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Fuzzy AHP for Control of Data Transmission by Network Selection in Heterogeneous Wireless Networks

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Abstract: Multiple radio access technologies (RATs) are available for the mobile users for the Internet connectivity. Traditional handover algorithms select the RAT based on the signal strength only. But quality of service (QoS) attributes are different for every application like VOIP requires lower network delay while video streaming application requires higher data rate. Therefore, these QoS parameters should be involved also in network selection In this paper, extent analysis on fuzzy analytic hierarchy process (AHP) is applied on selecting the RAT among multiple RATs by calculating the values of fuzzy synthetic extent. The selection mechanism is analyzed for interactive, streaming and conversational applications. Numerical simulation calculates the total score of each RAT with respect to the application type. Based on these score appropriate RAT is chosen. Finally, the time complexity required for the executing the network selection mechanism is calculated.

Keywords: Wireless Networks, network selection, fuzzy AHP, extent analysis on fuzzy AHP

1. INTRODUCTION

Internet can be accessed by small hosts like cell phones, tablets, laptops etc. A user wants to connect to the network that provides the quality of service (QoS) requirements. These QoS parameters will vary from one application to another. When a node is moving between the ranges of different networks, selecting the best network is a challenge. When the selection of network is between same types of networks, it is called horizontal handover. If this selection is to be made on different types of networks, it is called vertical handover [1]. Mobile devices have multiple interfaces to access the different technologies which tends the heterogeneous network system towards convergence. Selecting the network for vertical handover for different

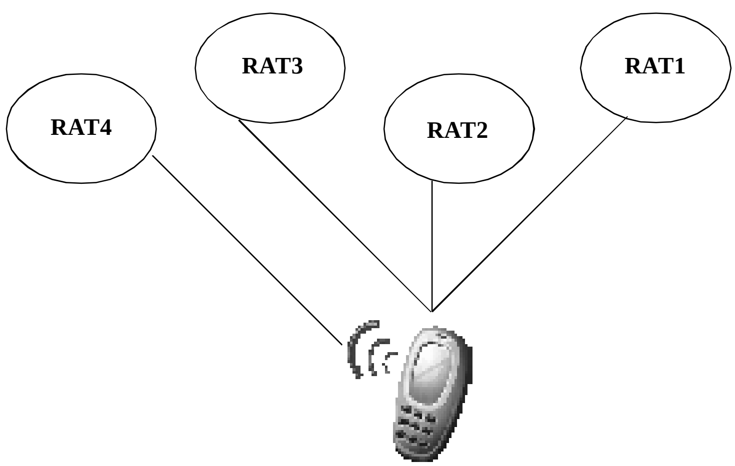

Figure 1: Network selection in a multi-RAT environment

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types of applications like streaming, interactive video conferencing, and Voice over IP (VOIP) require different set of network attribute values. Traditional handover algorithms consider signal strength only without considering other QoS parameters for network selection *i.e*, when a user moves out of the range of the network, only then the node triggers for handover. But with the increase in growth of internet applications, QoS parameters need to be taken in account for network selection. Figure 1 shows the scenario of a mobile node within the ranges of four radio access technologies (RATs).

This network selection problem can be formulated as multiple attribute decision making (MADM) problem, based on various QoS parameters and user preferences as shown in Figure 2. A RAT is chosen based on the Service Price, Data Rate, Security, Battery Consumption and Network Delay.

