Access Network Selection in a 4G Networking Environment

by

Yang Liu

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

An all-IP pervasive networking system provides a comprehensive IP solution where voice, data and streamed multimedia can be delivered to users at anytime and anywhere. Network selection is a key issue in this converged heterogeneous networking environment. A traditional way to select a target network is only based on the received signal strength (RSS); however, it is not comprehensive enough to meet the various demands of different multimedia applications and different users. Though some existing schemes have considered multiple criteria (e.g. QoS, security, connection cost, etc.) for access network selection, there are still several problems unsettled or not being solved perfectly. In this thesis, we propose a novel model to handle this network selection issue. Firstly, we take advantage of IEEE 802.21 to obtain the information of neighboring networks and then classify the information into two categories: 1) compensatory information and 2) non-compensatory information; secondly, we use the non-compensatory information to sort out the capable networks as candidates. If a neighboring network satisfies all the requirements of non-compensatory criteria, the checking of the compensatory information will then be triggered; thirdly, taking the values of compensatory information as input, we propose a hybrid ANP and RTOPSIS model to rank the candidate networks. ANP elicit weights to compensatory criteria and eliminates the interdependence impact on them, and RTOPSIS resolves the rank reversal problem which happens in some *multiple criteria decision making* (MCDM) algorithms such as AHP, TOPSIS, and ELECTRE. The evaluation study verifies the usability and validity of our proposed network selection method. Furthermore, a comparison study with a TOPSIS based algorithm shows the advantage and superiority of the proposed RTOPSIS based model.

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Dedication

The thesis is dedicated to my parents.

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Chapter 1
Introduction

1.1 Overview of Future Heterogeneous Wireless Networks

Along with the development of the mobile technologies as well as the rapid growing number of mobile users, the all-IP backbone which provides the possibility to integrate heterogeneous access networks and technologies becomes the development trend in wireless communications, supporting ubiquitous communications and seamless mobile computing. In a fourth generation (4G) environment, a mobile node equipped with multiple interfaces can handover seamlessly between heterogeneous networks to guarantee the continuity of an ongoing application session such as voice over IP (VoIP) and online gaming. In order to make seamless handover possible, future network devices should be capable to roam freely across various access technologies such as wireless local area networks (WLANs), WiMAX networks, cellular systems, etc [1]. An illustration of a wireless Internet roaming scenario across heterogeneous access networks that involve a personal area network (PAN), a local area network (LAN), a wide area network (WAN), and a cellular system is shown in Fig. 1.1.

