



## Network Selection Problems - QoE vs QoS. Who is the Winner?

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### ABSTRACT

In network selection problem (NSP), there are now two schools of thought. There are those who think that using Quality of Experience (QoE) is the best yardstick to measure the suitability of a Candidate Network (CN) to handover to. On the other hand, Quality of Service (QoS) is also advocated as the solution for network selection problems. In this article, a comprehensive framework that supports effective and efficient network selection is presented. The framework attempts to provide a holistic solution to network selection problems that is achieved by combining both of the QoS and the QoE measures. Using this hybrid solution the best qualities in both methods are combined to overcome issues of the network selection problem. According to ITU-R (International Telecommunications Union – Radio Standardization Sector), a 4G network is defined as having peak data rates of 100Mb/s for mobile nodes with speed up to 250 km/hr and 1Gb/s for mobile nodes moving at pedestrian speed. Based on this definition, it is safe to say that the mobile nodes (MN) which can go from pedestrian speed to speed of up to 250 km/hr will be the norm in the future. This indicates that the MN's mobility will be highly dynamic. In particular, this article addresses the issues of network selection for high speed MN's in 4G networks. The framework presented in this article also discusses how the QoS value collected from CNs can be fine-tuned to better reflect an MN's current mobility scenario.

**Keywords:** Network Selection Problem, 4G Network, QoS, QoE

### 1. INTRODUCTION

There are vast amount of researches [17, 30, 50, 51] done using different techniques to solve NSPs (Network Selection Problems). They range from using multi-attribute decision making methods (MADM), fuzzy logic, neural networks, artificial intelligence based methods and genetic algorithms. The key theme in these methods is the use of QoS values in order to make an informed decision. Work in [16, 35] relates various mechanisms to collect the said QoS values. This article does not cover QoS value collection techniques and assumes that the values are available. There are two key components in network selection solutions:

- 1) assigning weights to attributes and
- 2) ranking of the candidate networks (CNs).

Attributes here refer to the criteria that are used to evaluate Candidate Networks (CN). Weightage reflecting the importance of each criterion is assigned in the first step. The second step involves ranking the prospective CNs in decreasing order of suitability; presumably the first in the list is the best network to handover to.

Researchers have shown [1, 25, 35] that if the network selection is executed based on a higher number of criteria then the ranking is more reflective of the Mobile Nodes (MN) context, thereby satisfying the MN's requirements in the process. This can be construed as fulfilling a user's QoE. Detractors of this technique argue that the QoS requirements are poor substitute for QoE. QoS values mostly indicate theoretical values of what the CNs can support. Most often than not, these theoretical values are not achieved at the end user. This explains the growing support to use QoE values as means to select the right access network to handover to. QoE refers to how QoS requirements are actually experienced at the user side thereby reflecting whether the CN that the MN handover to is truly is the best option. Network selection based on QoE is primarily based on AI concepts. In [16], QoE measurements are taken and used as a learning tool to improve the network selection technique. Critics of this method argue that a network selection method that learns on the job may be too slow to adapt especially in a dynamic 4G networking environment. Most network selection problem (NSP) solutions focus on either apportioning the weights or ranking or both which is hardly a holistic approach. A holistic approach to NSP should address not only the issue of 'who' to handover to but also 'when' to handover. One cannot solve one aspect of the problem without addressing the other equally important component. Network selection techniques may identify the best CN to handover to but if handover is not initiated at the right moment then the benefits of handing over to the best network may not be realized fully. Therefore, in this article, a hybrid method that combines both QoS and QoE values is essential in order to provide a holistic solution.

Always Best Connected (ABC) is a popular concept that network operators as well as MN aspire to achieve. ABC means an MN is always connected to the best network. In essence, this also means that an MN that does not need to handover may choose to handover still because a better CN has showed up. Handing over inflicts a certain cost in terms of packets lost or reduced throughput until the connection is established at the new best CN. This may not be ideal in all situations. The new CN may have best QoS values but that does not mean it will translate to a better QoE than what the MN is currently experiencing. The framework presented in this article will address this issue.

