NETWORK SELECTION IN AN INTEGRATED WIRELESS LAN AND UMTS ENVIRONMENT USING MATHEMATICAL MODELING AND COMPUTING TECHNIQUES

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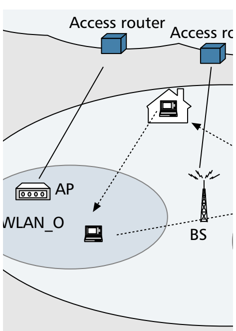

The authors develop a network selection scheme for an integrated cellular/wireless LAN system. The design goal is to provide the user the best available Quality of Service (QoS) at any time.

ABSTRACT

The increasing demand for broadband service, at least in hot spot areas, in today's wireless communications is causing cellular network providers to consider the integration of 3G cellular systems and wireless LAN. This has the particular advantage of high data rates and unlicensed spectrum. Consequently, network selection techniques play a vital role in ensuring quality of service in heterogeneous networks. In this article we develop a network selection scheme for an integrated cellular/wireless LAN system. The design goal is to provide the user the best available QoS at any time. The proposed scheme comprises two parts, with the first applying an analytic hierarchy process (AHP) to decide the relative weights of evaluative criteria set according to user preferences and service applications, while the second adopts grey relational analysis (GRA) to rank the network alternatives with faster and simpler implementation than AHP. Simulations conducted in a heterogeneous system with UMTS and wireless LAN reveal that the proposed network selection technique can effectively decide the optimum network through making trade-offs among network condition, user preference, and service application, while avoiding frequent handoffs.

INTRODUCTION

In recent years, adverse wireless networks have emerged and played key roles in modern telecommunications. General Packet Radio Service (GPRS) enables Global System for Mobile Communications (GSM) users to access IP networks, such as the Internet, and third-generation (3G) cellular systems, such as Universal Mobile Telecommunications System (UMTS) and cdma2000, support wireless Internet over a wide geographical area. In the evolution of cellular networks, one obstacle is that the data rates in these networks are limited. The data rate in GPRS is up to 144 kb/s; in UMTS it is from 384 kb/s to 2 Mb/s. One widely acceptable way to deal with this limitation is the complementary use of wireless local area network (WLAN) technology in hot spot areas (e.g., business centers, airports, hotels, and campuses) since WLAN can provide up to 54 Mb/s data rate with coverage of a few thousand square meters around a single access point.

Several interworking architectures between 3G cellular and WLAN systems have been proposed in the technical literature. The European Telecommunications Standards Institute (ETSI) specifies two generic approaches toward WLAN-cellular integration, known as loose and tight coupling [1]. In loose coupling, the WLAN acts as an access network complementary to the cellular network, which means only signaling is transported between two systems while the WLAN data flow directly to the external IP network. In tight coupling, the WLAN emulates a radio access network (RAN), communicating (including data and signaling) with the external network through the core of the cellular network. Apart from the research activities in ETSI, the Third Generation Partnership Project (3GPP) has recently developed a 3GPP-WLAN interworking architecture [2]. The main objective is to enable 3GPP cellular network subscribers to access WLAN service. The research includes enabling reuse of a 3GPP subscription, developing a network selection mechanism, and defining authentication, authorization, and accounting (AAA). A WLAN terminal equipped with a 3GPP subscriber identity module (SIM)/universal SIM (USIM) smart card can access both the 3GPP subscriber database and WLAN. 3GPP has also approved network selection based on the network access identifier (NAI). Two charging methods, postpaid and prepaid, are used for the 3GPP-WLAN interworking system. An overview of the aforementioned functions for the integration of 3GPP and WLAN is presented in [3].