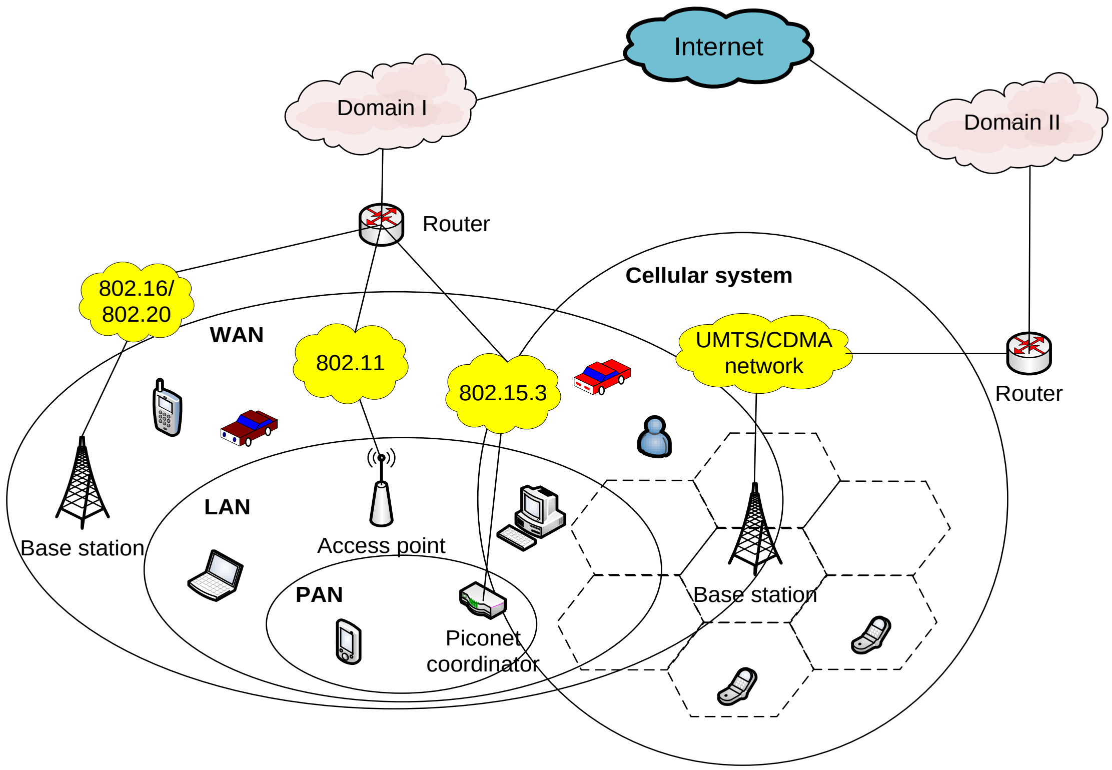

Fig. 1.1 An illustration of a wireless roaming scenario.

However, supporting seamless roaming among heterogeneous networks is a crucial but challenging task, for different access networks having different unique networking characteristics such as mobility, quality-of-service (QoS), and security requirements. For example, cellular networks generally support user mobility and provide relatively reliable communication links, thanks to circuit-switching; however, the date rate supported in the cellular systems is usually lower. On the contrary, with larger bandwidth, WLANs provide higher date rate. QoS provisioning, however, is difficult due to the contention nature of medium access. Therefore, unlike the handover within any access network of the same type (i.e., *horizontal handover*, shown in Fig. 1.2), the handover between different access networks (i.e., *vertical handover*, shown in Fig. 1.2) poses new challenges: 1) interactive applications such as voice over IP (VoIP) and streaming media such as PowerPoint streaming have stringent QoS requirements on end-to-end delay and packet loss. The vertical handover process will have to take care of the delays introduced as a result of network discovery, configuration, binding update procedures, etc; 2) movement between two different administrative domains (e.g., from cellular systems to WLANs) poses additional challenges since a mobile will need to reestablish authentication and authorization in the new domain, leading to additional delays; and 3) radio resource management is expected to perform globally rather than locally. Thus, existing handover schemes may not be applicable to a pervasive heterogeneous network. A novel approach for network selection is imperative. In order to provide an effective and efficient solution for network selection in a heterogeneous networking environment, we propose a hybrid model that takes advantages of IEEE 802.21 services [2, 3].