Initially, in order to solve NSPs, single criterion is used to assess prospective CNs. The most popular single criterion used is Required Signal Strength (RSS). It seems logical that the CN with the strongest RSS is the best alternative. Other researchers [1, 25, 35] deem that single criterion based network selection algorithms does not necessarily identify the best CN. Single criterion approaches were inadequate in understanding a MN's context. Therefore, multiple criteria based network selection techniques were suggested [1, 25, 35]. Works in [6, 33] identified that QoS values were good indicators of the best CN. Numerous researchers [35, 54] discussed various ways to acquire these QoS values in an efficient way. Since value collection techniques are not addressed in this article, we will look at network selection methodologies that use these values in order to identify the best CN. Additionally, various applications were differentiated based on whether they were one of four classes: voice (conversational), video (streaming), background and best-effort (interactive). Based on the type of application, different weightage is assigned to reflect the importance of various attributes i.e for voice traffic, higher weightage should be given to Packet Error Rate (PER) as voice traffic is very sensitive to dropped packets.

The next section relates the main groups of network selection methods using both QoS and QoE based values. A discussion on the proposed framework follows in Section 3. Section 4 presents some analysis and discussion. Finally, a conclusion is made in the last section together with a suggested future work.

## 2. RESEARCH BACKGROUND

### 2.1 MADM BASED APPROACHES

The multi-attribute decision making (MADM) method addresses the problem of finding a solution when multiple attributes and factors need to be considered. MADM based approaches are natural fit to NSPs. They have been praised as an effective solution to NSPs [6]. To better understand the context of an MN that needs to select a new access network to handover to, the more criteria values collected the better. MADM based approaches have been identified as being simple and scalable therefore rendering it suitable to support high number of criteria [6]. Some MADM techniques are more suited to perform the weightage assignment and some MADM techniques were used to identify the ranking of CNs.

Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP) both break down the decision making problem into a hierarchical structure, making it easier to tackle. Weightage is assigned using a pair wise comparison ratio meaning an attribute's importance is derived by identifying how important it is compared to another attribute. AHP scale of 1 to 9 is used [42].

Ranking mechanism such as Simple Additive Weighting (SAW) [45] and Multiplicative Weighting Exponent (MWE) [45] use formulas to calculate scores for CNs. Elimination et choix traduisant la realite (ELECTRE) [7] method uses direct pair wise comparisons of CNs for each attribute value to evaluate the CNs. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [53] works by first identifying ideal positive solutions and negative solutions. The best CN must be as close as possible to the positive solution and as far as possible from the negative solution based on Euclidean distances. Grey Relational Analysis (GRA) uses grey system theory. This method identifies a reference network with attributes values that constitute an ideal solution and each CN is given scores as to how similar the CN is to the ideal solution [50].

Besides the fact that the works described above used QoS values to make decisions, they were also criticized for not addressing QoE. Most of the methods did not include user preference into the decision matrix and even if they did, only one attribute is usually used (usually cost) to indicate the user preference. Identifying user's needs is of utmost importance in order to provide QoE and it cannot be simplified into a single criterion.

### 2.2 AI BASED APPROACHES

MADM techniques need crisp and precise values for the attributes and have been criticized as being unable to handle imprecise and inaccurate data [26]. Therefore AI based network selection algorithms such as Fuzzy AHP were suggested. Fuzzy AHP inserts fuzzy numbers in the pairwise comparison ratio [29]. Fuzzy Inference System uses an inference system to assign the weightage by using a series of rules [6]. Some

researchers, e.g. [32], also used neural network strategies to solve NSPs. The main drawback of AI based approaches is that they have been criticized as too complex and therefore may not suit high speed MN's needs. Because of its complexity, it is not scalable [26,35].

### **2.3 HYBRID APPROACHES**

Combinations of two or more of the above techniques are also popular solutions for NSPs. SAW and MEW were used in [45] to solve NSP for a vertical handover. AHP and GRA are used by [49, 50] to identify the best target network. Fuzzy AHP was used for apportioning weights and ELECTRE determines the ranking of CNs [8]. A combination of fuzzy logic and adaptive neural fuzzy inference system (ANFIS) is proposed in [5]. Alkhawlan & Alsalem [3] uses fuzzy logic, AHP and genetic algorithm to perform network selection.

The methods discussed above use QoS values and sometimes combine user preference (in limited form) to address NSPs. As previously mentioned, this will not bode well in supporting ABC as ABC refers to best connected for a particular user. QoS can be used as a mere guideline to select the best network but only QoE will truly reflect whether the selection is indeed the best for that particular user.