In this article we focus on network selection for integrated WLAN and cellular systems. The biggest challenge in selecting a network is to decide the most favorable trade-off among user preference, service application, and network

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condition. Network selection is usually carried out in three steps. The first step is collecting the necessary information that has some impact on the final decision. The information might be user preference, service application, and network condition. The second step is using the collected information as inputs to a certain handoff algorithm that aims to keep the user always best connected (ABC) [4]. The meaning of ABC is that the user is not only connected but also enjoys the best possible quality of service (QoS) at any time and any place. The last step is making a decision according to the algorithm's output.

A number of researchers proposed some network selection algorithms in the literature. The most conventional algorithm is a fuzzy-logic-based algorithm that adopts the radio signal strength (RSS) threshold and hysteresis values as input parameters [5]. Reference [6] dynamically uses a mobile station's speed estimations and the WLAN traffic load as additional parameters to decide the best network. The algorithm presented by Ylianttila, Pande, Makela, and Mahonen [7] optimizes the network selection process through minimizing handoff delay for real-time service and maximizing throughput for non-real-time service. However, all these network selection methods are based on inadequate decision factors. RSS and traffic load alone are not able to present the whole performance of a network. The user's requirements are too important to be ignored.

On the contrary, in this article we consider network condition, service application, and user preference for QoS as the decision factors. ABC is the design goal, which means the network is selected on behalf of the user. The QoS characteristics in network conditions are analyzed in a coordinated manner according to the user's preferences. We propose an integrated analytic hierarchy process (AHP) and grey relational analysis (GRA) algorithm for network selection in a heterogeneous system. AHP [8] is a method for finding the best solution to a complex problem by synthesizing all the problem-defining details. AHP has already been applied in a number of areas, such as predicting outcomes [9] and allocating resources [10]. GRA is introduced in [11] to select the best among the comparative series through building grey relationships with an ideal series. The technique is largely adopted in project selection [12] and performance evaluation [13]. In the proposed network selection algorithm, the user's preferences and service requirements for QoS are valued based on their contributions to the final goal through AHP. The performances of the network alternatives are ranked by the GRA, where the calculations are faster and simpler than AHP. In this article we consider UMTS and WLAN as network alternatives. The proposed technique would, however, be applicable to systems with more heterogeneity (e.g., cdma2000-WLAN, GPRS-WLAN-PCN), and this will be the subject of future work.

The rest of this article is organized as follows. We introduce AHP and GRA theory, respectively. We then apply AHP and GRA to the network selection algorithm. We provide several case studies in implementing the proposed algorithm. Conclusions and further research are then detailed.

	Location	Salary	Prospect
Location	1	1/5	1/3
Salary	5	1	2
Prospect	3	1/2	1

Table 1. *An example of an AHP matrix.*

AHP is defined as a procedure to divide a complex problem into a number of deciding factors and integrate the relative dominances of the factors with the solution alternatives to find the optimal one.

ANALYTIC HIERARCHY PROCESS

AHP is defined as a procedure to divide a complex problem into a number of deciding factors and integrate the relative dominances of the factors with the solution alternatives to find the optimal one. AHP is carried out in five steps [8]:

Step 1 Structuring a problem as a decision hierarchy of independent decision elements

Step 2 Collecting information about the decision elements

Step 3 Comparing the decision elements pairwise on each level in the matter of their importance to the elements in the level above

Step 4 Calculating the relative priorities of decision elements in each level

Step 5 Synthesizing the above results to achieve the overall weight of each decision alternative

In a typical hierarchy, the problem to be resolved is in the topmost level. For example, Mr. Smith is trying to make a selection among three job offers from companies A, B, and C, respectively. The topmost level would be "choosing a job offer." The subsequent levels comprise the deciding factors, possibly location, salary, and prospect. The solution alternatives (i.e., the companies) are in the bottom level.

The relative magnitudes of factors and subfactors with respect to their parents are estimated through pairwise comparison based on human's knowledge and experience. The smaller one of a pair is chosen as a unit, and the larger one is estimated as a multiple of that unit based on the perceived intensity of importance. The judgments are ranked on a 9-point scale in AHP. Numbers 1 to 9 are used to present equally, weakly moderately, moderately, moderately plus, strongly, strongly plus, very strongly, very very strongly, and extremely important to the objective, respectively. When one element is less important than another, the comparison result equals the reciprocal of one of the numbers.