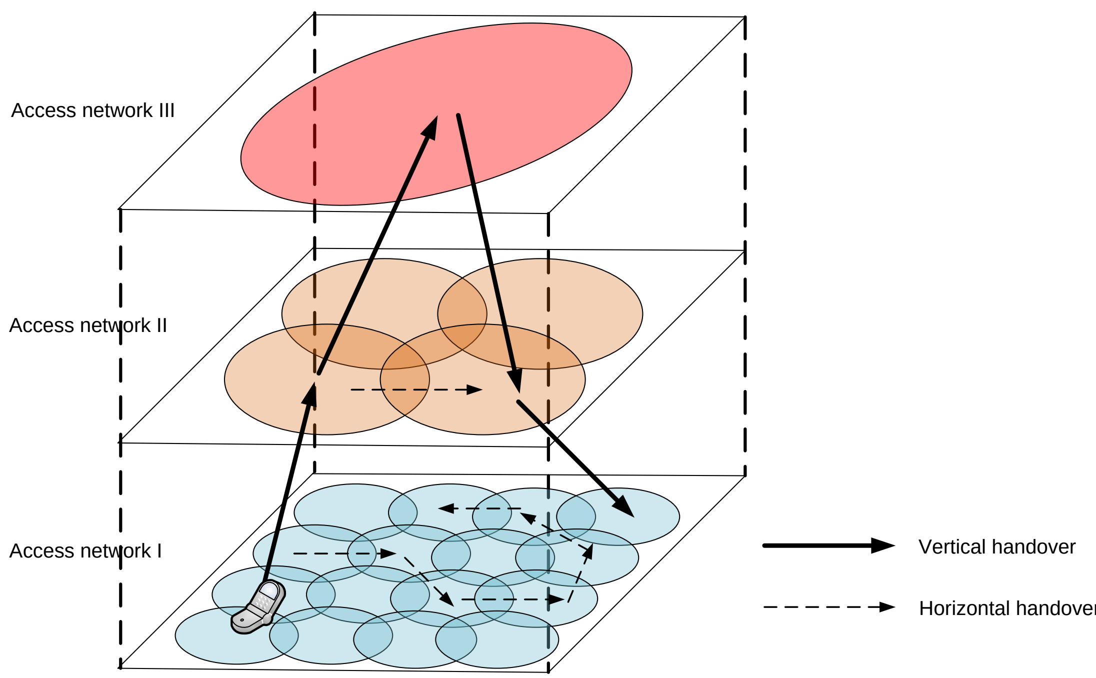

Fig. 1.2 Vertical and horizontal handovers in a wireless overlay networking paradigm.

1.2 Handover Issues

Concerning the seamlessness problem in homogeneous networks environments, in IEEE 802 group, the IEEE 802.11r will enable the fast *basic service set* (BSS) transitions between *access points* (APs) within the same *extended service set* (ESS), while IEEE 802.11k which is proposed for radio resource management will provide the information to discover the best available access point [4, 5, 39]. These two ongoing projects will plausibly be the key contributions for seamless handover in a homogeneous WLAN environment. IEEE 802.16-2004 was amended by IEEE 802.16e-2005 to support the mobility in a wireless metropolitan area network (WMAN). It is referred to as “Mobile 802.16” or sometimes called “Mobile WiMAX”. Unlike 802.1x based networks, cellular networks are designed for mobile users, therefore, the seamless handover are provided by the 3GPP/3GPP2 agreements at the first place [6, 34]. However, the *received signal strength* (RSS) based decision making scheme is not flexible or effective enough to fulfill the fasting changing consumer demands.

With respect to the vertical handover, current 802.1x standards do not support the handover between heterogeneous networks. However, more and more effort is being put into the development that helps with this issue. IEEE 802.21 is an emerging standard designed to facilitate handover between heterogeneous access networks by exchanging information and defining commands and events to assist the handover decision making process. The framework within IEEE 802.21 enables seamless handover between networks of the same type (i.e., horizontal handover) as well as handover between different network types (i.e., vertical handover). This emerging standard allows entities to detect and select appropriate network access points in a way that is independent of the media type. Information related to handover issues are collected and provided via *Media Independent Handover Function* (MIHF). Obviously, this emerging standard reflects the developing trend in future network communications. Thus, it leads into the amendments to other existing standards. 802.11u is an amendment to the IEEE 802.11 standard cooperating with the 802.21 to improve inter-working with external networks. It is now in the stage of proposal evaluation, and the formal standard is scheduled to be published in March 2009. Likewise, IEEE 802.16g is an amendment to IEEE 802.16 whose extension *service access points* SAPs will support MIH related primitives. Meanwhile, the *Internet Engineering Task Force* (IETF) working group is trying to address the problem about Media Independent Handover (MIH) information delivery.

1.3 Motivations

The fast-changing network topologies, networking technologies, user requirements, service and application types, etc. are all driving the need for an all-IP networking system that integrates various types of networks, providing a ubiquitous networking ambience. As a matter of fact, the migration to IP communications has already started its march in industry. In terms of the survey launched by Imago, the organizers of IP’06 event, 25%-75% overall running cost savings delivered by all-IP communications over legacy communications are expected in the great majority of case; 87% of the respondents agree that implementing IP telephony eases the adoption of other IP-based communications services and applications; and 81.1% of industry suppliers see that today’s disparate flavors of broadband wireless will ultimately converge, meaning that the heterogeneous networks will be integrated [7]. Without doubt, the all-IP evolution is leading into reconstruction of the existing networks.