QoE reflects user's perception of how well the network is fulfilling its expectations. It is a more behavioral, cognitive science and psychological concept as opposed to QoS which is a technical concept. Due to that differentiation, it is harder to measure and calculate users' QoE compared to QoS even though QoE essentially refers to perceived QoS. QoE is a subjective value and differs among users. Even though by acquiring excellent QoS will indirectly increase QoE, it may not necessarily translate to higher user satisfaction. Also, ABC, in technical terms, means the best QoS values but in reality it may carry different meanings to different users making QoE values a natural choice to support ABC. QoE based network selection is much more challenging and even more challenging to evaluate its success. Research direction on QoE measurements falls into one of two major categories: subjective and objective [16]. The most popular subjective method to calculate QoE is by using Mean Opinion Score for audio [23] and video [24] as defined by ITU Telecommunication Standardization Sector (ITU-T). Subjective measurements experiments are expensive to conduct and error prone. Therefore, ITU-T also defined objective standards for evaluating the QoE [20, 21, 22]. Many published works [4, 34, 41, 44] dictate ways in which the QoE can be modeled based on QoS values. These focus on creating models that can correctly identify the QoE based on the technical characteristics of the QoS parameters as subjective measures were deemed not practical. In [41], the resulting QoE model is used as a determining factor in network selection. Other works [9, 16] have highlighted how QoE can be calculated in real-time. There are three ways to measure QoE: no-reference (NR), reduced reference (RR) and full-reference (FR). The problem in using these values is that the values are measured at the point where users are experiencing it. That means they cannot be useful when deciding which network to choose as the target network as this decision has to be made prior to connection establishment. On the other hand, we can predict QoE values by using the QoE models derived from QoS values but this means we are not actually basing the network selection on the user's 'real' experience. It is just a predicted 'experience'. Network Selection based on QoE is discussed next.

## 2.4 QoE BASED APPROACHES

In [38], QoE of users who are currently attached to prospective CNs are estimated. This value is used by the current MN as a deciding factor for choosing target CN. CNs in [38] use a pseudo-Subjective Quality Assessment mechanism to estimate the attached user's minimum QoE. This value is also broadcasted to all other users in the vicinity. This essentially defeats the purpose of supporting ABC. By using other users' QoE, this method will project another user's experience onto the current user. Also, users may not be comfortable in sharing their QoE with other users. Additionally, each CN may be supported by different network operators, sharing how their customers are experiencing quality in their respective network may not be good for business on the long run especially if you have to share this information with your own competitors.

Multi-Agent Reinforcement Learning (MARL) technique is used by [16] to select a network to handover to. This is a self-learning method that uses User Perceived Quality as defined in [43] as a reward or penalty to train it.

Shen [46] uses Fuzzy AHP to match QoS parameters (referred to as key Performance Indicators) to QoE values (referred to as Key Quality Indicators). In essence, this is also a QoE modelling technique as well. In [36], a method that performs automatic network selection is proposed. This is achieved by using an analytical model to capture users' preferences. A multi-criteria utility function is used to assign weightages to end user's preferences. User preferences are collected from the user and are kept in the user's preference database. This does not totally relate to QoE but it is used to improve it.

Game theory based network selection is proposed in [37]. The proposed method is said to be executing user-centric network selection. In this case, QoE is defined in terms of only QoS parameters and cost, whereby two groups of users are defined. One type of user is called a good user where high quality of service is expected and is willing to pay a premium cost. On the other hand, a fair user is said to be a user who compromises on the quality and prefers a lower cost. This again falls back to satisfying limited user preferences and not at all the same as fulfilling QoE.

Generally, there are not many researches that used QoE per se as network selection criteria. Most of the researchers use user preference as a generalization of the concept of QoE. User preference is a limited view of QoE. ITU-T has defined QoE as "overall acceptability of an application or service, as perceived subjectively by the end user" [39] while according to ETSI QoE refers to "a measure of user performance based on both objective and subjective psychological measures of using an ICT service or product" [13]. Therefore, it is very clear that user preference as well as QoS values are indicatives of QoE but do not define QoE in the strictest terms. In fact, there is a non-linearity in modelling QoE values based on QoS parameters [18]. User preference can be used to identify user's preference with regard to cost, security and QoS but as per the definition it is only a subset of the real QoE. As shown above modelling QoE from QoS have been tried to enable

selection of the best target network but it is just that a model of the QoE and not really the QoE of the user. Ghahfarokhi [16] has used real-time QoE as a means to predict when is the right time to handover as well as which CN to handover to. But, the method used needs to be trained into making the right decision eventually. During the training phase there is a high possibility that the technique might make an erroneous selection. Also, the QoS values of the CNs are not taken into account and they are actually inferred. In our opinion, if there is a way for CNs to exchange QoS values to the MN, then it should be used as one of the factors in determining the best CN. Networks' QoS values should not be disregarded as it can also be used to eliminate unsuitable CNs from being considered. For an extensive survey of challenges in QoE management in wireless networks, refer to [47].