The comparison results within each parent are presented in a square matrix to which we refer as the *AHP matrix*. The decision factors under a parent are arranged in the same order in row and column headings. When the ith element in the column heading is compared to the jth element in the row heading, the judgment is presented at the ith row and jth column. An example of an AHP matrix on "choosing a job offer" is shown in Table 1. It is observed that the diagonal elements of the matrix are 1, show-

GRA builds grey relationships between elements of two series to compare each member quantitatively. One of the series is composed of best-quality entities, while the other series contains the comparative entities.

ing the elements' self-comparisons. The other entries in the matrix are symmetric with respect to the diagonal, as a result of the inverted comparisons.

The relative weights of the factors are achieved through calculating the eigenvector of the matrix with the eigenvalue (x_{max}) that is closest to the number (n) of factors [8]. Since comparisons performed in AHP are subjective, judgment errors are inevitable and have to be detected through calculating a consistency index (CI) of the AHP matrix, given by $((x_{max} - n)/(n - 1)$, and then comparing it with a random index (RI), which is the average CI of a randomly generated reciprocal matrix. All RI values for different matrix dimensions are provided by [8]. If CI is equal to zero, the matrix is perfectly consistent; otherwise, CI should be positive. The ratio of CI to RI for the same dimension matrix is called the *consistency ratio* (CR). Adjustment of the comparisons is needed when CR > 10 percent. This process is repeated downward level by level to the bottom of the hierarchy.

It is important to remember that the weights achieved by calculating the eigenvector of the comparison matrix only reflect appropriate distributions to the elements' parent, not the final goal. These weights must be transformed into the final weights through being multiplied by the weight of their parent with respect to the goal.

GREY RELATIONAL ANALYSIS

GRA builds grey relationships between elements of two series to compare each member quantitatively. One of the series is composed of best-quality entities, while the other series contains comparative entities. The less difference between the two series, the more preferable the comparative series. A grey relational coefficient (GRC) is used to describe the relationship between them and is calculated according to the level of similarity and variability. GRA is usually implemented following six steps [14]:

Step 1 Classifying the elements of series by three situations: larger-the-better, smaller-the-better, and nominal-the-best
Step 2 Defining the lower, moderate, or upper bounds of series elements
Step 3 Normalizing individual entities
Step 4 Defining the ideal series
Step 5 Calculating the GRCs
Step 6 Selecting the alternative with the largest GRC

We assume that n series ($S_1, S_2, \ldots, S_n$) are compared, and each series has k entities. The upper bound (u_j) is defined as $\max\{s_1(j), s_2(j), \ldots, s_n(j)\}$, and similarly the lower bound (l_j) is $\min\{s_1(j), s_2(j), \ldots, s_n(j)\}$, where $j = 1, 2, \ldots, k$. In the situation of nominal-the-best, the objective value, which is between the lower and upper bound, is considered as the moderate bound (m_j).

Before calculating the GRCs, the series data need to be normalized. The absolute difference between $s_i(j)$ and l_j or u_j divided by the difference between l_j and u_j can achieve the normalizations ($s_i^*(j)$) for larger- or smaller-the-better, where $i = 1, 2, \ldots, n$. The normalization for nominal-the-best is presented as

$$1 - \frac{|s_i(j) - m_j|}{\max\{u_j - m_j, m_j - l_j\}}.$$

u_j for larger-the-better, l_j for smaller-the-better, and m_j for nominal-the-best are chosen to compose a reference series S_0, which actually presents the ideal situation. The GRC can be calculated from

$$\Gamma_{0,i} = \frac{1}{k} \sum_{j=1}^{k} \frac{\Delta_{min} + \Delta_{max}}{\Delta_i + \Delta_{max}} \quad (1)$$

where

$$\Delta_i = |s_0^*(j) - s_i(j)|,$$

$$\Delta_{max} = \max_{(i,j)}(\Delta_i),$$

$$\text{and } \Delta_{min} = \min_{(i,j)}(\Delta_i).$$

$\max_{(i,j)}()$, $(\min_{(i,j)}())$ are the functions of the maximum and minimum value of a set of numbers varying with i and j, respectively, which are independent. The comparative series with the largest GRC has the highest priority.

