Ranking the Quality of Service of a Wireless Cellular Network for Different Periods of a Day

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Abstract

There is a need to quantitatively evaluate the quality of service of a wireless cellular network for different periods of a day 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 a network can be a very challenging task. In this paper we will adapt the classical Analytic Hierarchy Process method to quantitatively evaluate a particular wireless cellular network to determine how well it performs for different periods of a day.

Keywords: *AHP, Ranking, QOS, Wireless Cellular Network, Evaluation*

1. Introduction

Without a structured technique, trying to evaluate the overall quality of service (QoS) of a wireless cellular network for different periods of the day can be a very challenging task. Indeed the evaluation methodology must allow users to compare how well a network performs in the same geographical region based on pre-defined evaluation criteria. 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.

Therefore, we need a methodology that can formalize decision making where there are a number of choices to evaluate the QoS with each having a number of evaluation parameters which are difficult to formalize. The methodology must identify and weigh evaluation parameters, analyze the data collected for each parameter and expedite the decision-making process. The methodology must also be helpful in capturing both subjective and objective evaluation measurements and provide a useful mechanism for checking the consistency of the evaluation measurements.

One such 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 is helpful in capturing both subjective and objective evaluation measurements in a quantitative manner and provides a useful mechanism for checking the consistency of the evaluation measurements. To decide the best outcome we need to know the problem, the need and purpose of the outcome, the measurements of the outcome, their sub-criteria, effect and the alternative actions to take – from these we then try to determine the best outcome [1].

AHP provides a powerful tool that can be used to evaluate different network providers based on multiple QoS Evaluation Criteria (QEC). It starts by transforming the QoS evaluation problem into a structured hierarchy where each QEC is quantified and related to overall goals for evaluating alternative solutions. Once the hierarchy is built, we systematically evaluate the various elements of the network by comparing them to one another two at a time based on their impact on application that is be measured. In making the comparisons, we use data obtained about the network using various measurement tools. It is the essence of the AHP that human judgments, and not just the underlying information, be used in performing the evaluations. We convert the evaluations 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 of the hierarchy. In the final step of the process, numerical priorities are calculated for each of the decision.

In this paper we will adapt the classical AHP process to evaluate the QoS offered by a particular wireless cellular network to determine the periods of the day that offer the best QoS in Nigeria.

The structure of this paper is as follows. In section 2 we describe the classical AHP process and how we have adapted it to rank the QoS of wireless cellular networks for different periods of the day. Section 3 describes how our new approach has been applied to a real life case study. Section 4 discusses related work and final conclusions are given in section 5.

2. AHP

Saaty [2, 3] proposed AHP as a decision aid to help solve unstructured problems in various areas of human endeavor. AHP enables the decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environments in confliction [4]. AHP is a methodology for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria [5]. 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.

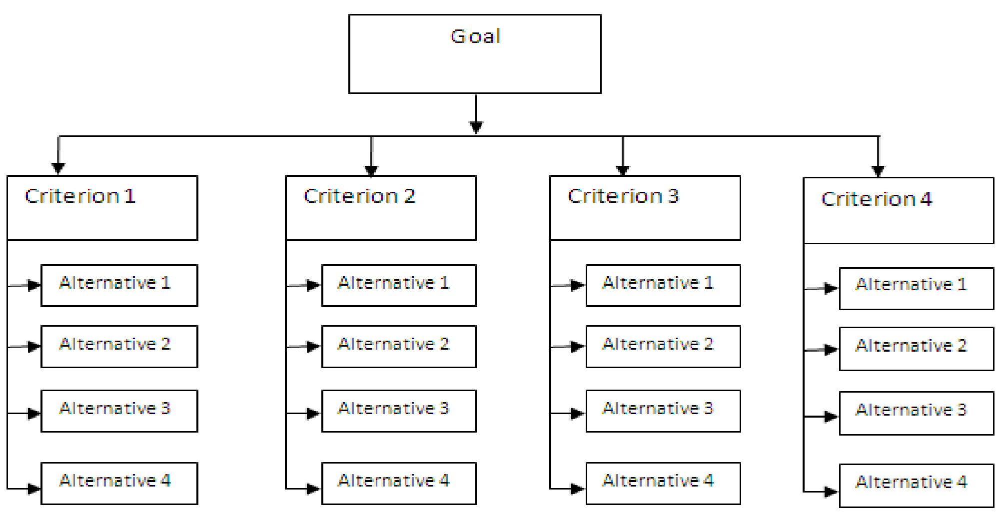

Figure 1. AHP Hierarchy

The application of the AHP to a complex problem usually involves the following four major steps [4]:

1. Break down the complex problem into a number of small constituent elements and then structure the elements in a hierarchical form.
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on threshold comparisons of the elements.
3. Use the eigenvector method to estimate the relative weights of the elements.
4. Aggregate these relative weights and synthesize them for the final measurement of given decision alternatives.

The first step in AHP is to organize the critical aspects of a problem into a hierarchy rather like a family tree [6, 7]. 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.

$$A = \begin{matrix} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ . \\ C_n \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & C_3 & C_4 & .... & C_n \end{matrix} \\ \begin{pmatrix} 1 & A_{12} & A_{13} & A_{14} & & A_{1n} \\ A_{21} & 1 & A_{23} & A_{24} & & A_{2n} \\ A_{31} & A_{32} & 1 & A_{34} & & A_{3n} \\ A_{41} & A_{42} & A_{43} & 1 & & A_{4n} \\ . & . & . & . & & \\ A_{n1} & A_{n2} & A_{n3} & A_{n4} & & 1 \end{pmatrix} \end{matrix}$$

Figure 2. Comparison Matrix

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.

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. 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 [3]. 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 [8]. A decision maker may use the eigenvectors according to his particular needs and interests.

$$
A = \begin{array}{c} \\ N_1 \\ \\ N_2 \\ \\ N_3 \\ \\ . \\ \\ N_n \end{array}
\begin{array}{c} \begin{array}{cccccc} N_1 & N_2 & N_3 & \cdots & \cdots & N_n \end{array} \\
\begin{pmatrix}
\frac{W_1}{W_1} & \frac{W_1}{W_2} & \frac{W_1}{W_3} & \cdots & \cdots & \frac{W_1}{W_n} \\
\frac{W_2}{W_1} & \frac{W_2}{W_2} & \frac{W_2}{W_3} & \cdots & \cdots & \frac{W_2}{W_n} \\
\frac{W_3}{W_1} & \frac{W_3}{W_2} & \frac{W_3}{W_3} & \cdots & \cdots & \frac{W_3}{W_n} \\
; & ; & ; & & & ; \\
; & ; & ; & & & ; \\
\frac{W_n}{W_1} & \frac{W_n}{W_2} & \frac{W_n}{W_3} & \cdots & \cdots & \frac{W_n}{W_n}
\end{pmatrix} \end{array}
$$

Figure 3. Weight Matrix

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.

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

The weights used for matrix A_z are derived by our pair-wise comparison scale shown in table 1. Our scale is in the range 1 to 7 where the middle scale 4 represents the value of the measured parameter to be about same as the threshold of the measured parameter as agreed by the international telecommunication regulatory body. The use of thresholds is to benchmark the level of preference of the measured parameter on the expected performance of the particular application. This will reduce the subjectivity for network parameters as QoS evaluators establish preferences between different networks using the pair-wise comparison scale and the pair-wise comparison matrices.

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.

$$A_{norm} = \begin{pmatrix} \frac{A_{11}}{\sum_{j=1}^{n} A_{j1}} & \ldots\ldots\ldots & \frac{A_{1n}}{\sum_{j=1}^{n} A_{jn}} \\ . & . & . \\ . & . & . \\ \frac{A_{n1}}{\sum_{j=1}^{n} A_{j1}} & \ldots\ldots\ldots & \frac{A_{nn}}{\sum_{j=1}^{n} A_{jn}} \end{pmatrix}$$

Figure 4. Normalised Matrix

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

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* [9, 10, 11]. 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.