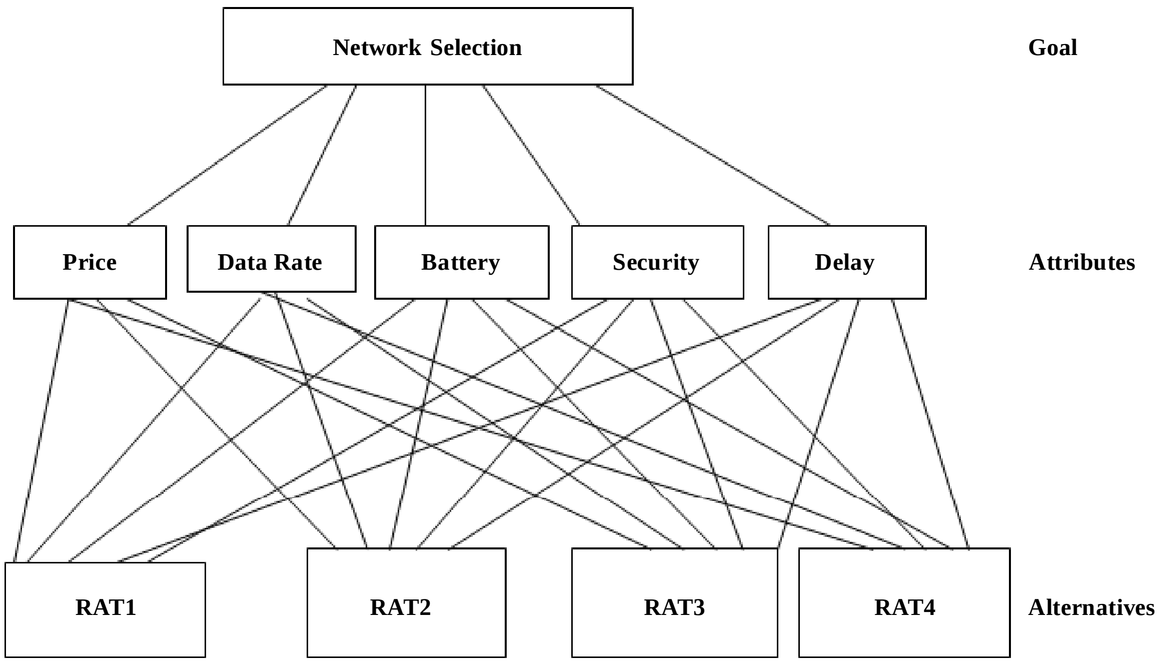

Figure 2: Multiple Attribute Decision Making for Network Selection

Many MADM (Multiple Attribute Decision Making) methods are available in literature [3]. Many researchers have applied these methods for making vertical handover decision. AHP and GRA (Grey Rational Analysis) based technique where AHP is used for selection criteria and GRA evaluates heterogeneous networks is presented in [4]. Mohamed Lahby et al. [5] have proposed an enhanced TOPSIS method by using the Analytic Network Process to weigh the criteria and then apply the TOPSIS method. Different fuzzy based MADM methods have also been used for vertical handovers [6]. Fuzzy logic and TOPSIS method is used to reduce the number of handovers and increase user satisfaction [7]. Xinjun Liu et al. [8] have proposed fuzzy TOPSIS based network selection for heterogeneous networks based on connection number a+bi where a denotes the certainty number and bi denotes the uncertainty number in the fuzzy language number. Falwo et al. [9] have presented TOPSIS based network solution considering maximum data rate, security, delay, battery power consumption and cost. This method selects the network based on single application or multiple applications.. Mohamed Lahby et al. [10] have presented the novel validation approach for network selection by considering the group weighting techniques for MADM methods. AHP method is applied to determine the weight of interclass and intra class attributes.

In this paper application of extent analysis on fuzzy AHP is applied on network selection using synthetic fuzzy numbers. Three applications i.e., interactive, conversational and streaming applications are analyzed on the basis of five network attributes namely service price, data rate, security, battery consumption and network delay. Section 2 describes the proposed technique for network selection. The comparative relative matrices are formed based on triangular fuzzy numbers for criteria and alternatives. Then the total score of each alternative RAT is calculated based on the fuzzy AHP method. Section 3 elaborates the results of RATs for interactive, conversational and streaming applications. Section 4 presents the conclusion.

2. NETWORK SELECTION USING EXTENT ANALYSIS ON FUZZY AHP

In this section, extent analysis on fuzzy AHP is used for a RAT selection in multi-RAT environment for various applications. We have considered four different types of networks available to the mobile user as shown in Table 1. To select the appropriate RAT for the particular application is the main objective to solve this multi criteria decision making problem. Triangular fuzzy sets are used for representing fuzzy numbers (l, m, u) as shown in equation 1.

$$\mu_A(x) = \begin{cases} 0 & \text{for } x < l, \\ \dfrac{x-l}{m-l} & \text{for } l \le x \le m, \\ \dfrac{u-x}{u-m} & \text{for } m \le x \le u, \\ 0 & \text{for } x > u \end{cases} \tag{1}$$

AHP was proposed in 1980 by Satty [11]. Chang [12] has proposed extent analysis method on fuzzy AHP. We have applied this method for network selection among multiple RATs. The various steps used in network selection by extent analysis method on fuzzy AHP are explained in algorithm 1.

