2012 International Conference on System Engineering and Modeling (ICSEM 2012)
IPCSIT vol. 34 (2012) © (2012) IACSIT Press, Singapore

A Quantitative Approach for Evaluating QOS in Wireless Cellular Networks using the Analytic Hierarchy Process Method

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Abstract. There is a need to quantitatively evaluate the quality of service of wireless cellular networks in order to make an informed decision about the state of the network for users and operators. Without a structured technique, trying to evaluate the overall quality of service of different networks in a country can be a very challenging task. In this paper we will adapt the classical Analytic Hierarchy Process method to quantitatively evaluate the network to determine which network provides the best quality of service in a particular location.

Keywords: AHP, QOS, Wireless Cellular Network, Evaluation.

1. Introduction

Without a structured technique, trying to evaluate the overall quality of service (QoS) of different wireless cellular networks in a country can be a very challenging task. Usually after choosing your QoS evaluation parameters such jitter, throughput, latency and data loss you have to determine how to compare each network on these parameters, how to quantify this information, and how to aggregate all your measurements into a meaningful metric. Finally, you have to decide how to interpret your results.

One approach is to use the Analytic Hierarchy Process (AHP) to evaluate the QoS of networks. AHP provides a proven, effective means to deal with complex decision making with multiple goals, criteria and alternatives. AHP converts various evaluations metrics value to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element in the problem, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way.

In this paper we will adapt the classical AHP process to evaluate the QoS offered by the various wireless cellular networks in determine the network that offers the best QoS in Nigeria.

2. AHP

AHP is a method for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria [1]. With AHP, the decision maker selects the alternative that best meets his or her decision criteria while developing a numerical score to rank each decision based on how well each alternative meets them.

The first step in AHP is to organize the critical aspects of a problem into a hierarchy rather like a family tree. The essence of the process is the decomposition of a complex problem into a hierarchy with a goal to be achieved at the top of the hierarchy, criteria and sub-criteria at lower levels of the hierarchy to achieve the goal, and finally decision alternatives at the bottom of the hierarchy of which we want to determine the best outcome to achieve the given goal – this is illustrated in figure 1.

In the second step, the decision makers systematically evaluate the various alternatives in the hierarchy by comparing them to one another with respect to the criteria. In making these comparisons, the decision makers can use concrete data about the alternatives, but they typically use their judgments about the alternatives' relative meaning and importance. The same process is made for comparing the criterion with respect to the goal. This process results in a comparison matrix as shown in figure 2.

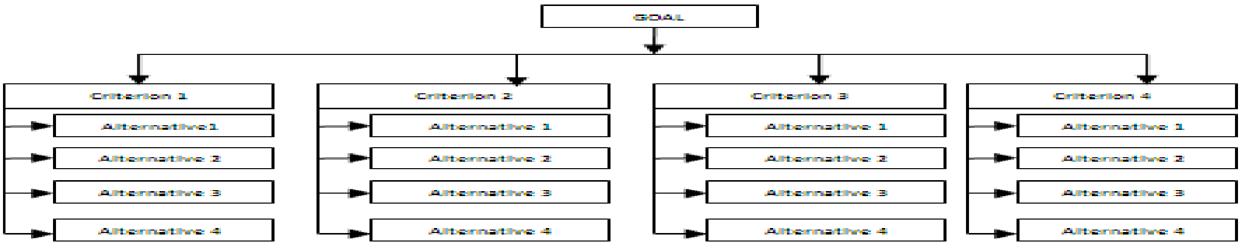

Figure 1 – AHP Hierarchy

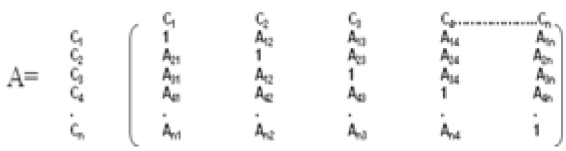

Figure 2 – Comparison Matrix

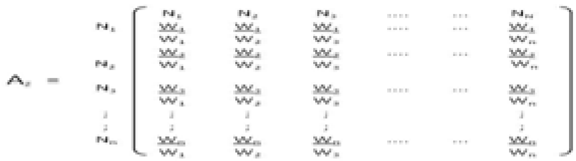

Figure 3 – Weight Matrix

Table 1: Proposed pair-wise comparison scale

Scale	Description
7	Much Better Than The Threshold
6	Better Than The Threshold
5	Slightly Better Than The Threshold
4	About The Same As The Threshold
3	Slightly Worse Than The Threshold
2	Worse Than The Threshold
1	Much Worse Than The Threshold

