournot game theory the maximum SINR is found to be 0.007db.

Fig. 3 - Graphical Representation of the SINR for Different SU's using Cournot Game Theory. The SINR Value is High when the Number of Secondary Users is Less



From Figure 4 it was observed that an increase in the number of secondary users decreases the SINR(db).it was found that as secondary users increased interferences also increased. These are the results obtained from algorithms based on Stackelberg game theory. In Stackelberg game theory the maximum SINR is found to be 0.4db.

Fig. 4 - Graphical Representation of the SINR for Different SU's Using Stackelberg game Theory. The SINR Value is High when the Number of Secondary Users is Less



From Figure 5 it was observed that SINR of Stackelberg is found to be significantly higher than Cournot game theory. SPSS software is used to perform statistical analysis by taking 10 samples in each group. The statistical results show that Stackelberg is having mean SINR of 100.9mdb and Cournot is having mean SINR of 13.1182mdb (Table 1). Stackelberg game obtained a standard deviation of 7.71 and Cournot game theory obtained a Standard deviation of 1.61. The Significance value is found to be <0.005(Table 2).

Table 1 - (T-test) Comparison of SINR of Secondary users using Stackelberg and Cournot game theory. The statistical results shows that Stackelberg is having mean of 100.9mdb and Cournot is having mean SINR of 13.1182mdb.This shows that Stackelberg is having high SINR compared to Cournot game theory.

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
SINR	Stackelberg	10	100.9091	7.716276	2.326545
	Cournot	10	13.1182	1.617126	0.487582

Table 2 - (Independent Sample Test) The Mean, Standard deviation and Significance difference of SINR of Stackelberg and Cournot game theory. There is a Significant difference between the two groups since ($p<0.05$)

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SINR	Equal variances assumed	26.848	0.00	3.693	20	0.001	87.79091	23.77088	38.20573	137.37609
	Equal variances not assumed			3.693	10.877	0.004	87.79091	23.77088	35.39913	140.18269

Fig. 5 - Comparison of SINR of Secondary users by Stackelberg game theory and Cournot game theory. The Red line indicates Stackelberg and blue line indicates Cournot. SINR of Stackelberg is found to be significantly higher than Cournot game theory

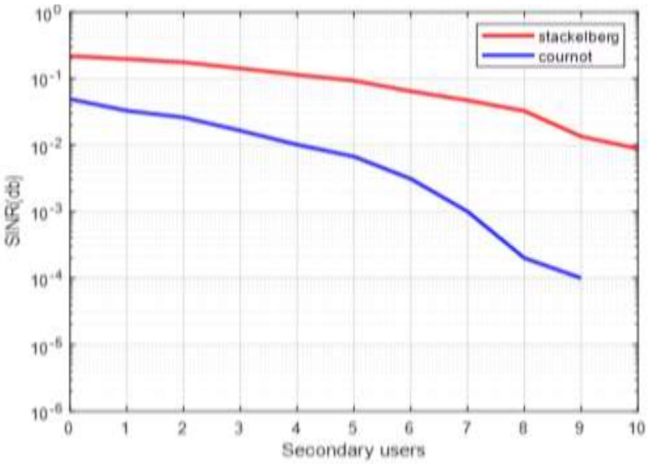
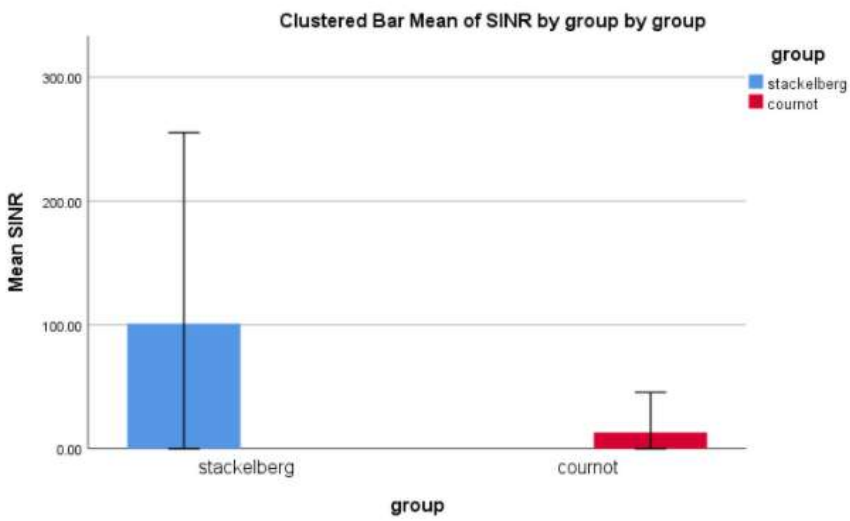