A NETWORK SELECTION SCHEME USING AHP AND GRA

In this section we apply AHP and GRA to network selection. The factors that decide the network selection and the relationship among the factors are defined. The whole selection process is presented by a model and detailed explanations.

In the network selection scenario, users are always trying to seamlessly access high-quality wireless service at any speed, any location, and any time through selecting the optimal network. Therefore, ensuring a specific QoS is the objective in the process of network selection. As a result, QoS is in the topmost level of the AHP hierarchy for network selection. According to a survey of QoS components in mobile communications [14], the main QoS components in a network are defined as *throughput* (α), *timeliness* (β), *reliability* (γ), *security* (δ), *and cost* (ε), which are in the second level of the hierarchy. In consequent levels, received signal strength (RSS) and *coverage area* are used to present *availability*. The adoption of coverage area is in order to avoid frequent handoffs for high-speed users. Three parameters, *delay* (ζ), *response time* (η), *and jitter* (θ), decide *timeliness*. Bit error rate (BER, λ), *burst error* (μ), *and average number of retransmissions per packet* (ν) are used to define reliability. In our scheme, UMTS and WLAN are considered as available network alternatives (in the bottom level of the hierarchy), and have various parameters in these QoS factors and subfactors.

The whole network selection model is shown in Fig. 1. Since availability is the precondition to other QoS deciding factors, in order to save resources we use network availability as a trigger for the QoS data collector. Only after a network is detected as available, the network performance, service class, and user preference are

