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A Hybrid Technique for Quality of Service Evaluation of Cellular Wireless Networks

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Abstract: To make an informed decision about the state of a wireless celullar network for users and operators there is a need to quantitatively evaluate the quality of service using a structured technique. In this paper we will adapt the classical Analytic Hierarchy Process method to quantitatively evaluate a wireless cellular network in Nigeria to determine which period of the day provides the best quality of service for a particular geographical location.

Keywords: Analytic Hierarchy Process, Quality of Service, Wireless Cellular Network

I. INTRODUCTION

Evaluating the overall quality of services (QoS) of different networks in a country requires a structured technique. Usually after choosing your attributes, you have to determine how to compare each network on each attribute, how to quantify that information and how to aggregate all the data into a meaningful metric in order to decide how to interpret your results.

To properly evaluate QoS of data services in cellular networks, analysts must follow a methodology that considers user-experiences in specific application scenarios [1]. Furthermore, the evaluation methodology must allow users to compare how well a network performs (relative to competitors) in the same geographical region based on predefined evaluation criteria. One such approach is to use the Analytic Hierarchy Process (AHP) to evaluate QoS in competing networks.

AHP is a method for formalizing decision making where there are a limited number of choices and each has a number of attributes some of which are difficult to formalize. AHP can assist with identifying and weighting selection criteria, analyzing the data collected for each criteria and expediting the decision-making process. AHP is a technique that is helpful in capturing both subjective and objective evaluation measures and providing a useful mechanism for checking the consistency of the valuation measures.

In this paper we will adapt the classical AHP process to evaluate the QoS offered by a specific wireless cellular network in Nigeria to determine which period of the day offers best QoS. The output provided by the AHP approach can be used as unified measurement of the perceived QoS by users on different networks.

The structure of this paper is as follows. In section 2 we describe the classical AHP process and we adapted it to determine the QoS for a wireless cellular network. In section 3 we describe how we applied the classical AHP process to rank the QoS of a wireless cellular network in Nigeria for different periods of day for a specific location. Section 4 discusses related work and final conclusions are given in section 5.

II. TYPE ANALYTIC HIERARCHY PROCESS

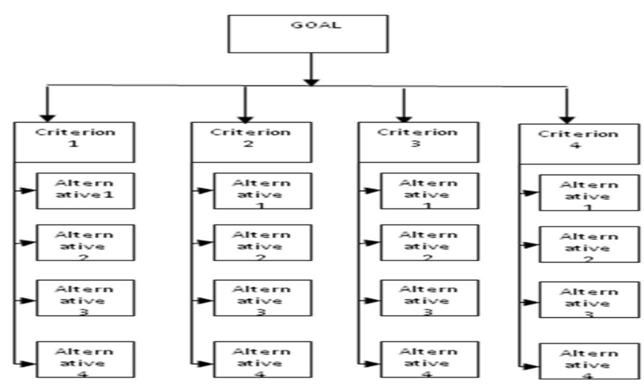

Figure 1 – AHP Hierarchy

AHP is a methodology for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria [2]. 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 alternative 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. This involves decomposing 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.

$$A= \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ . \\ C_n \end{array} \begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 \ldots\ldots & C_n \\ 1 & A_{12} & A_{13} & A_{14} & A_{1n} \\ A_{21} & 1 & A_{23} & A_{24} & A_{2n} \\ A_{31} & A_{12} & 1 & A_{34} & A_{3n} \\ A_{41} & A_{42} & A_{43} & 1 & A_{4n} \\ . & . & . & . & . \\ A_{n1} & A_{n2} & A_{n3} & A_{n4} & 1 \end{array}$$

Figure 2 – Comparison Matrix

The second step in AHP requires the decision makers to 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.

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 a 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 [3] 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 [4]. A comparison matrix will be generated for each criteria and another to compare all the criteria.