In figure 2, at a given level in the hierarchy, the comparison matrix A is created by putting the result of pair-wise comparison of element i with element j into the position a_{ji}. The result is represented as weight where a low weight indicates less importance in the element comparison whereas a high weight indicates a greater importance in the element comparison. The weights are obtained from table 1 which was developed by the authors. The table is an adaptation of the 5 pair-wise scales used by [2] which is difficult to use for QoS because internationally agreed thresholds for QoS parameters such as jitter that may have a value that may be less than or greater than the measured parameter value. The weight is derived by comparing the value of element by comparing against an international standard. Note that N is number of criteria to be evaluated, C_i is the i^{th} criteria, and A_{ij} is the comparison of the i^{th} criteria with respect to the j^{th} criteria. This process is repeated upwards for each level until the top of the hierarchy is reached. A comparison matrix will be generated for each criteria and another to compare all the criteria.

The AHP method then computes and aggregates the eigenvectors for each comparison matrix until the composite final vector of weight coefficients for alternatives is obtained. The entries of the final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of the hierarchy. A decision maker may use the eigenvectors according to his particular needs and interests.

We then derive a weight matrix A_z for each comparison matrix where a weight vector W is computed to determine the relative importance of each alternative in the comparison matrix – this is shown in figure 3. Here, assuming we have the weight vector $w= [\ w_1\ w_2\ \ldots\ldots w_n]$, the value of w_i represents the relative importance of alternative i of the associated comparison matrix based on criterion C_z.

We then normalise A_z using the formula shown figure 4. Here A_{ji} represents the A^{th} element at row j and column i of the respective alternative versus alternative or criteria versus criteria comparison matrix.

Given A_{norm}, a weight eigenvector is then calculated using the formula in figure 5. The overall weight coefficient with respect to the goal for each decision alternative is then obtained in this weight eigenvector. Using the equation in figure 5 the alternatives are compared with each other in terms of each one of the decision criteria which results in an overall ranking with respect to the criteria.

Figure 4 – Normalised Matrix

$$W = \left[w_1 = \frac{\sum_{i=1}^{n} A_{1i}}{n} \quad w_2 = \frac{\sum_{i=1}^{n} A_{2i}}{n} \quad \ldots\ldots \quad w_n = \frac{\sum_{i=1}^{n} A_{mi}}{n} \right]$$

Figure 5 – Weight vector calculation

Once all weight eigenvectors in the evaluation problem have been computed, they are used to determine the alternatives that provide the best goal. For example, if a problem has *M* alternatives and *N* criteria, then the decision maker is required to construct *N* judgment matrices (one for each criterion) of order *MxM* and one judgment matrix of order *NxN* [3]. If we assume that the output of each alternative judgment matrix is $W^{A}{}_{i}$ where $i=1,2,3\ldots\ldots N$ and $W^{C}{}_{i}$ is the output of the criteria judgment matrix then we need to multiply them to obtain the final score of the goal at the top of the hierarchy – this calculation is shown in figure 6.

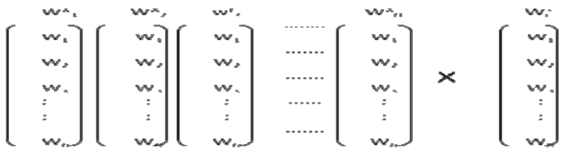

Figure 6: Final AHP Matrix Configuration

$$S_i = \sum_{i=1}^{n} W_i \,(WA_i\,) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Figure 7 – Calculation of overall scores

To obtain the final score of the goal we compute the relative preference for alternative *i*, we let $WA = W_i$, and $W_C = WA$, and define S_i as the overall score for network *i,* where *i* represents the i^{th} element of the vectors WA and W_C. S_i is calculated as shown in figure 7. Once overall scores are computed for all networks, the highest score is identified as the alternative providing the best goal, followed by the second highest score, and so on.

3. Case Study

The first step to solving the problem is to decompose the problem into an AHP hierarchy as shown in figure 9 – this identifies the goal, criteria and alternatives for our case study. For each network in our study we obtained the average value of the QoS parameters we were measuring for web browsing. The values were obtained using measurement tools such as *ping* and *traceroute*. The measurements were taken in Yola, Nigeria in April 2011. Our recorded measurements are shown in table 4.