Table 1
Attributes of the RATs

Networks	*Service Price*	*Data Rate*	*Security*	*Battery Consumption*	*Network Delay*
RAT1	Low	Very High	Low	Medium	High
RAT2	High	Low	Very High	High	Low
RAT3	Medium	High	Medium	Very High	Very Low
RAT4	Medium	Medium	High	High	Low

Table 2
Comparative ratings of alternatives and weights of the criteria

Comparison Terms	*Fuzzy triangular matrix*
Equable	(1, 1, 3)
Slightly greater	(1, 3, 5)
Fairly greater	(3, 5, 7)
Extremely greater	(5, 7, 9)
Absolutely greater	(7, 9, 9)

Algorithm1

Step1: Objective of the problem is to be formulized. In our case, RAT selection from available RATs is the objective of the problem.

Step2: Obtain the matrix having the information of the alternatives according to the different criteria. Information of RATS according to Service Price, Data Rate, Security, Battery Consumption and Network delay is shown in Table 1.

Step 3: Prepare the relative comparison matrices of criteria and attributes with respect to each criterion. The fuzzy triangular numbers used for the ratings of alternatives and weights of criteria are illustrated in Table 2-Table 5 and Table 7-Table 11.

Step 4: Compute the value of the fuzzy synthetic extent with respect to the i^{th} object according to the equation 2.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{2}$$

where all M_{gi}^{j} are triangular fuzzy numbers.

Step 5: Compute the degree of possibility of S_2 and S_1 as shown in equation 3. S_2 and S_1 are calculated from Step4.

$$V(S_2 \geq S_1) = \sup_{y \geq x}[\min(\mu_{S_2}(y), \mu_{S_1}(x)] \tag{3}$$

which can be represented as equation 4 and equation 5.

$$V(S_2 \geq S_1) = hgt(S_1 \cap S_2] = \mu_{S_2}(d) \tag{4}$$

$$\mu_{S_2}(d) = \begin{cases} 1 & if \;\; m_2 \geq m_1 \\ 0 & if \;\; l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{m_2 - u_2} & otherwise \end{cases} \tag{5}$$

Step 6: Compute the degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers S_i. This is to be calculated as shown in equation 6.

$$\text{V} (S > S_1, S_2 \ldots \ldots S_k) = \min \text{V} (S > S_i), i = 1, 2 \ldots \ldots k. \tag{6}$$

Step 7: Calculate the weight vector for each comparison matrix as (min $V(S_1 \geq S_j)$, min $V(S_2 \geq S_j)$ ... ... min $V(S_k \geq S_j))^T$, $i = 1, 2, \ldots \ldots k$, $j = 1, 2 \ldots \ldots k$, $k \neq j$.

Then the weights are normalized. Weights of each criterion $\text{W}C_i$ and alternative with respect to each criterion $\text{WA}C_i$ are calculated.

Step 8: Total Score of each alternative is calculated as in equation 8.

$$\text{Total Score} = \sum_{i=1}^{n} \text{WA}C_i * \text{W}C_i, \; i = 1, 2 \ldots n, \text{ where } n = \text{number of criteria} \tag{8}$$

Step 9: Sort the alternatives in descending order according to the total scores calculated in Step8.