Forth generation communications system (4G) is targeting at realizing an all-IP based packet switched system which integrates almost all the existing 2G and 3G technologies [36]. Also, higher data rate and network capacity, better QoS assurance, more effective spectrum utilization, and seamless handover across heterogeneous networks, etc. are the objectives of 4G wireless communication standard defined by 4G working group. Thus, 4G can be considered as a convergence cooperating platform, where heterogeneous networks coexist. As we know, the previous wireless communications systems (1G to 3G) are designed for wide area cellular telephone access, therefore obviously, a paradigm shift is required to approach 4G. Luckily, both intra- and inter-network operations have been considered and involved since 3G, where WLANs started playing a part in the big picture. With the dramatically increasing demands from users, a concept of AAA comes up, that is, to provide *always best services* (ABS) to *always best connected* (ABC) users, at *anytime*, *anywhere*, and *anyhow*. This AAA ability is the goal that 4G aiming at.

The significance, urgency, and necessity of the 4G networking system make researchers and developers flung themselves into various fields of the all-IP networks, trying to perfect the system. Some major challenges are listed below [40, 41].

- *Seamless connectivity*. Both vertical and horizontal handovers are critical for 4G, and to maintain the seamlessness, soft handover is preferred other than hard handover. In the vertical handover case, the heterogeneity and variety of networks exacerbate the problem.
- *User centric approach*. Developing technology based on the user requirements and expectations is the exorable trend for 4G networks.
- *Complex resource allocation*. Resource allocation of time, frequency and space in a multi-network, multi-user environment is vital.
- *Interference*. Multi-access interference control and mitigation in heterogeneous environments (coexisting air interfaces, varied terminals and services) is an issue.
- *Power consumption*. Without doubt, power consumption will sharply increase in future multi-function multi-standard and multi-interface 4G terminals. How to extend the battery life could be very problematic and challenging.
- *Security*. The integration of heterogeneous networks brings some new challenges to network security. The current security schemes might not optimally support mobility. Though the

existing schemes used in cellular networks considered mobility in design, the variety of networks in the future emerging networking system requires improvements of current schemes; otherwise, the security-related signaling delay could have a strong impact on seamlessness during vertical handovers.

One of the major challenges listed above is realizing seamless connectivity and global roaming across various communication systems with guaranteed QoS. IEEE 802.21 is emerged to enable seamless handover in both homogeneous and heterogeneous environments. Information collection and exchange can be done to via MIHF and its related services such as MIH Event Service, MIH Command Service and MIH Information Service. However, IEEE 802.21 only provides the possibility and capability for the mobile users or networks to select a proper network access point to handover, but leaves how to make good use of the information to make a network selection decision undefined. On the other hand, most of the network selection algorithms make decisions merely according to single-criterion, but it is not adequate to make a wise decision in a highly integrated platform. Multiple criteria should be taken into account to achieve better performance and more pleasant user experience. Although some work have already considered multi-criteria, the weight elicitations for different criteria such as available bandwidth, packet loss rate, transport cost, etc. are either too casual or applying an inappropriate algorithm. The weight elicitation plays a very important role in ranking the candidate networks, and directly effects result, thus, a new algorithm needs to be applied to assign the weights more properly. The ranking algorithm is another impeding issue that has not been addressed perfectly. Rank irregularity even rank reversal happens in some existing schemes. Furthermore, information gathering is another issue which was seldom referred in previous network selection related researches. Thanks to IEEE 802.21 standard, we can take advantage of it to collect information that relates to network selection decision making. This thesis presents a comprehensive and novel approach to rank candidate networks in the stage of handover decision, targeting at maximizing user satisfaction under limited choices.

1.4 Contributions

The followings are the major contributions of this research work.

- A study of wireless communications evolution and an identification of handover related issues in future 4G networking environment.

- A survey and a comparison study on current network selection algorithms in heterogeneous networks.
- An intensive study of some traditional decision making algorithms and their subsequent impairments and improvements.
- A hybrid model based on several decision making algorithms to select the best candidate network(s) from the user perspective is proposed. It takes into account different types of access networks available for end-to-end service provisioning, as well as QoS requirements of the ongoing applications, network conditions and user requirements.
- A comparison evaluation discovers the rank reversal problem in a widely used algorithm, and verifies the validity of our proposed scheme.

1.5 Thesis Outline

This thesis consists of 6 chapters. Chapter 2 gives the background information and provides a literature survey of network selection algorithms. Our approach is described in details from Chapter 3 to Chapter 5. Chapter 6 concludes the work.