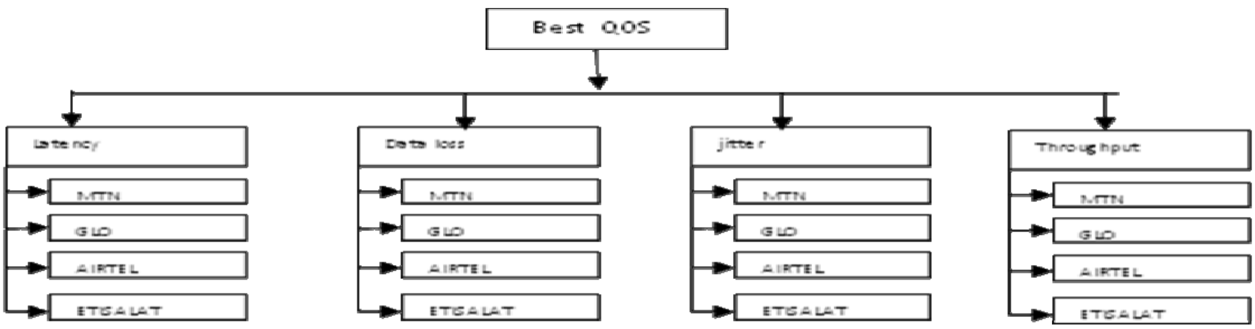

Figure 9 AHP Diagram for Case study

We present a case study using our proposed approach in order to investigate the efficacy of our technique. Our case study is a comparative evaluation of QoS of data services for the following four cellular networks in Nigeria: *MTN, Glo, Airtel* and *Etisalat*. The basic criteria used to evaluate QoS are *throughput, latency, data loss* and *jitter* - these factors indicate the state of each network's responsiveness, reliability and speed at any particular location.

Table 4 - Mean value of network performance for each network

criteria	jitter	loss	latency	throughput
Etisalat	103.75	33.26	3.58	545
MTN	110	34.76	4.63	703
Airtel	83.75	36.31	3.66	460
Glo	115	31.43	6.04	623.5

The next step is to create all the comparison matrices required in a pair-wise manner. There are 5 comparison matrices in all - one for the criteria comparisons with respect to the goal and four for each of the criteria with respect to alternatives. We shall look at each of these.

Table 5 – Criteria Comparison Matrix
Table 6 – Normalised Comparison Matrix for
Table 7 – Weighted criteria versus criteria Eigenvector

	4	4	7	5
criteria	jitter	loss	latency	throughput
jitter	1.00	1.00	0.57	0.80
loss	1.00	1.00	0.57	0.80
latency	1.75	1.75	1.00	1.40
throughput	1.25	1.25	0.71	1.00
total	5.00	5.00	2.86	4.00

	jitter	loss	latency	through put
jitter	0.20	0.20	0.20	0.20
loss	0.20	0.20	0.20	0.20
latency	0.35	0.35	0.35	0.35
throughput	0.25	0.25	0.25	0.25

jitter	0.20
loss	0.20
latency	0.35
throughput	0.25

Criteria versus criteria pair-wise comparisons were carried out for each network based on our proposed scale in table 3 – this resulted in table 5 which is the equivalent of the comparison matrix of figure 2. Since the measurements were taken from a network which was being used for web browsing factors such as jitter and data loss were not so critical, therefore we gave them the value of 4. However latency was the most important factor followed by throughput so we gave them the values 7 and 5 respectfully. Table 5 is then normalised using the formula in the matrix of figure 4 – this is shown in table 6. Using the formula in figure 5 the weighted eigenvector for the comparison matrix for criteria is obtained in table 7.

Table 8 – Network Comparison Matrix for jitter
Table 9 - Normalised Network Comparison Matrix for
Table 10 – Weighted Jitter Eigenvector

	2	1	3	1
Jitter	Etisalat	MTN	Airtel	Glo
Etisalat	1.00	2.00	0.67	2.00
MTN	0.50	1.00	0.33	1.00
Airtel	1.50	3.00	1.00	3.00
Glo	0.50	1.00	0.33	1.00
Total	3.50	7.00	2.33	7.00

Jitter	Etisalat	MTN	Airtel	Glo
Etistat	0.29	0.29	0.29	0.29
MTN	0.14	0.14	0.14	0.14
Airtel	0.43	0.43	0.43	0.43
Glo	0.14	0.14	0.14	0.14

Etisalat	0.29
MTN	0.14
Airtel	0.43
Glo	0.14

Network versus network pair-wise comparisons were carried out by using the international agreed threshold for jitter to determine the pair-wise rating of each network based on our proposed scale – this resulted in obtaining table 8 which is the equivalent of the comparison matrix of figure 2. Jitter in the Etisalat's network was far lower than the threshold so we used the value 2. The MTN and Glo network values were far worse than the threshold value so we used the value 1. Airtel value was slightly worse than the threshold so we used the value 3. Table 8 is then normalised using the formula in the matrix of figure 4 – this is shown in table 9. Using the formula in figure 5 the weighted eigenvector for the comparison matrix for jitter is obtained in table 10.