Table 3
Relative Importance matrix of fuzzy numbers of the aggregated weights of the criteria for streaming applications

	Service Price	*Data Rate*	*Security*	*Battery Consumption*	*Network Delay*
Service Price	(1, 1, 1)	(.14, .2, .33)	(.33, 1, 1)	(.33, 1, 1)	(.2, .33, 1)
Data Rate	(3, 5, 7)	(1, 1, 1)	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)
Security	(1, 1, 3)	(.14, .2, .33)	(1, 1, 1)	(1, 1, 3)	(.2,.33, 1)
Battery Consumption	(1, 1, 3)	(.14, .2, .33)	(.33, 1, 1)	(1, 1, 1)	(.2,.33, 1)
Network Delay	(1, 3, 5)	(.2,.33, 1)	(1, 3, 5)	(1, 3, 5)	(1, 1, 1)

Table 4
Relative Importance matrix of fuzzy numbers of the weights of the criteria for conversational applications

	Service Price	*Data Rate*	*Security*	*Battery Consumption*	*Network Delay*
Service Price	(1, 1, 1)	(.2, .33, 1)	(.33, 1, 1)	(.33, 1, 1)	(.14, .2, .33)
Data Rate	(1, 3, 5)	(1, 1, 1)	(1, 3, 5)	(1, 3, 5)	(.2, .33, 1)
Security	(1, 1, 3)	(.2, .33, 1)	(1, 1, 1)	(1, 1, 3)	(.14, .2, .33)
Battery Consumption	(1, 1, 3)	(.2, .33, 1)	(.33, 1, 1)	(1, 1, 1)	(.14, .2, .33)
Network Delay	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)	(1, 1, 1)

Table 5
Relative Importance matrix of fuzzy numbers of the aggregated weights of the criteria for interactive applications

	Service Price	*Data Rate*	*Security*	*Battery Consumption*	*Network Delay*
Service Price	(1, 1, 1)	(.14, .2, .33)	(1, 1, 3)	(1, 1, 3)	(.14, .2, .33)
Data Rate	(3, 5, 7)	(1, 1, 1)	(3, 5, 7)	(3, 5, 7)	(1,1,3)
Security	(.33, 1, 1)	(.14, .2, .33)	(1, 1, 1)	(.33, 1, 1)	(.14, .2, .33)
Battery Consumption	(.33, 1, 1)	(.14, .2, .33)	(1, 1, 3)	(1, 1, 1)	(.14, .2, .33)
Network Delay	(3, 5, 7)	(.33, 1, 1)	(3, 5, 7)	(3, 5, 7)	(1,1,1)

For streaming application,

$S_{1=Prices}$ = (2, 3.53, 4.33) ⊗ (1/60.33, 1/36.18, 1/19.33) = (0.03, 0.1, 0.24)

$S_{2=Data\ Rate}$ = (7, 15, 23) ⊗ (1/60.33, 1/36.18, 1/19.33) = (.12, .41, 1.19)

$S_{3=Security}$ = (3.4, 3.66, 9) ⊗ (1/60.33, 1/36.18, 1/19.33) = = (.06, .01, .47)

$S_{4=Battery\ Consumption}$ = (2.73, 3.66, 7) ⊗ (1/60.33, 1/36.18, 1/19.33) = = (.05, .01, .36)

$S_{5=Network\ Delay}$ = (4.2, 10.33, 17) ⊗ (1/60.33, 1/36.18, 1/19.33) = (.07, 0.29, .88)

$$V\,(S_{Price} \geq S_{Data\ Rate}) = \frac{.12-.24}{(.1-.24)-(.41-.12)} = .28$$

Similarly,

$V\,(S_{Price} \geq S_{Security}) = 1$, $V\,(S_{Price} \geq S_{Battery\ Consumption}) = 1$, $V\,(S_{Price} \geq S_{Network\ Delay}) = 0.48$,

d' (S_{Price}) = min $V(S_{Price} \geq S_{Data\ Rate}, S_{Security}, S_{Battery\ Consumption}, S_{Network\ Delay})$ = min (.28, 1,1, .48) = .28

and similarly, d' $(S_{Data\ Rate})$ = 1, d' $(S_{Security})$ = .53, d' $(S_{Battery\ Consumption})$ = .49 and

d' $(S_{Network\ Delay})$ = .75

Therefore W' = $(.28, 1, .53, .49, .75)^T$

and after normalization we have obtained the weight vectors with respect to Service Price, Data Rate, Security, Battery Consumption and Network delay as

$$W = (.09, .33, .17, 0.16, .24)^T.$$

We can calculate the normalized weight vectors of different criteria for interactive and conversational applications. Normalized weight vectors of criteria for different types of applications are shown in Table 6.