### 3. PROPOSED FRAMEWORK

Based on the works discussed above, we can safely say that network selection is not a fairly straightforward problem. Both QoE and QoS are complimentary aspects that can be used to identify the most suitable CN. On top of that, aspects of user preferences towards cost, security, preferred network provider are not measured but instead stated by the user and can be very useful in order to formulate a user's QoE. As far as we know, there is no method that combines both QoS and QoE to support network selection. The proposed framework is an extension of a method already presented in [35]. This framework uses AHP for determining weightage and GRA to provide ranking of prospective CNs. In order to provide a holistic solution to NSP and provide ABC, holistic network selection using AHP and GRA (H-AHP-GRA) was suggested in [35]. As QoE values have a growing importance as a factor to consider when selecting CN, H-AHP-GRA is extended to include QoE values. Figure 1 illustrates what is the information used by the new version of H-AHP-GRA (known as H-AHP-GRA henceforth) and its respective sources.

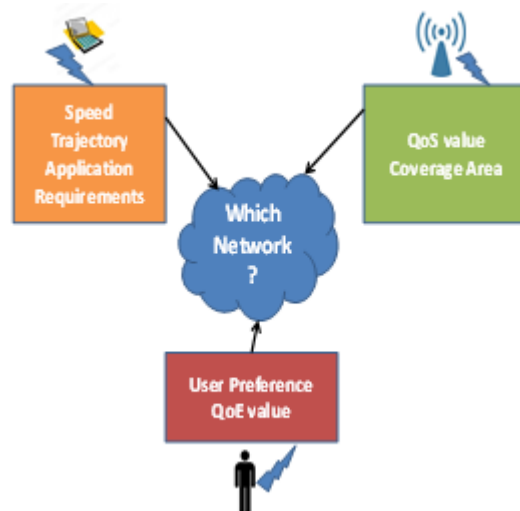


FIGURE 1. Type and Source of Information for H-AHP-GRA

Previous work to solve NSP using a hybrid method of AHP and GRA [49] was criticized as being static and unable to adapt to a dynamic networking environment. The weights assigned remain permanent and does not reflect the current context on which the selection occurs. GRA is recommended because of its non-monotonic and monotonic utilities towards attributes, rendering it suitable to overcome conflicting objectives [35]. On the other hand, AHP is hailed as a simple and scalable method for NSP. MADM algorithms have been praised as extremely suited for a multi criteria decision making problems as in the case of NSP. Figure 1 illustrates that there are various criteria to consider rendering the suggested solution an effective and holistic solution to NSP.

Selection policy is used as a guide to determine the weights for the AHP matrix as well as the GRA ranking. For example, when a MN moves at high speed, certain access networks (i.e. Wi-Fi) will not be able to provide meaningful connection to the said MN because of the limited coverage area. By the time the Wi-Fi network is selected, the MN might need to handover again. Therefore, the MN's speed can be used as an eliminating factor to weed out unsuitable CN from even being considered. Also, as presented in [35], when the MN moves at a high speed it experiences higher packet drops and lower throughputs. This means weightage that is more reflective of the speed of the MN has to be assigned to the criteria of packet drops and throughput. This shows that it is important that the MN's current context be included when identifying the weights and determining the rank. GRA uses three formulas to establish the ranking; the larger the better (i.e. for throughput), the smaller the better (i.e. for delay) and nominal the best (for best-effort values). The selection policy also influences the GRA formula to be used on different attributes. H-AHP-GRA is then applied to rank the CNs. Once connection is established at the selected CN, user's QoE is measured. The calculated QoE can be used to adjust the selection policy. QoE can be measured using user perceived quality (UPQ). The framework presented here uses reduce-reference method to calculate UPQ as defined in [21]. UPQ is then used as a feedback to the selection policy. According to [55], in future, access network selection is expected to be adaptive to user QoE. UPQ calculations have been done extensively for voice traffic as user satisfaction in terms of voice quality is easier to attain as good voice quality is easily defined [16, 40]. Segmental Signal to Noise Ratio (SSNR) has been chosen as the most widely used metric to evaluate voice quality objectively [40]. On the other hand, the most widespread metric used to objectively calculate video quality is Peak Signal to Noise Ratio (PSNR) [27]. Both of these metrics can be used to identify UPQ for both voice and video data streams. The measured UPQ is then compared to satisfaction thresholds [43]. If the UPQ value attained is smaller than the defined threshold values, then the selection policy needs to be adjusted. Also, by using UPQ, unnecessary handoffs can be averted while supporting ABC. ABC in the strictest terms means handover is initiated even when it is unnecessary when a CN with better score shows up. UPQ value can be used to avoid this. If the current UPQ value is above the satisfaction threshold value then ABC is already achieved, why then handover to a 'better' CN.