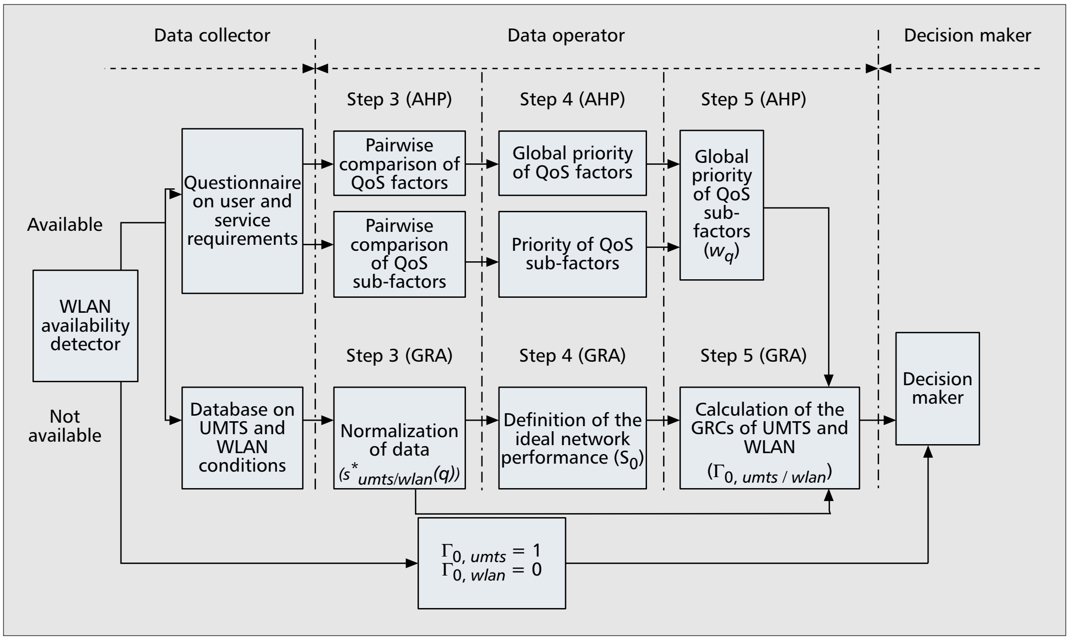


Figure 1. *The AHP and GRA based network selection model.*

estimated and collected. Because UMTS could be always on, deciding the availability of WLAN becomes the main problem. Once the RSS of WLAN is larger than the RSS threshold (e.g., –80 dBm), which allows communication service for a period of time, and the user is estimated to be in the coverage of WLAN for more than a time limit (e.g., 1 min), the network selector begins to collect other QoS information from the network and user to determine whether to hand off to WLAN; otherwise, the GRCs of WLAN and UMTS are assigned 0 and 1, respectively, allowing the decision maker to keep UMTS connected.

The process of deciding is actually a trade-off between network performance and user profile specification. Therefore, two types of data, user-based and network-based, need to be collected for comparison. Meanwhile, users themselves have different requirements for service; for instance, some people are concerned about cost, others about security. The questionnaire (shown in Fig. 1) is actually the database containing all user-based information. User preferences are filled into the questionnaire before accessing any network, and the current service class is detected and mapped into a number of specific QoS attributes. User preferences might be some certain ranges or generic terms, such as strict, bounded, tolerable, and unbounded. Because we deal with pairwise comparison intangibly, and the results only express the intensities of importance of the factors, the above two types of user-based parameters are both acceptable. There are two types of network-based parameters, quantitative and qualitative. Quantitative parameters can be processed directly by GRA, while qualitative parameters are evaluated with a rating from 1 to 10; the larger the number, the better.

Once all the information on the QoS parameters is collected, pairwise comparisons are performed at each level (step 3 [AHP], Fig. 1). Three AHP matrices are constructed. One of them is used to compare QoS factors, and the other two are used to compare *timeliness* and *reliability* subfactors, respectively. The priorities of these elements are derived by the method mentioned earlier (step 4 [AHP], Fig. 1). The global priorities of subfactors are achieved through multiplying priorities of subfactors by the global priorities of the corresponding parent (step 5 [AHP], Fig. 1).

The performances of UMTS and WLAN are evaluated by deciding the differences from the ideal network condition (S_0). The network condition data are first normalized using the method introduced earlier (step 3 [GRA], Fig. 1). There are only two situations, larger- and smaller-the-better, in the network selection scenario; therefore, the reference S_0 can be defined as step 4 (GRA, Fig. 1). Since the effect of each factor on the final goal is different, Eq. 1 can be modified as step 5 (GRA, Fig. 1):

$$\Gamma_{0,umts/wlan} = \frac{1}{\sum_{q=1}^{9} w_q \left| s^*_{umts/wlan}(q) - s_0 \right| + 1}, \qquad (2)$$

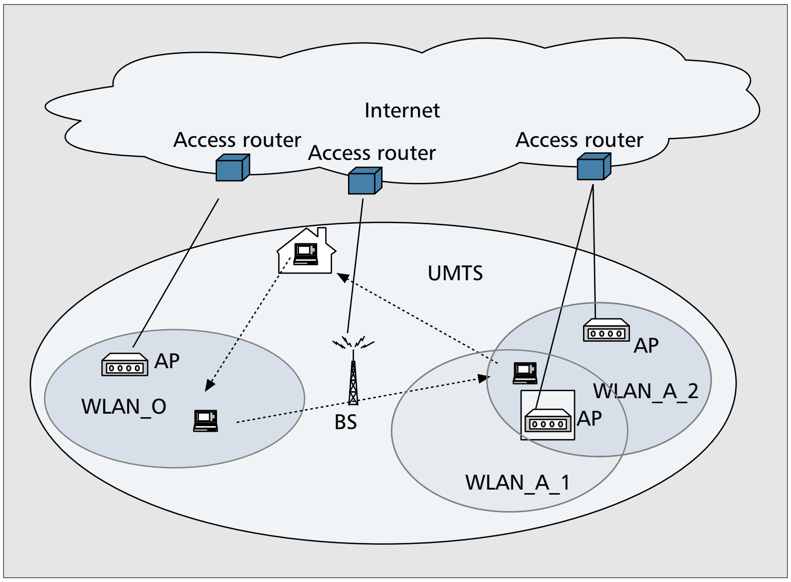
where $s^*_{umts/wlan}(q)$ is the normalization of the qth UMTS QoS data or WLAN QoS data, and w_q is the qth QoS parameter's weights.