Table 6
Normalized Weight vectors of the criteria for different types of applications

Criteria	Normalized Weights		
	Streaming	Interactive	Conversational
Service Price	.09	.01	.2
Data Rate	.33	.43	.29
Security	.17	0	.14
Battery Consumption	.16	.03	.09
Network Delay	.24	.43	.45

In the next step comparison matrices of alternative networks with respect to each criteria is made and their normalized weights are obtained. Table 7-Table 11 shows the relative importance matrices of the alternatives with respect to each criterion respectively. Table 12 shows the normalized weights of RAT with respect to each criterion.

Table 7
Relative Importance matrix of fuzzy numbers of the aggregated weights of the RATs related to Service Price

	RAT1	RAT2	RAT3	RAT4
RAT1	(1, 1, 1)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)
RAT2	(.14, .2, .33)	(1, 1, 1)	(.2, .33, 1)	(.2, .33, 1)
RAT3	(.2,.33,1)	(1, 3, 5)	(1, 1, 1)	(1, 1, 3)
RAT4	(.2,.33,1)	(1, 3, 5)	(.33, 1, 1)	(1, 1, 1)

Table 8
Relative Importance matrix of fuzzy numbers of the aggregated weights of the RATs related to Data Rate

	RAT1	RAT2	RAT3	RAT4
RAT1	(1, 1, 1)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)
RAT2	(.14, .2, .33)	(1, 1, 1)	(.14, .2, .33)	(.2, .33, 1)
RAT3	(.2,.33, 1)	(3, 5, 7)	(1, 1, 1)	(1, 3, 5)
RAT4	(.14, .2, .33)	(1, 3, 5)	(.2,.33, 1)	(1, 1, 1)

Table 9
Relative Importance matrix of fuzzy numbers of the aggregated weights of the RATs related to Security

	RAT1	RAT2	RAT3	RAT4
RAT1	(1, 1, 1)	(.14, .2, .33)	(.33, 1, 1)	(.2,.33, 1)
RAT2	(3, 5, 7)	(1, 1, 1)	(1, 3, 5)	(1, 1, 3)
RAT3	(1, 1, 3)	(.2,.33, 1)	(1, 1, 1)	(.33, 1, 1)
RAT4	(1, 3, 5)	(.33, 1, 1)	(1, 1, 3)	(1, 1, 1)

Table 10
Relative Importance matrix of fuzzy numbers of the aggregated weights of the RATs related to Battery Consumption

	RAT1	RAT2	RAT3	RAT4
RAT1	(1, 1, 1)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)
RAT2	(.2,.33, 1)	(1, 1, 1)	(1, 3, 5)	(1, 1, 3)
RAT3	(.14, .2, .33)	(.2,.33, 1)	(1, 1, 1)	(.2,.33, 1)
RAT4	(.2,.33, 1)	(.33, 1, 1)	(1, 3, 5)	(1, 1, 1)

Table 11: Relative Importance matrix of fuzzy numbers of the aggregated weights of the RATs related to Network Delay

	RAT1	RAT2	RAT3	RAT4
RAT1	(1, 1, 1)	(.2,.33, 1)	(.14, .2, .33)	(.2,.33, 1)
RAT2	(1, 3, 5)	(1, 1, 1)	(.2,.33, 1)	(1, 1, 3)
RAT3	(3, 5, 7)	(1, 3, 5)	(1, 1, 1)	(1, 3, 5)
RAT4	(1, 3, 5)	(.33, 1, 1)	(.2,.33, 1)	(1, 1, 1)

Table 12: Normalized Weight vectors of the RATs for different criteria

	RAT1	RAT2	RAT3	RAT4
Service Price	.40	.08	.27	.25
Data Rate	.45	.03	.31	.20
Security	.09	.41	.19	.31
Battery Consumption	.40	.27	.08	.25
Network Delay	.08	.27	.40	.25