- **Chapter 2: Background Information.** This chapter gives a brief introduction to wireless communication networks and its evolvement from first generation analog cellular systems to fourth generation all-IP communication systems. Also, three different phases of handover are illustrated in this chapter. And at last, it discusses several existing network selection algorithms.
- **Chapter 3: Multi-Criteria Decision Making (MCDM).** MCDM problems and classifications are introduced in this chapter. An example is given to explain the widely used method named AHP and its advanced version named ANP. Then a newly developed ranking algorithm RTOPSIS is specified.
- **Chapter 4: Hybrid ANP and RTOPSIS Model for Network Selection.** This chapter talks about the network selection process in details. First of, information is collected with the help of IEEE 802.21; second of, non-compensatory information plays as a trigger of calculating the score for candidate networks; third of, our proposed hybrid ANP and RTOPSIS method is applied to rank the capable networks.

- **Chapter 5: Evaluation of RTOPSIS for Network Selection.** Three scenarios are considered to show the usability of our RTOPSIS based method. And also, we compare our proposed scheme with a TOPSIS based network selection scheme.
- **Chapter 6: Conclusion**. We summarize our work and propose some future work.

Chapter 2
Related Work

2.1 Evolution of Wireless Communications

First generation (1G) mobile radio systems based on analog transmission for speech services was introduced in early 1980s. A cellular cell covering a large area (i.e., 150km radius) was supported by a single base station. Examples are Nippon Telephone and Telegraph (NTT) and Advanced Mobile Phone System (AMPS). 1G systems usually offered handover and roaming capabilities but the cellular networks were unable to interoperate between countries. Another disadvantage of 1G mobile systems is that the base station and the mobile stations might have to transmit at higher powers in order to communicate, thereby making mobile handsets infeasible.

With the emergence of digital communications, second-generation (2G) mobile systems were introduced in the end of 1980s, supporting both (low bit-rate) data services and conventional voice services. One well-known system is the Global System for Mobile Communications (GSM) introduced in Europe. GSM technology has been continuously improved to increase spectrum efficiency and offer better services in the market, compared with 1G systems. New technologies have been developed based on the original GSM system, bringing about some more advanced systems known as 2.5 Generation (2.5G) systems. In 2G systems, the notion of *frequency reuse* was introduced to increase the system capacity [6, 34]. Instead of deploying a powerful base station in large coverage area, the area is divided into multiple smaller cells and a base station deployed in each cell can use smaller transmit power. Thus, two transmissions can employ the same frequency if they are far away enough such that the co-channel interference level is below a desired threshold (see Fig. 2.1).

With the rising demand of mobile communications, third generation (3G) systems were emerged, providing higher date rate to facilitate new multimedia applications such as video telephony and wireless Internet access. There are three primary standards that comprise 3G technology: wideband-code division multiple access (W-CDMA), CDMA2000, and time division-code division multiple access (TD-CDMA) [8]. The 3G standards can be found in [9]