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.

$$\overset{W^{A_1}}{\begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ ; \\ ; \\ w_n \end{pmatrix}} \overset{W^{A_2}}{\begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ ; \\ ; \\ w_n \end{pmatrix}} \overset{W^{A_3}}{\begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ ; \\ ; \\ w_n \end{pmatrix}} \begin{matrix} \ldots\ldots \\ \ldots\ldots \\ \ldots\ldots \\ \ldots\ldots \\ \ldots\ldots \end{matrix} \overset{W^{A_N}}{\begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ ; \\ ; \\ w_n \end{pmatrix}} \times \overset{W^{C_i}}{\begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ ; \\ ; \\ w_n \end{pmatrix}}$$

Figure 6. Final AHP Matrix Configuration

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

Figure 7. Calculation of Overall Scores

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. Application of AHP to Network QoS Evaluation

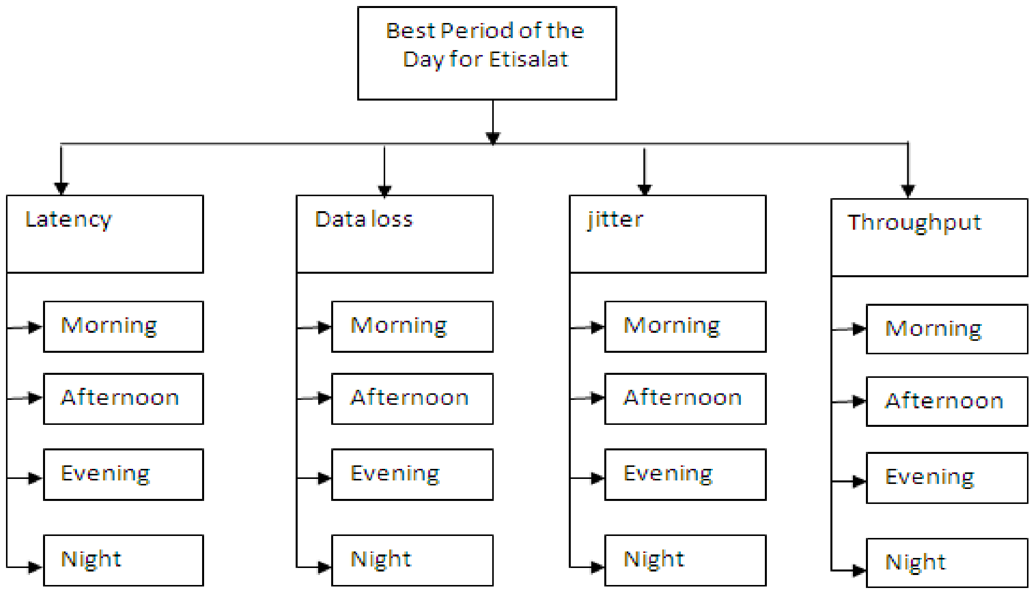

Figure 8. Network QoS Evaluation Hierarchy

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 of data services for the *Etisalat* 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 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.

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. The set up on which the measurements were obtained are described in our paper [12]. Our recorded measurements are shown in table 2.

Table 2. Mean Value of Network Performance for each Network

period	jitter	loss	throughput	latency
morning	65.00	3.50	41.35	452.00
Afternoon	108.00	4.50	16.67	480.00
Evening	119.00	5.33	6.58	504.00
Night	43.00	1.33	68.45	406.00

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	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

Table 4. Normalised Comparison Matrix for Criteria versus Criteria

	jitter	loss	latency	throughput
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

Table 5. Weighted Eigenvector for Comparison Matrix for Criteria versus Criteria

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 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, 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.

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 – this resulted in obtaining Table 6 which is the equivalent of the comparison matrix of Figure 2. Since jitter at night in Etisalat's network is almost equal to the international jitter threshold we used the value 4. Jitter was slight worse in the morning we used the value 3. Our jitter measurements got worse in the evening so it was given the value 2. Likewise, jitter was even worse and further away from the international threshold in the afternoon 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 6. Network Comparison Matrix for jitter

	3	1	2	4
jitter	morning	afternoon	evening	night
morning	1.00	3.00	1.50	0.75
afternoon	0.33	1.00	0.50	0.25
evening	0.67	2.00	1.00	0.50
night	1.33	4.00	2.00	1.00
	3.33	10.00	5.00	2.50