Also, there are already many researchers that have been using trajectory information to predict when to handover [11, 48]. Trajectory of the MN can be a useful tool to identify suitable CNs. H-AHP-GRA uses trajectory information to identify which CN will have the longest travelling trajectory [35]. In order to

identify this, not only we need to know the MN's travelling trajectory, but also we need to know each CN's coverage area. By using this information a CN that provides lower throughput may still be selected as target network compared to a CN with a higher throughput. If the MN is travelling for a longer duration in the CN with the smaller throughput then the throughput 'experienced' can be better when compared to the other CN [35]. Therefore, the bit rate value collected from CNs can be fine-tuned in tandem with the duration of the travelling trajectory. MNs can use GPS to predict travelling trajectory and sensors to identify MN's speed.

Although collecting QoS values is not addressed in this article, IEEE 802.21 Media Independent Handover (MIH) [19] mechanism can be used to perform the collection. There have been many related works [10, 12, 31] that have proven that using IEEE 802.21 is feasible in collecting and exchanging information.

H-AHP-GRA is a terminal controlled, user-assisted and network assisted methodology. By enabling it to be terminal controlled, the mechanism is decentralized. By including user's input, QoE and user's preference is addressed. By being network assisted, CN's QoS values can be included as input. Target network selection can occur when handover is imminent or when ABC is practiced. Either way, Figure 2 illustrates how H-AHP-GRA performs network selection.

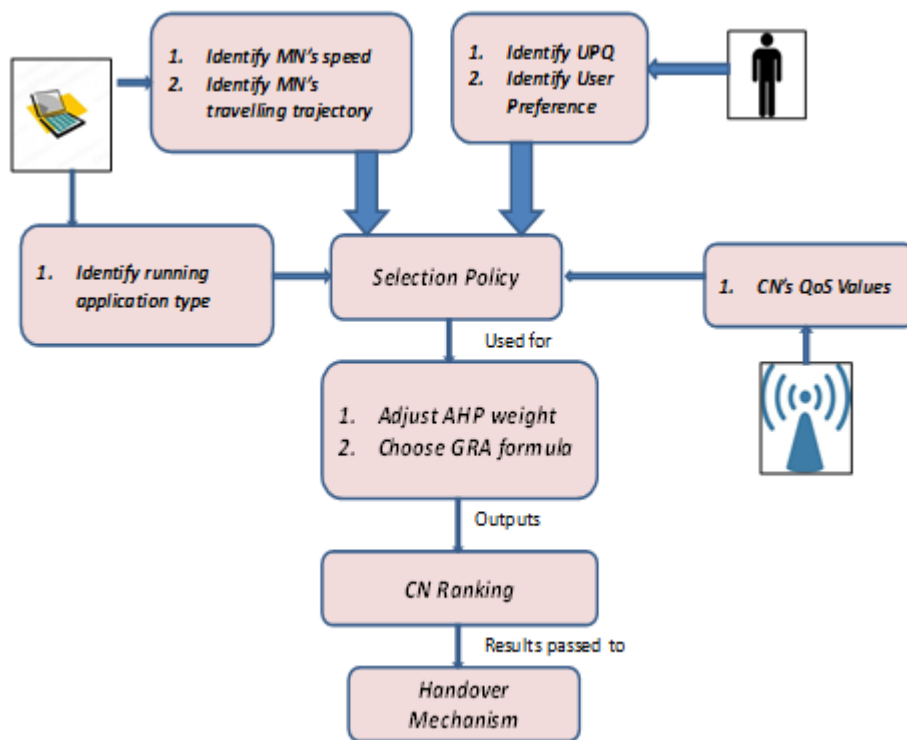


FIGURE 2. – H-AHP-GRA Implementation

#### 4. RESULTS AND DISCUSSION

There are four traffic classes each in IEEE 802.11e, 802.16e and 3GPP and each of this traffic classes have different QoS needs. The four traffic classes are as listed in Table 1.