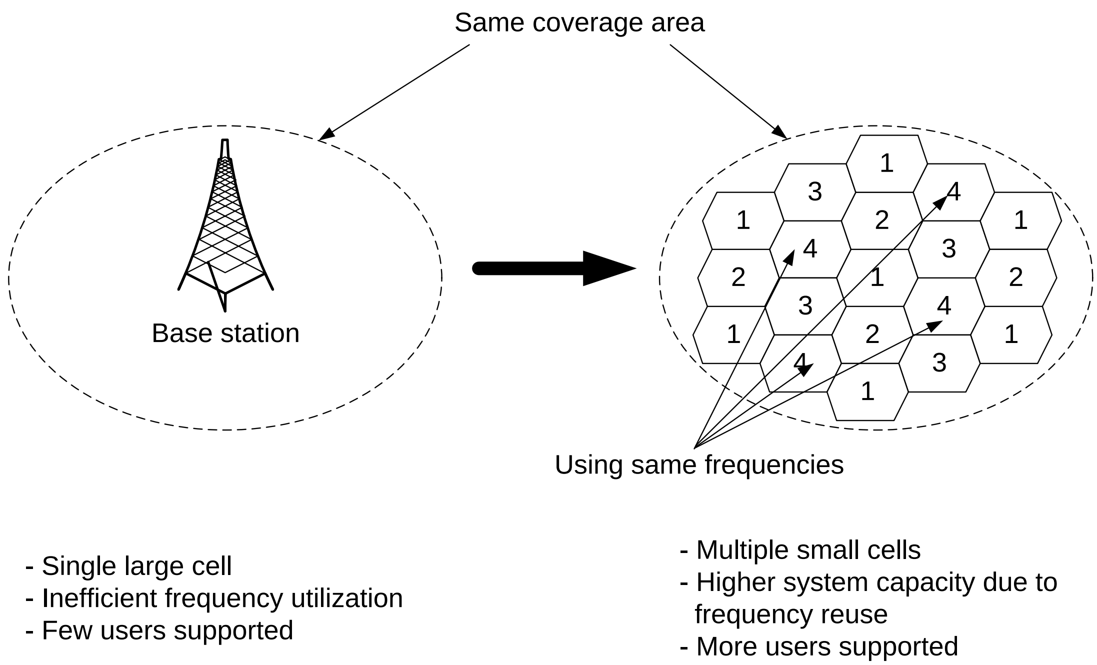

Fig. 2.1 Comparison between 1G systems and the cellular systems with frequency reuse.

If 3G is a linear enhancement of 2G, then 4G should be considered as a real evolution which will probably restructures the network operator and service provider industries. The competing relationship among heterogeneous networks tends to a complementation relationship. The all-IP backbone not just allows different networks coexist, but drives them to complement each other, constructing a pervasive networking environment.

Technologies such as *multiple input, multiple output* (MIMO), *software defined radio* (SDR) are attracting more and more attention, and they are considered as the key enablers of 4G evolution. With MIMO implemented, the signal transmitted by *m* antennas is received by *n* antennas to deliver performance improvements. SDR helps with simultaneous multi-channel processing, which can be a powerful aid in providing multi-standard, multi-band equipments with greatly reduced development efforts and costs for a manufacturer. Network selection enabler is another key to the migration to 4G networks. Without a comprehensive networks selection scheme, the efficiency and effectiveness of this integrated system will be greatly reduced.

The new networking paradigm complicates the issue of handover. Convergence of heterogeneous networks leads into the problem of frequent handovers. Thus, an effective and efficient handover process is vital to quickly switch a subscriber's connection from one cell to a neighboring cell, when the subscriber moves from one location to another. An illustration of a handover scenario is depicted in Fig. 2.2, where a mobile station (MS) travels from base station (BS) A to BS B. Initially, the MS is connected to BS A. The overlap between the two cells is the handover region in which the mobile may be connected to either BS A or BS B. At a certain time during the travel, the mobile is handed over from BS A to BS B. When the MS is close to BS B, it remains connected to BS B. The goal is to avoid involving the user in the handover process and to conduct it without the user's awareness (i.e., seamless handoff). In fact, there are two types of handover: 1) hard handover; and 2) soft handover. Hard handover is sometimes referred to as "break before you make", whereas soft handover is sometimes referred to as "make before you break." Thus, it is easier to realize seamless handover in soft handover than in hard handover.

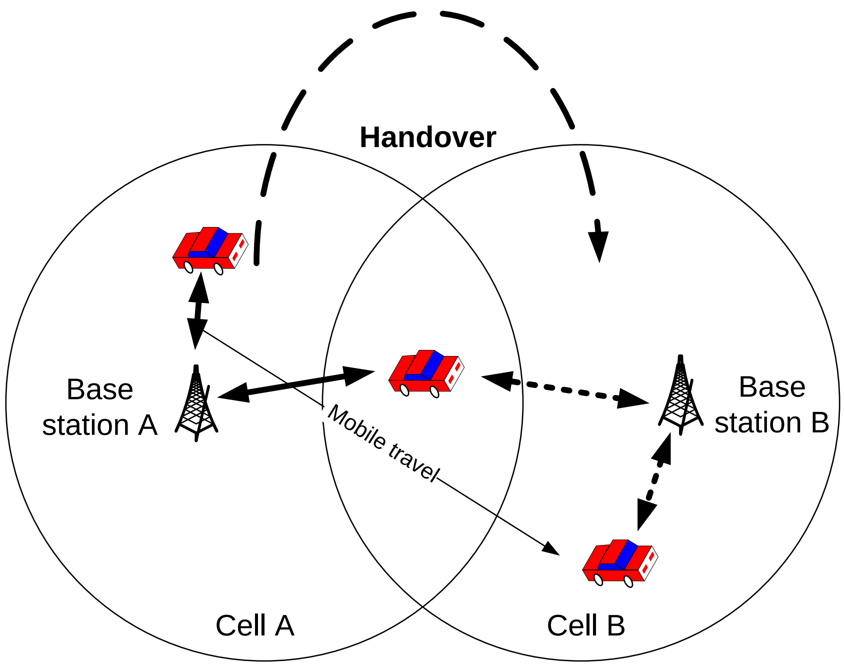

Fig. 2.2 Handover scenario in cellular systems.