The GRCs of UMTS and WLAN are compared in the handoff decision maker. The larger the coefficient, the more ability the network has to fulfill the requirements of user and service. Therefore, the network alternative with the largest GRC is selected as the next network service provider.

Simulation Results

In this section we present simulation results related to network selection between UMTS and WLAN. We demonstrate the process of finding a trade-off between user profile specification and network condition using AHP and GRA.

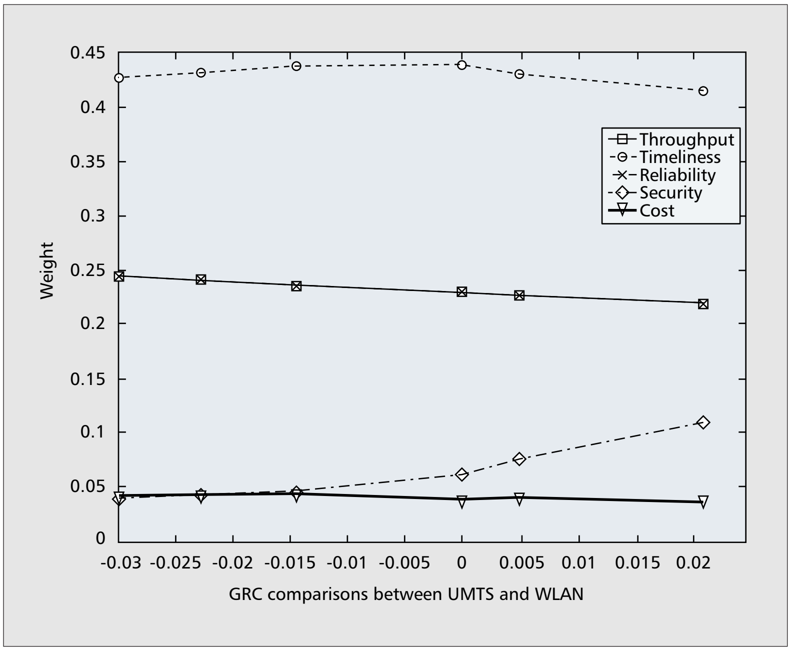
There are two types of network-based parameters, quantitative and qualitative. The quantitative parameters can be processed directly by GRA, while the qualitative parameters are evaluated with a rating from 1 to 10, with the larger number being the better.



■ **Figure 2**. *The network selection simulation scenario.*

In the simulation we consider an area in which home (H), office (O), and airport (A) form a triangle. UMTS covers the whole simulation area. There exist three WLAN systems, one of which is at O; the other two overlay partly at A, as shown in Fig 2. The network conditions of UMTS, WLAN_O, and (WLAN_A_1/2) are described in Table 2.

In an example scenario, a mobile user first receives meeting text and speech components on the train to the office with the requirement of low cost (case 1). He receives the meeting speech and video components (case 2_1) and downloads some files (case 2_2) after arriving at his office. While sending a file, he leaves his office for the airport (case 3). He continues to transfer the file at the airport till he finishes (case 4). In order to show how AHP and GRA work together in network selection, we assume that the availability of WLAN means that not only RSS from WLAN is strong enough for transmitting data, but also the user would stay in the coverage of WLAN for more than 5 min, which reduces the possibility of frequent handoff.