Fig. 6 - Bar Chart comparing the mean (+-1 SD) SINR of Stackelberg and Cournot by varying the number of secondary users.There is a significant difference between the two groups $p<0.005$(Independent Sample T test)



The Independent T test is used to compare Stackelberg and Cournot games. Mean, Standard deviation and Significance difference of SINR of Stackelberg and Cournot game theory was calculated in this analysis. There is a Significant difference between the two groups since ($p<0.05$),with this statistical results it is observed that the algorithm based on Stackelberg game shows better performance than the Cournot game.

4. Discussion

In this study we observed that algorithm based on Stackelberg game appears to be better than Cournot game. SINR in CRN is simulated using MATLAB software with required communication tool box using algorithms based on Stackelberg and Cournot game theory by varying the number of secondary users in the network. As the Secondary users in the network increases the SINR value decreases. After analysing the plots, it has been noticed that the SINR of Stackelberg game theory is higher than the Cournot game theory. T-test analysis of SINR of Stackelberg and Cournot game theory shows that Stackelberg is having highest mean of (100.32mdb) and Cournot is having lowest mean SINR of (13.1182mdb).There is a significant difference between the two groups $p<0.005$(Independent Sample T test).

The factors that influence the SINR in this research is the number of Secondary users. The frequency of the network is kept constant and SINR is calculated by varying numbers of Secondary users. In the previous works the SINR is calculated for different frequencies due to which the interference in particular range of frequency for multiple secondary users was not estimated properly. Due to this limitation the utility in specified frequency is not possible to estimate. [(Malanchini, Cesana, and Gatti 2009; Sofia, Sumithra Sofia, and Shirly Edward 2020)]. So in this paper the research is carried out by calculating SINR for different secondary users in fixed frequency range. Due to the increase in the number of users besides growing popularity for the smart gadgets needs more frequency bands, so multiple access schemes concept is introduced these are strategies that are implemented to multiplex different users into single medium without interferences [(Kumar and Kumar 2020)],but it takes more time to multiplex the users to overcome this Stackelberg game is implemented.

Our institution is passionate about high quality evidence based research and has excelled in various fields ((Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

The limitation of the research is that the proposed algorithm based on Stackelberg is implemented only on Secondary users but not on Primary users due to which the Interference among primary users is not possible to estimate. In future the proposed algorithm can be tested for different Applications such as the Internet of things, public Safety Networks etc.

5. Conclusion

In Cognitive Radio Networks Mutual interferences among Secondary users is found to be the main reason for reducing the channel utility due to which an efficient algorithm based on game theory is proposed to solve this problem. The simulation is done by using MATLAB and SINR of the Stackelberg game theory is compared with Cournot game theory. The Simulated results shows that the Stackelberg game theory increases the signal strength by reducing interference noises as a result of this SINR is increased. Due to the increased value of SINR the network performance along with QOS characteristics are improved. The Statistical analysis made through SPSS proved Stackelberg is having highest mean SINR of 100.90mdb and Cournot is having lowest mean SINR of 13.1182mdb.

Declarations

Conflict of Interest

No conflict of interest in this manuscript.

Authors Contributions

Author BS was involved in data collection, data analysis, manuscript writing. Author PSB was involved in conceptualization, data validation, and critical review of manuscript.

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