2.2 Handover Process

Typically, a handover process consists of three phases as shown in Fig. 2.3: 1) handover initiation; 2) handover preparation; and 3) handover execution.

1) *Handover initiation* – A mobile terminal starts searching for new links. After neighboring networks are discovered, the mobile terminal will select the most appropriate network according to certain handover criteria (e.g., QoS requirements) and then handover negotiation will be underway.

2) *Handover preparation* – After a new network is selected, a new link between the mobile terminal and a base station (or an access point) located in the new network is setup. Connectivity and protocols on Layer 2 (medium access) and Layer 3 (IP) are established.

3) *Handover execution* – after a new link is setup, all the communications associated with the old link are transferred to the new link. The control signals and data packets are allocated to the connection associated with the new base station or access point.

Notice that IEEE 802.21 helps with handover initiation, network selection, and interface activation (i.e., phase 1 and phase 2 of a handover process), and network selection happens in phase 1—handover initiation [10].

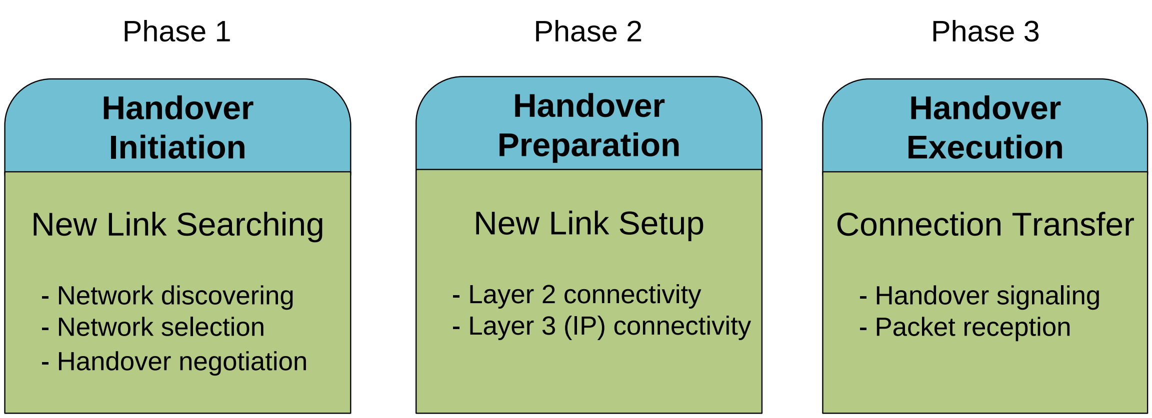

Fig. 2.3 Three phases of a handover process.

2.3 Literature Survey/Existing Work

The network selection problem has been mainly addressed in WLAN/cellular integrated environments [18, 31, 42]. [42] formulates this problem as a variation of the Knapsack problem with multiple knapsacks, and further proved it is NP-Hard. The best network for a given user *i*, is the one that maximize its total sum of admitted flows and also satisfy the QoS requirements. However, the approach used in [42] addresses the problem from a network perspective. What it is maximized is the admitted flow, not the user satisfaction. Take a FTP application as an example, network A and B can both fulfill the user requirements. Network A can provide 1Mbps bandwidth to user while B can only offer 200Kbps. Due to the fact that user requirement is just 100Kbps, as a result, B is chosen to be the target network because of the maximization of admitted flow instead of user satisfaction.

A centralized algorithm is proposed in [11]. Researchers formulate the network selection problem into an *integer linear programming* (ILP) problem to maximize the global spectrum efficiency. But they only focus on the global bandwidth usage, not even take the user experiences into account, nor the fairness. Therefore, it is not comprehensive enough to make a good decision.