3. RESULTS AND DISCUSSION

In this section, results of the extent analysis on Fuzzy AHP for network selection are discussed. Total scores of the RATs for three different applications i.e., conversational (VOIP), interactive (video conferencing) and streaming are calculated as described in Step8 of Algorithm1. Figure 2 shows the scores of the RATs for different applications. For conversational applications, RAT3 is the preferred network as it has the least network delay among the four networks. The ranking order of the RATs is 3>4>1>2. Again for interactive applications RAT3 ranked first. These type of applications require higher data rate and low delay. RAT1 has the highest data rate but network delay is very high. Therefore it lags behind RAT3. The ranking order in this case is 3>1>4>2. For streaming applications data rate is more important than other attributes. Therefore RAT1 has the highest total score. The ranking order in this application is 1>4>3>2. RAT2 has the least total score for all the applications. It provides the maximum security but, it has poor values for the other main attributes required for running the applications like data rate and network delay.

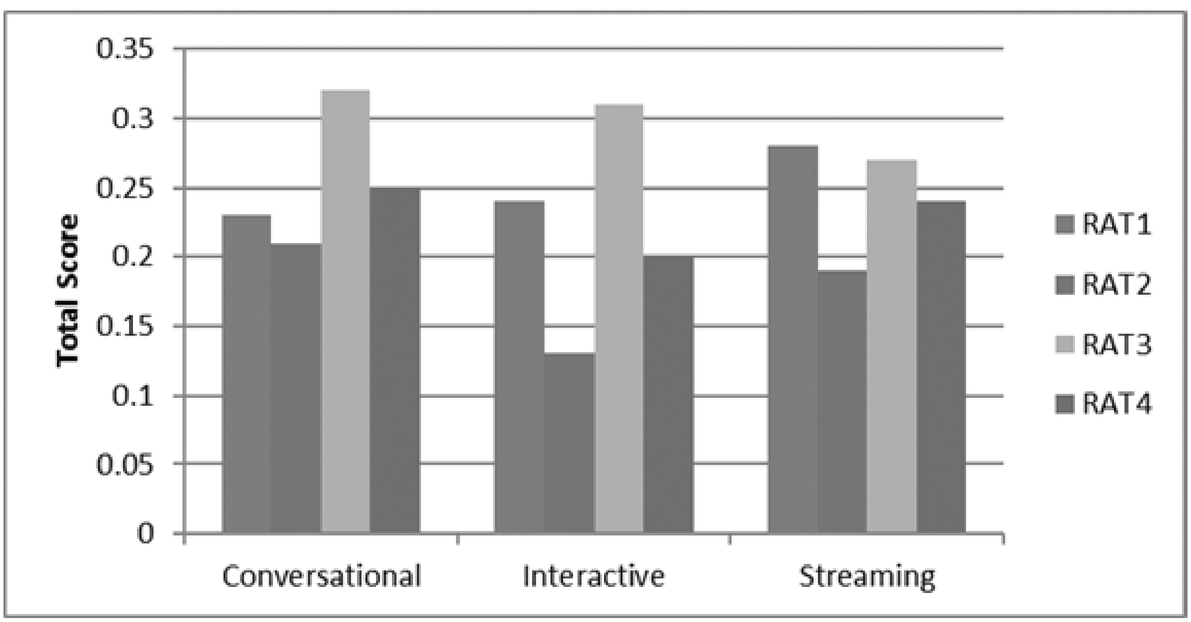

Figure 3: Comparison of total scores of RATs for different types of applications

Time complexity $T(n, m)$ of the extent analysis using fuzzy AHP is n (n + 6) + mn (m + 6) for m alternatives and n criteria and n alternatives [12]. For four alternatives and five criteria the time complexity of our algorithm is 275 i.e., 275 operations are required to execute the Fuzzy AHP algorithm.

4. CONCLUSION

In this paper, application of extent analysis of fuzzy AHP is analyzed for network selection among multiple RATs. Fuzzy synthetic extents are used to calculate the total score. Based on these scores the RAT networks are sorted for handover. For video streaming, RAT with highest data rate is chosen, for interactive and conversational applications, RAT with comparatively higher data rate and lowest network delay is chosen. The time complexity for this network selection algorithm is 275.

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