■ **Figure 3**. *Network selection with increased weight of security.*

Case 1

In case 1 only the signal from UMTS is sensed; therefore, UMTS is directly selected. This is an example of a simple case with no selection process involved.

Case 2

In case 2_1 the user is trying to receive meeting video and speech components in the office. After confirming that WLAN_O is available for transmission and the user is estimated to be in the office for at least 5 min, the network selector begins to determine the optimum network using AHP and GRA, as shown in Table 2. It is clear that the performance of WLAN_O is closer to the optimal criteria. The decision maker then selects WLAN_O as service provider on the basis of the comparison results.

It is observed that the exact values of the QoS parameters become much less important after normalization. Hence, in the situation of two alternatives, we only need to know which alternative is higher or larger with respect to a certain QoS parameter without estimating the exact value. It significantly reduces the complexity of implementation.

Figures 3 and 4 show the weights of QoS factors and the corresponding selection decisions on the assumption that the user changes requirements for *security* or *cost*, and the requirements for *throughput*, *timeliness*, and *reliability* are fixed based on the service class. When GRC of UMTS is less than that of WLAN_O (i.e., the comparison result is negative), WLAN_O is selected; otherwise, UMTS is selected. It is observed that the selection result would change when the priority of security is increased to around 0.06 (as shown in Fig. 3), but cost does not play a key role during selection, as shown in Fig. 4. Even though the user has no requirement on cost, WLAN_O is still selected due to high bandwidth. The perceived quality has to be sacrificed for high security, however, which is an advantage of UMTS.

After the meeting, the user begins to transmit some files (case 2_2). Once the network selector discovers that the current service class changes to background class, it maps the service class into a series of QoS characteristics. The network detector then reevaluates the weights of QoS factors and subfactors, as shown in Table 2. Given that the conditions of UMTS and WLAN_O are the same as estimated while transmitting the meeting components, the results show that WLAN_O is still the optimum option for the user, and additionally WLAN_O is more desirable in the scenario of providing background-class service.

This is a more complex example than case 1. The network selection scheme is executed twice. It happens once when a new network alternative is sensed, and again when the service class changes.

Weights of QoS factors and subfactors											
Weight		α	β			γ			σ	ε	
			ζ	η	θ	λ	μ	ν			
Case 2_1		0.246	0.427			0.246			0.039	0.042	
			0.043	0.043	0.341	0.065	0.165	0.015			
Case 2_2		0.397	0.048			0.397			0.110	0.042	
			0.021	0.021	0.007	0.258	0.091	0.048			
Case 4		0.238	0.048			0.238			0.238	0.238	
			0.021	0.021	0.007	0.154	0.055	0.029			
UMTS and WLAN performance											
		α (Mb/s)	ζ (ms)	η (ms)	θ (ms)	λ (dB)	μ	ν	σ (level)	ε (kbyte)	
UMTS		2	20	10	5	10^{-3}	0.4	0.5	9	1	
WLAN_O		25	30	30	10	10^{-5}	0.2	0.2	7.5	0.1	
WLAN_A_1		25	50	30	10	10^{-5}	0.25	0.3	6	0.5	
WLAN_A_2		23	45	28	10	10^{-6}	0.25	0.2	7	0.2	
Normalization of network data											
Normalization		α	ζ	η	θ	λ	μ	ν	σ	ε	GRC
Case 2_1	UMTS	0	1	1	1	0	0	0	1	0	0.654
	WLAN_O	1	0	0	0	1	1	1	0	1	0.680
Case 2_2	UMTS	0	1	1	1	0	0	0	1	0	0.543
	WLAN_O	1	0	0	0	1	1	1	0	1	0.864
Case 4	UMTS	0	1	1	1	0	0	0	1	0	0.668
	WLAN_A_1	1	0	0	0	0.991	0.75	0.667	0	0.625	0.714
	WLAN_A_2	0.913	0.167	0.1	0	1	1	1	0.333	1	0.818

Table 2. *Weights of QoS factors and subfactors, network performance, and normalization of network data.*

CASE 3

In case 3, the signal from WLAN_O starts decaying when the user leaves the office. WLAN_O is kept connected for as long as possible until RSS from WLAN_O is detected as lower than the threshold for a period of time. Consequently, the remaining files must be transferred through UMTS.