The third step in AHP involves computing and aggregating 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 [5]. A decision maker may use the eigenvectors according to his particular needs and interests.

$$A_z = \begin{array}{c} \\ N_1 \\ \\ N_2 \\ N_3 \\ ; \\ ; \\ N_n \end{array} \left\{ \begin{array}{cccccc} N_1 & N_2 & N_3 & \ldots. & \ldots & N_N \\ \frac{W_1}{W_1} & \frac{W_1}{W_2} & \frac{W_1}{W_3} & \ldots. & \ldots & \frac{W_1}{W_n} \\ \frac{W_2}{W_1} & \frac{W_2}{W_2} & \frac{W_2}{W_3} & \ldots. & \ldots & \frac{W_2}{W_n} \\ \frac{W_3}{W_1} & \frac{W_3}{W_2} & \frac{W_3}{W_3} & \ldots. & \ldots & \frac{W_3}{W_n} \\ ; & ; & ; & & & ; \\ ; & ; & ; & & & ; \\ \frac{W_n}{W_1} & \frac{W_n}{W_2} & \frac{W_n}{W_3} & \ldots. & \ldots & \frac{W_n}{W_n} \end{array} \right\}$$

Figure 3 – Weight Matrix

The fourth step of AHP is to 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.

$$A_{norm} = \left[\begin{array}{ccc} \dfrac{A_{11}}{\sum_{j=1}^{n} A_{j1}} & \ldots\ldots & \dfrac{A_{1n}}{\sum_{j=1}^{n} A_{jn}} \\ . \quad . & & . \quad . \\ . \quad . & & . \quad . \\ \dfrac{A_{n1}}{\sum_{j=1}^{n} A_{j1}} & \ldots\ldots & \dfrac{A_{nn}}{\sum_{j=1}^{n} A_{jn}} \end{array} \right]$$

Figure 4 – Normalised Matrix

The fifth step of AHP is to 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.

$$W = \left(w_1 = \frac{\sum_{i=1}^{n} A_{1i}}{n} \quad w_2 = \frac{\sum_{i=1}^{n} A_{2i}}{n} \quad \ldots\ldots \quad w_n = \frac{\sum_{i=1}^{n} A_{ni}}{n} \right)$$

Figure 5 – Weight vector calculation

Given A_{norm}, the sixth step of AHP is to derive a weight eigenvector which is 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.

Given all weight eigenvectors, the final step of AHP is 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* [6]. 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.

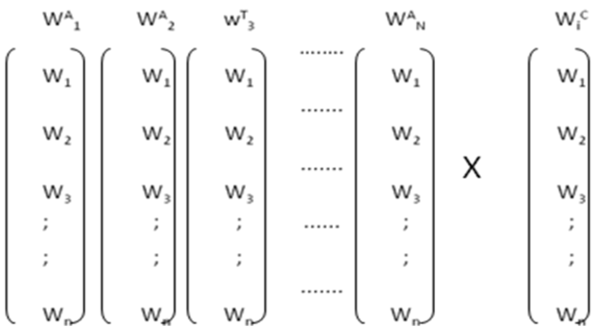

Figure 6: Final AHP Matrix Configuration.

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.

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

Figure 7 – Calculation of overall scores

Once overall scores are computed, the highest score is identified as the alternative providing the best goal, followed by the second highest score, and so on.

III. 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 the QoS for web browsing for the *MTN* cellular network in Nigeria for different periods of the day: *morning*, *afternoon*, *evening* and *night*. *Morning* is considered between 7am-12pm, *Afternoon* between 1pm-6pm, *Evening* is between 7pm-12am, and *Night* is between 1am-6am. The basic criteria used to evaluate the 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. The values were obtained using measurement tools such as *ping* and *traceroute*. The measurements were taken in Yola, Nigeria in April 2011. The set up on which the measurements were obtained are described in our paper [7].

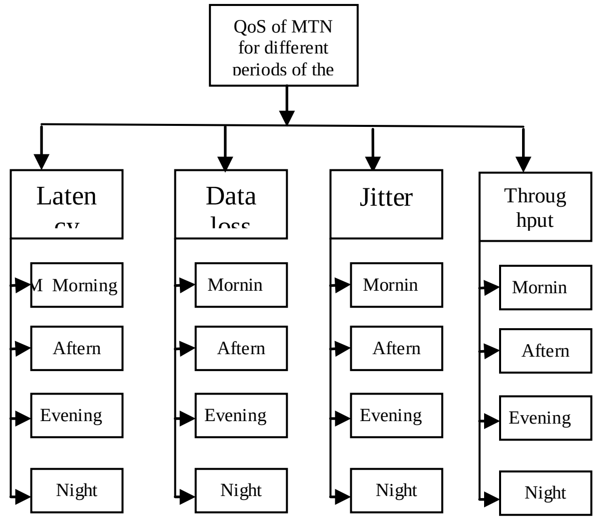

Figure 8: Network QoS Evaluation hierarchy

The first step to solving the problem is to decompose the problem into an AHP hierarchy as shown in figure 8 – this identifies the goal, criteria and alternatives for our case study.