TABLE 1.  
IEEE 802.16e, 802.11e and 3GPP Traffic Class

	802.11e	802.16e	3GPP
C1	AC_VO (voice)	UGS, eRT-VR	Conversational
C2	AC_VI (video)	Rt-VR	Streaming
C3	AC_BK (background)	Nrt-VR	Background
C4	AC_BE (best-effort)	BE	Interactive

Authors in [2, 14, 15] have shown how to match and correlate the QoS indicators of these standards with IEEE 802.21. This is shown in Table 2 below. Therefore, CNs of different access type can be compared objectively.

TABLE 2.  
QoS Parameter Mapping Table

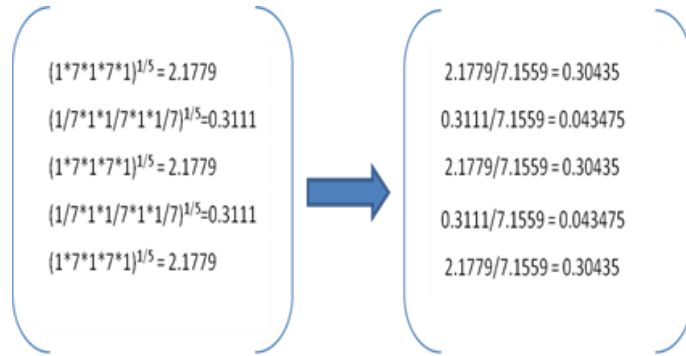
802.21	802.11	802.16	3GPP
Max bit rate	Peak data rate	Max. sustained traffic rate	Max bit rate
Min bit rate	Min data rate	Min reserved traffic rate	Guaranteed bit rate
Packet error rate	Packet error rate	Packet error rate	SDU error ratio
Delay	Delay bound	Max latency	Transfer delay
Jitter	Jitter	Tolerated jitter	Delay variation
Priority	User priority	Traffic priority	Traffic handling priority

Generally, C1 class traffic requires stringent priority, delay and jitter requirements. Therefore, the following AHP matrix for C1 traffic is recommended [52] and depicted in Table 3.

TABLE 3.  
AHP matrix for C1

C1	Priority	Bit Rate	Delay	PER	Jitter
Priority	1	7	1	7	1
Bit Rate	1/7	1	1/7	1	1/7
Delay	1	7	1	7	1
PER	1/7	1	1/7	1	1/7
Jitter	1	7	1	7	1

The weights of C1 traffic are determined using geometric mean method as shown below.



Scenario 1:

There are two CNs to choose from and their attribute values are listed in Table 4.

TABLE 4.  
Candidate Networks Attribute Values

Candidate Network	Priority	Available data rate	Average Delay	Average Jitter	Average Packet Error Rate
Network1	20	1 Mbps	50ms	10ms	0.01
Network2	10	2Mbps	80ms	10ms	0.008

GRA is the only ranking technique that has three formulas to identify the utility of an attribute. Other ranking techniques describe the utility of an attribute as increasing (i.e throughput) or decreasing monotonically (i.e delay) whereas GRA has an additional third formula that is known as closer-to-desired-value-the-better or nominal-the-best. This third formula is very handy for situations where the selection policy dictates a not so straightforward solution. Also, the attribute values need to be normalized as the values are of different units. For a NSP that has  $m$  candidate networks with  $n$  attributes, the  $i_{th}$  alternative can be translated into its equivalent comparability sequence  $x_i = (x_{i1}, x_{i2}, \dots, x_{ij}, \dots, x_{in})$  using one of the following equations where  $i = 1, 2, \dots, m$  and  $j = 1, 2, \dots, n$ . [35].