CASE 4

In case 4, three networks (UMTS, WLAN_A_1, and WLAN_A_2) are available to the user. The GRCs are calculated as shown in Table 2 and then compared in the decision maker. WLAN_A_2 with the largest GRC is selected.

In this case, WLAN_A_1 provides a little higher throughput, which is advantageous to background class service; the network selector however selects lower-throughput WLAN_A_2, which has the merits of higher reliability, higher security and lower cost. This example illustrates that the network selection mechanism is actually a trade-off among user preference, service application, and network condition.

In the above simulation cases, the user enjoys either real-time or non-real-time service during movement. The delay-sensitive network alternative is selected for real-time applications, and the high-throughput high-reliability network alternative is selected for non-real-time applications. It reveals that the proposed scheme bal-

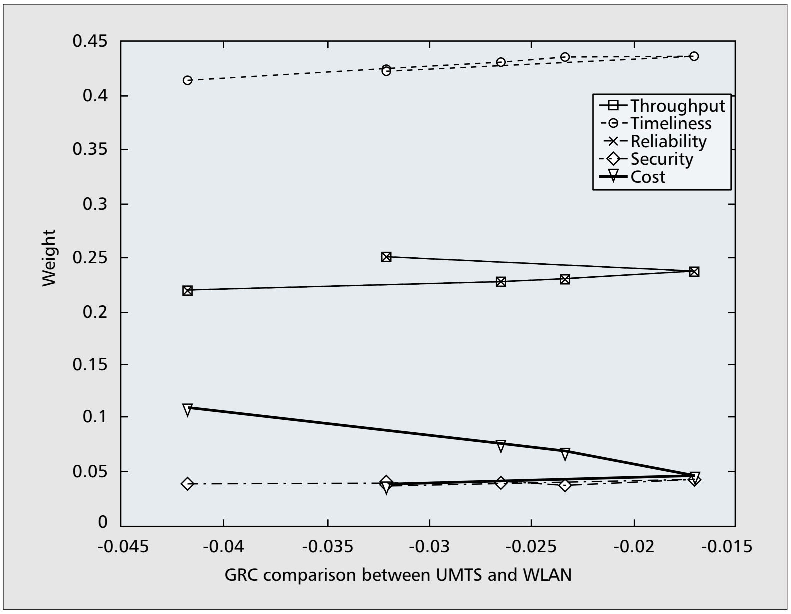


Figure 4. *Network selection with decreased weight of cost.*

ances more comprehensive QoS decision factors than the aforementioned papers [5–7], and efficiently makes a handoff decision more favorable for the user.

Conclusions

In this article we present a novel network selection scheme for the integration of UMTS and WLAN to always guarantee the best QoS through selecting the most suitable network while preventing frequent handoffs. We improved the utilization by using a combination of AHP and GRA to evaluate user preferences and service classes quantitatively and ranked the network alternatives efficiently. AHP takes advantage of hierarchy and pairwise comparison, and GRA focuses on finding the difference between the comparative and ideal options. Unlike other schemes, we considered as many QoS-deciding factors as we could, and weighted them based on their importance to QoS. This ensures that users can enjoy the best available service without unnecessary handoff.

The simulation results reveal that the proposed network selection scheme can efficiently decide the trade-off among user preference, service application, and network condition. In addition, the priorities of options can be decided based on approximate comparisons among the QoS parameters instead of exact values of the QoS parameters in the heterogeneous system with only two network alternatives, which means simpler implementation. Future research will test the proposed scheme in more comprehensive situations with more network alternatives and selection criteria.

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