Table 2 - Mean value of network performance for each network

Period	Jitter	Data Loss	Throughput	Latency
Morning	120	3.83	43.56	648
Afternoon	115	6.00	14.35	846
Evening	150	7.00	8.69	758
Night	55	1.67	72.43	563

Our recorded measurements for each criterion are shown in table 2.

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 3 – Criteria Comparison Matrix

	4	**4**	**7**	**5**
Criteria	**Jitter**	**Data Loss**	**Latency**	**Throughput**
Jitter	1.00	1.00	0.57	0.80
Data 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

Table 4 – Normalised Comparison Matrix for criteria versus criteria

	Jitter	**Data loss**	**Latency**	**Throughput**
Jitter	0.20	0.20	0.20	0.20
Data 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

Table 5 – Weighted Eigenvector for Comparison Matrix for criteria versus criteria

Jitter	0.20
Data Loss	0.20
Latency	0.35
Throughput	0.25

Criteria versus criteria pair-wise comparisons were carried out for our network under study based on our proposed scale in table 1 – this resulted in obtaining table 3 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 so 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 3 is then normalised using the formula in the matrix of figure 4 – this is shown in table 4. Using the formula in figure 5 the weighted eigenvector for the comparison matrix for criteria is obtained in table 5.

Table 6 – Criteria Comparison Matrix for jitter

	1	**2**	**1**	**3**
Jitter	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	1.00	0.50	1.00	0.33
Afternoon	2.00	1.00	2.00	0.67
Evening	1.00	0.50	1.00	0.33
Night	3.00	1.50	3.00	1.00
	7.00	3.50	7.00	2.33

Table 7 – Normalised Comparison Matrix for criteria versus criteria

Jitter	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	0.14	0.14	0.14	0.14
Afternoon	0.29	0.29	0.29	0.29
Evening	0.14	0.14	0.14	0.14
Night	0.43	0.43	0.43	0.43

Table 8 – Weighted Eigenvector for Comparison Matrix for criteria versus criteria

Morning	0.14
Afternoon	0.29
Evening	0.14
Night	0.43

Alternative versus alternative pair-wise comparisons were carried out by using the international agreed threshold of the criteria to determine the pair-wise rating of each alternative based on our proposed scale in table 1 – this resulted in obtaining table 6 which is the equivalent of the comparison matrix of figure 2. Since jitter at night in MTN's network is slightly worse to the international jitter threshold we used the value 3. Jitter got worse in the afternoon so we used the value 2. Our jitter measurements got much worse in the morning and evening so it was given the value 1. Table 6 is then normalised using the formula in the matrix of figure 4 – this is shown in table 7. Using the formula in figure 5 the weighted eigenvector for the comparison matrix for jitter is obtained in table 8.

Table 9 – Network Comparison Matrix for throughput

	5	**2**	**1**	**6**
Throughput	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	1.00	2.50	5.00	0.83
Afternoon	0.40	1.00	2.00	0.33
Evening	0.20	0.50	1.00	0.17
Night	1.20	3.00	6.00	1.00
	2.80	7.00	14.00	2.33

Table 10 - Normalised Network Comparison Matrix for throughput

Throughput	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	0.36	0.36	0.36	0.36
Afternoon	0.14	0.14	0.14	0.14
Evening	0.07	0.07	0.07	0.07
Night	0.43	0.43	0.43	0.43

Table 11 - Weighted Eigenvector for the Network Comparison Matrix for throughput

Morning	0.36
Afternoon	0.14
Evening	0.07
Night	0.43

The same process was applied to the criteria *throughput* and the results are shown in tables 9 to 11.