$$x_{ij} = \frac{y_{ij} - \text{Min}\{y_{ij}\}}{\text{Max}\{y_{ij}\} - \text{Min}\{y_{ij}\}} \quad (1)$$

$$x_{ij} = \frac{\text{Max}\{y_{ij}\} - y_{ij}}{\text{Max}\{y_{ij}\} - \text{Min}\{y_{ij}\}} \quad (2)$$

$$x_{ij} = 1 - \frac{|y_{ij} - y_{ij}^*|}{\text{Max}\{\text{Max}\{y_{ij}\} - y_{ij}^*, y_{ij}^* - \text{Min}\{y_{ij}\}\}} \quad (3)$$

where  $y_{ij}$  is the value of alternative  $i$ 's attribute  $j$  value,  $y^*_j$  refers to the closer to the desired value. Equation 1 is used on the larger the better attributes, equation 2 is for the smaller the better attributes and equation 3 is nominal the best. Equation 1 is used on Available data rate and Priority whereas Equation 2 is used on all the other values. This is to normalize the attribute values so that they can be compared objectively to each other. For example, for available data rate, the maximum value is 2 from Network 2 and the minimum value is 1 from Network 1. Using Equation 1, the normalized value for network 1 is  $(1-1)/(2-1) = 0$ . The entire normalize values are shown Table 5.

TABLE 5.  
Normalised Value

Candidate Network	Priority	Available data rate	Average Delay	Average Jitter	Average Packet Error Rate
Network 0	1	1	1	1	1
Network1	1	0	1	0	0
Network2	0	1	0	0	1

For a CN, if the normalized value for an attribute is nearest to 1, then that CN is the best CN for that particular attribute. Next a reference sequence (network 0) that represents the best alternative where the normalized values are all 1's is defined and is also added to Table 5. The next step is to find the network that has the closest comparability sequence to the reference sequence. This is identified by a grey relational coefficient (GRC). The network with the largest GRC is the best CN. The following equation calculates GRC [28].

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{ij} + \zeta \Delta_{max}} \quad (4)$$

$$\Delta_{ij} = |x_{0j} - x_{ij}|,$$

$$\Delta_{min} = \text{Min}\{\Delta_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\},$$

$$\Delta_{max} = \text{Max}\{\Delta_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\},$$

**$\zeta$  is the distinguishing coefficient,  $\zeta \in [0, 1]$**

If  $\Delta_{min}=0$ ,  $\Delta_{max}=1$ , and  $\zeta=0.5$ , then GRC for Available data rate for Network 1 is  $\gamma(\text{network 0}, \text{network 1}) = (0 + 0.5 \times 1) / (1 + 0.5 \times 1) = 0.5/1.5 = 0.3333$ . GRC for all attributes for both CNs is shown in Table 6.

TABLE 6.

GRC Values

Candidate Network	Priority	Available data rate	Average Delay	Average Jitter	Average Packet Error Rate
Network 1	1	0.3333	1	0.3333	0.3333
Network 2	0.3333	1	0.3333	0.3333	1

Next, the grey relational grade between each CN and Network 0 is calculated.

$$\text{Grey relational grade (Network 0, Network i)} = \sum_{j=1}^n w_j \gamma(\text{Network 0, Network i})$$

where  $w_j$  refers to the weight of the said attribute.

$$\text{Network 1 grade} = 0.30435 \times 1 + 0.043475 \times 0.3333 + 0.30435 \times 1 + 0.30435 \times 0.3333 + 0.043475 \times 0.3333 = 0.43477$$

$$\text{Network 2 grade} = 0.30435 \times 0.3333 + 0.043475 \times 1 + 0.30435 \times 0.3333 + 0.30435 \times 0.3333 + 0.043475 \times 1 = 0.39127$$

Based on the grade network 1 will be selected as best network.

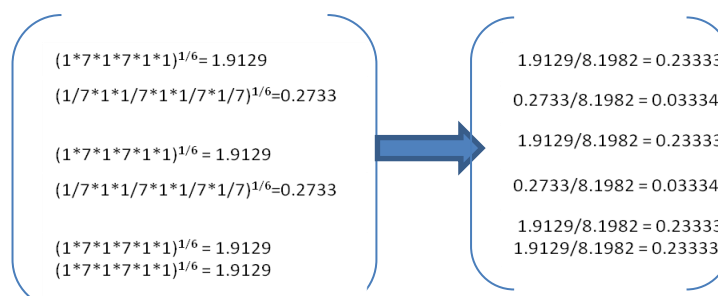
**Scenario 2:**

Now let us say the user preference has indicated that cost is extremely important. The running application is still C1. And cost is added to the AHP matrix and Table 7 shows the new matrix.