Table 7. Normalised Network Comparison Matrix for jitter

jitter	morning	afternoon	evening	night
morning	0.3	0.3	0.3	0.3
afternoon	0.1	0.1	0.1	0.1
evening	0.2	0.2	0.2	0.2
night	0.4	0.4	0.4	0.4

Table 8. Weighted Eigenvector for the Network Comparison Matrix for jitter

morning	0.30
afternoon	0.10
evening	0.20
night	0.40

Table 9. Network Comparison Matrix for Throughput

	1	3	5	6
throughput	morning	afternoon	evening	night
morning	1.00	0.33	0.20	0.17
afternoon	3.00	1.00	0.60	0.50
evening	5.00	1.67	1.00	0.83
night	6.00	2.00	1.20	1.00
	15.00	5.00	3.00	2.50

Table 10. Normalised Network Comparison Matrix for Throughput

throughput	morning	afternoon	evening	night
morning	0.07	0.07	0.07	0.07
afternoon	0.20	0.20	0.20	0.20
evening	0.33	0.33	0.33	0.33
night	0.40	0.40	0.40	0.40

Table 11. Weighted Eigenvector for Network Comparison Matrix for Throughput

morning	0.07
afternoon	0.20
evening	0.33
night	0.40

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
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

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

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 18 which gives the final rankings of the QoS of Etisalat'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 Etisalat's network offers the best QoS at night followed by morning, evening and then afternoon.

Table 15. Network Comparison Matrix for Latency

	3	2	1	4
latency	morning	afternoon	evening	night
morning	1.00	1.50	3.00	0.75
afternoon	0.67	1.00	2.00	0.50

evening	0.33	0.50	1.00	0.25
night	1.33	2.00	4.00	1.00
	3.33	5.00	10.00	2.50

Table 16. Normalised Network Comparison Matrix for Latency

latency	morning	afternoon	evening	night
morning	0.30	0.30	0.30	0.30
afternoon	0.20	0.20	0.20	0.20
evening	0.10	0.10	0.10	0.10
night	0.40	0.40	0.40	0.40

Table 17. Weighted Eigenvector for the Network Comparison Matrix for Latency

morning	0.30
afternoon	0.20
evening	0.10
night	0.40

	jitter	loss	latency	throughput
morning	0.30	0.29	0.30	0.07
afternoon	0.10	0.14	0.20	0.20
evening	0.20	0.14	0.10	0.33
night	0.40	0.43	0.40	0.40

X

jitter	0.20
loss	0.20
latency	0.35
throughput	0.25

Figure 9. Final AHP of Problem

Table 18. Final Scores for each Network

morning	0.24
afternoon	0.17
evening	0.19
night	0.41

4. Related Works

In [13], the authors present 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 of the network was studied. The end goal of the proposed methodology is QoS comparison 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.

In [14] the author presents a performance evaluation of Nigerian cellular mobile communication services that is based on the call failure feature. In his work, efforts were made to do a quantitative study of the phenomenon where test calls were made to different identified routes of the networks. In the work he made efforts to access the performance of the operators using the call failure rate profile. Based on call failure, he observed that definite call failure patterns could not be observed when viewed over the hours of the day as is expected in normal traffic studies. He concluded that factors like infrastructural deficiencies other than trunk dimensioning, contributed to the excessive call failure rate in the networks. The work was just a study that did not provide a heuristic solution to QoS evaluation in wireless networks.

In [15] the authors presented a methodology for evaluating the quality of the FTP data service in cellular Universal Mobile Telecommunications System (UMTS) networks based on data collected through drive testing and can be easily extended to other cellular data services. In their work, the authors specify user experience as a key factor in determining the network operator's success. However, the proposed methodology concentrates on evaluating end-user experience based only on data services on a single network.

In [16], the authors presented a methodology for evaluating the QoS provided by a cellular network for background services such as e-mail and text messaging based on data collected from drive testing. The data obtained from the drive testing were used to evaluate different drive routes on a UMTS network. Since their approach is bounded to a single UMTS, their methodology cannot be used universally on different networks

5. Summary and Conclusions

An approach to evaluating the QoS of a wireless cellular network during different periods in a day 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 the QoS of a wireless cellular network and determine what period of the day 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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