Table 12 - Network Comparison Matrix for data loss

	2	**1**	**1**	**3**
Data Loss	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	1.00	2.00	2.00	0.67
Afternoon	0.50	1.00	1.00	0.33
Evening	0.50	1.00	1.00	0.33
Night	1.50	3.00	3.00	1.00
	3.50	7.00	7.00	2.33

Table 13 - Normalised Network Comparison Matrix for data loss

Data Loss	Morning	Afternoon	Evening	Night
Morning	0.29	0.29	0.29	0.29
Afternoon	0.14	0.14	0.14	0.14
Evening	0.14	0.14	0.14	0.14
Night	0.43	0.43	0.43	0.43

Table 14 - Weighted Eigenvector for Network Comparison Matrix for data loss

Morning	0.29
Afternoon	0.14
Evening	0.14
Night	0.43

The same process was applied to the criteria *data loss* and the results are shown in tables 12 to 14.

Table 15 - Network Comparison Matrix for latency

	2	**1**	**1**	**2**
Latency	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	1.00	2.00	2.00	1.00
Afternoon	0.50	1.00	1.00	0.50
Evening	0.50	1.00	1.00	0.50
Night	1.00	2.00	2.00	1.00
	3.00	6.00	6.00	3.00

Table 16 - Normalised Network Comparison Matrix for latency

Latency	**Morning**	**Afternoon**	**Evening**	**Night**
Morning	0.33	0.33	0.33	0.33
Afternoon	0.17	0.17	0.17	0.17
Evening	0.17	0.17	0.17	0.17
Night	0.33	0.33	0.33	0.33

Table 17 - Weighted Eigenvector for Network Comparison Matrix for latency

Morning	0.33
Afternoon	0.17
Evening	0.17
Night	0.33

Likewise, the same process was finally applied to the criteria *latency* and the results are shown in tables 15 to 17.

	jitter	loss	latency	throughput
morning	0.14	0.29	0.33	0.36
afternoon	0.29	0.14	0.17	0.14
Evening	0.14	0.14	0.17	0.07
Night	0.43	0.43	0.33	0.43

X

jitter	0.20
loss	0.20
latency	0.35
throughput	0.25

Figure 10 – Final AHP of problem

Table 20 – Final Scores for each period of the days

Morning	0.29
Afternoon	0.18
Evening	0.13
Night	0.40

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 MTN's cellular networks under investigation in Yola, Nigeria for web browsing for different periods of the day. From the table it can be seen that MTN's network offers the best QoS at night followed by morning, afternoon and then evening.

IV. RELATED WORK

In [8] the authors designed and implemented a system that permits the measurement of the network QoS parameters of latency, jitter, packet loss and throughput. Their system allows for objective evaluation of the requirements of network applications for delivering user acceptable quality. The authors used *FastEthernet* taps to monitor full-duplex traffic and programmable network interface cards to extract all the information needed to compute the network QoS parameters. Their work only provided the framework for evaluation of FTP type application only, therefore not a heuristic approach.

In [9] the authors presented an efficient autonomous measurement model for the evaluation of the QoS metrics within a converged voice and data network. Their model provides the number of distributed units required by autonomous measurements in order to achieve a specified statistical confidence of the measurements performed on key network parameters. The evaluation performed by the model is based on the parameters' characteristics. Their work, as novel as it is, remains a theoretical model and therefore still requires implementation before it can be properly evaluated.

In [10] the authors presented a QoS assessment methodology for cellular communication networks based on data collected through drive testing which is focused on the end user perception of service quality and independent of access technologies implemented by the cellular networks. QoS assessment for both the circuit switched and packet switched aspects of the network was studied. The end goal of the proposed methodology is a comparison of QoS between cellular networks implementing different cellular technologies. However, the authors fail to provide QoS measurements as a function of both voice and data services simultaneously.

V. SUMMARY AND CONCLUSIONS

AHP is a proven tool that can be used to compare multiple criterion and rank them on the QoS based on users' perception of quality. 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 them.

In this paper we have adapted and shown that AHP is a tool that can be used to compare the QoS of a wireless cellular network in Nigeria to determine the period of the day 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..

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