TABLE 7.  
New AHP matrix for C1 traffic

C1	Priority	Bit Rate	Delay	PER	Jitter	Cost
Priority	1	7	1	7	1	1
Bit Rate	1/7	1	1/7	1	1/7	1/7
Delay	1	7	1	7	1	1
PER	1/7	1	1/7	1	1/7	1/7
Jitter	1	7	1	7	1	1
Cost	1	7	1	7	1	1

The geometric mean method is used again to formulate the weights for the attributes:



Equation 1 is used on Priority whereas Equation 2 is used on delay, PER, jitter and cost. Equation 3 will be applied on bit rate. This is because cost is considered very important and usually cost is charged according to the bit rate delivered. Therefore, instead of using the larger-the-better equation on bit rate, nominal-the-best is applied to bit rate so as to reduce cost. The attribute values are same as in Table 4 with cost for Network 1 is 0.9 and cost for network 2 is 0.1 added. The normalized values are shown in Table 8.

TABLE 8.  
Normalized Values for Scenario 2

Candidate Network	Priority	Available data rate	Average Delay	Average Jitter	Average Packet Error Rate	Cost
Network 0	1	1	1	1	1	1
Network1	1	0	1	0	0	0
Network2	0	0	0	0	1	1

The normalized value for bit rate is defined using Equation 3 whereby for network 1 it is calculated as shown below. The nominal-the-best value is chosen to be 1.5.

$$1-(|1 - 1.5| / \text{Max}(2 - 1.5, 1.5 - 1)) = 1 - (0.5 / 0.5) = 0$$

Similar calculation is done for Network 2. GRC is evaluated for Network 1 and 2 and is listed in Table 9.

TABLE 9.  
GRC Values for Scenario 2

Candidate Network	Priority	Available data rate	Average Delay	Average Jitter	Average Packet Error Rate	Cost
Network1	1	0.3333	1	0.3333	0.3333	0.3333
Network2	0.3333	0.3333	0.3333	0.3333	1	1

The final step is to rank the networks based on grey relational grade. Network 1 grade = 0.6444 and Network 2 grade = 0.51109.

Based on the grade, this time around Network 1 is again selected as the best network. Even though the same network is selected, it is based on maintaining low cost as well as reasonable bit rate as opposed to the previous scenario whereby only the best (in every way) CN is selected. In the same way as scenario 2 is depicted, the selection policy will be used to dictate the AHP weights as well as the GRA formula to use. There have been many other researchers [49, 50] that have defined various enhancements to the use of AHP and GRA but the enhancements are used to improve the mathematical aspect of the respective solution or to be used in tandem with imprecise attribute values [29]. However, what they did not do is to make the

network selection mechanism dynamic and change according to user's, terminal's and CN's context. As shown in Scenario 2, just by including user's preference towards cost, a different grey relational grade is acquired. Similarly, as shown in Figure 2, the selection policy must be dynamic to identify the context on which the network selection occurs.

The initial question was whether QoE or QoS is better for solving NSPs. Even though, research is moving towards QoE, it involves a lot of subjective research in the area of cognitive and behavioral psychology. QoE in the real sense of the definition is very complex and difficult to measure. Therefore, we have used UPQ to measure QoE. UPQ does not take into account the subjective aspects of QoE. User's mood is also included as a factor for QoE. How do we measure mood? If so, the QoE can change even though in every other aspect, the context is the same, just because the user is in a bad mood. UPQ is a concise mechanism for measuring QoE and can form a good substitute. ABC refers to the best connection experienced by the user. UPQ would be the best measure of this. If the current UPQ is below satisfactory level then this can also trigger a change in the AHP weights and/or GRA formula so that ABC is achieved. In fact, UPQ can also be used as a factor to decide when to handover. When UPQ degrades below an acceptable level, handover can be initiated.

## **5. CONCLUSION AND FUTURE WORK**

This article has presented a framework for NSP that is both dynamic and context-aware. It combines both QoS and QoE to solve NSP as they are both important for ABC. QoS defines the technical aspects of ABC and QoE (as in UPQ) the non-technical aspects. In addition to this, user's profile and MN's context is included too. This is done by using a selection policy that is fluid and dynamic. This selection policy is then used to dictate the AHP weights and the GRA formula.

Future work would be to include more scenarios depicting the impact of MN's speed, battery lifetime and travelling trajectory and also UPQ towards network selection. Simulation needs to be carried out to test out the efficacy of the proposed method.

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