Table 11 – Network Comparison Matrix for throughput
Table 12 - Normalised Network Comparison Matrix for
Table 13 – Weighted Throughput Eigenvector

	4	5	5	4
throughput	Etistat	MTN	Airtel	Glo
Etisalat	1.00	0.80	0.80	1.00
MTN	1.25	1.00	1.00	1.25
Airtel	1.25	1.00	1.00	1.25
Glo	1.00	0.80	0.80	1.00
	4.50	3.60	3.60	4.50

throughput	Etisalat	MTN	Airtel	Glo
Etisalat	0.22	0.22	0.22	0.22
MTN	0.28	0.28	0.28	0.28
Airtel	0.28	0.28	0.28	0.28
Glo	0.22	0.22	0.22	0.22

Etistat	0.22
MTN	0.28
Airtel	0.28
Glo	0.22

Table 14 – Network Comparison Matrix for data loss
Table 15 - Normalised Network Comparison Matrix for
Table 16 – Weighted data loss Eigenvector

	3	2	3	1
loss	Etistat	MTN	Airtel	Glo
Etisalat	1.00	1.50	1.00	3.00
MTN	0.67	1.00	0.67	2.00
Airtel	1.00	1.50	1.00	3.00
Glo	0.33	0.50	0.33	1.00
	3.00	4.50	3.00	9.00

Loss	Etisalat	MTN	Airtel	Glo
Etistat	0.33	0.33	0.33	0.33
MTN	0.22	0.22	0.22	0.22
Airtel	0.33	0.33	0.33	0.33
Glo	0.11	0.11	0.11	0.11

Etistat	0.33
MTN	0.22
Airtel	0.33
Glo	0.11

Table 17 – Network Comparison Matrix for latency
Table 18 - Normalised Network Comparison Matrix for
Table 19 – Weighted latency Eigenvector

	2	1	4	2
Latency	Etisalat	MTN	Airtel	Glo
Etisalat	1.00	2.00	0.50	1.00
MTN	0.50	1.00	0.25	0.50
Airtel	2.00	4.00	1.00	2.00
Glo	1.00	2.00	0.50	1.00
	4.50	9.00	2.25	4.50

Latency	Etisalat	MTN	Airtel	Glo
Etistat	0.22	0.22	0.22	0.22
MTN	0.11	0.11	0.11	0.11
Airtel	0.44	0.44	0.44	0.44
Glo	0.22	0.22	0.22	0.22

Etisalat	0.22
MTN	0.11
Airtel	0.44
Glo	0.22

Figure 10 – Final AHP of problem
Table 20 – Final Scores for each network

criteria	Jitter	Throughput	Loss	Latency
Etistat	0.29	0.22	0.33	0.22
MTN	0.14	0.28	0.22	0.11
Airtel	0.43	0.28	0.33	0.44
Glo	0.14	0.22	0.11	0.22

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Jitter	0.20
Throughput	0.20
Loss	0.35
Latency	0.25

Etisalat	0.27
MTN	0.19
Airtel	0.37
Glo	0.17

The same process was applied to the criteria *throughput* and the results are shown in tables 11 to 13, to *data loss* and the results are shown in tables 14 to 16 and finally to *latency* and the results are shown in tables 17 to 19. Using the formula in figure 6 we compute the final AHP of the problem as shown in figure 10 – this results in the eigenvector shown in table 20 which gives the final rankings of the QoS of the cellular networks under investigation. From the table it can be seen that Airtel's network offers the best QoS, followed by Etisalat, then MTN and Glo.

4. Related Work

In [2] the authors proposed a comprehensive evaluation scheme for QoS of wireless network based on grey clustering and rough set theories in heterogeneous environments. Their proposed scheme stated that the QoS evaluation result in a wireless network can be classified into good, normal or bad. However, this work remains a form of a statistical model which needs to be evaluated.

In [4] the authors presented an evaluation of QoS in packet routing which satisfies the requirements of performance and maximizes the utilization of a network's resources by using an intelligent selection of paths based on the resources needed. Their research is focused on the application of computational intelligence in a prototype of inter-domain routing based on policies. The research was based on investigating how QoS is related to the routing, within a domain. This work remains an analytical model that also needs to be evaluated.

5. Summary and Conclusions

An approach to evaluating QoS in competing networks is to use the AHP. AHP provides a proven and effective means to deal with complex decision making with multiple goals, criteria and alternatives. AHP is a method for formalizing decision making where there are a limited number of choices but each has a number of attributes and it is difficult to formalize some of those attributes. It can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria and expediting the decision-making process.

In this paper we have shown that AHP is a tool that can be used to compare multiple networks and determine the network that provides the best QoS based on users' perception of quality. The output provided by the AHP approach can be used as a unified measurement of the perceived QoS by users on different networks.

6. References

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