In [12], researchers consider using more than one criterion for network selection, and suggest setting up the user profile for network selection, where user should decide the upper bound or lower bound for every attribute. In this way, user needs to have a comprehensive grasp of networking related knowledge; otherwise, they will not be able to make a satisfactory choice. Moreover, even if users are capable of setting these parameters, what if none of the networks can fulfill their requirements? Then they should simply give up connecting to any network or try resetting the parameters? More comprehensive methodology should be raised regarding to network selection. The more severe problem occurs in the information collection step. They use the ping response time as the transmission delay, which is not reliable.

A multi-agent system is introduced in [43, 44] to collect dynamic information about networks and users, and also in charge of network selection, as well as resource allocation. Multiple criteria and user preference are both in the range of their consideration. The access network selection algorithm is based on a cost function they proposed. For each network, a cost function is applied to calculate its overall cost:

$$F_{\cos t} = f\left(g_1(x_1),\ldots,g_m(x_m)\right) = \sum_{j=1}^{m} g_j\left(x_j\right) = \sum_{j=1}^{m} p_j f\left(x_j\right) \quad ,$$

where p_j is the normalized weight for the j^{th} attribute taken into consideration, and $f(x_j)$ expresses the outcome about the j^{th} attribute of a network. The network with the minimum overall cost will be chosen as the target network. The foundation of this cost function is actually the *simple additive weighting method* (SAW), which is the best known and very widely used method in *multiple attribute decision making* (MADM) areas. However, SAW has been proven to be a special case of TOPSIS. The assumption is that alternative which has the shortest to the ideal solution is guaranteed to have the longest distance to the negative-ideal solution, then TOPSIS is equal to SAW. But this assumption is not true in a Euclidean space. Thus, TOPSIS should be a better solution compared to SAW, though it suffers the rank reversal problem. Moreover, nothing details about how to decide the weights of different attributes (cost, security, bandwidth, delay, packet loss rate, etc) are mentioned in these papers.

The work that has been done [13] is more comprehensive, it is based on the preceding paper [14] written by the same author. The former paper proposed an architecture in which terminal make decision with network assistance; while in the later one, they use a TOPSIS based scheme to rank the candidate networks. These two papers take multiple criteria into consideration, however, there still some problems left. For instance, weight elicitation is left unsolved; and the rank irregularity problem is not addressed. Rank irregularity means the ranking is not consisted when an attribute or alternative is added or deleted. For instance, that is a situation where the order of preference for candidate networks is, say, A, B, C then D, but if C is eliminated for other reasons, the order of A and B could be reversed so that the resulting priority is then B, A, then D. In [15], they try to solve the rank abnormality problem by adding another process if the scores of these candidate networks are too close. They claimed that it is not possible to cause the top network to appear at the bottom of the ranking list, which is the basis of their solution. However, this assertion is not true. We will give a counterexample in chapter 5. [16] applies fuzzy MADM algorithm on network selection, but this TOPSIS based algorithm suffers the same rank reversal problem as it is in [14, 15, 17]. [17, 18, 31] uses the eigenvector method of AHP to assign the weights to the metrics (attributes), but a strong potential assumption for AHP is that all the attributes and alternative are dependent. Thus, how to handle the interdependence is another big challenge hasn't been solved yet.

IEEE 802.21 working group [2] is developing a standardized framework that allows efficient interconnectivity across heterogeneous networks, including 802 based networks and other external networks, such as 3GPP and 3GPP2 systems. IEEE 802.21 draft standard defines a set of handover-enabling functions within a logical entity called MIH Function. Three services are provided by MIH Function [1, 3]: 1) Media Independent Event Service (MIES). It detects events and delivers triggers. One use case is that lower layer generate a *link going down* event to report link conditions are degrading and connection loss is imminent; 2) The Media Independent Command Service (MICS). It provides a set of commands for the MIH users to control handover relevant link states. For example, *MIH get status* is the command sent from network to client asking for the current link status; 3) The Media Independent Information Service (MIIS). It provides the information for handovers, such as link layer information, availability of services, etc. Making good use of this standard could enable more effective handover decisions including network selection.

Chapter 3
Multi-Criteria Decision Making

3.1 Introduction to MCDM

Decision making with more than one criterion to be considered happens in our daily lives. Though these *multiple criteria decision making* (MCDM) problems are widely diverse, they share some mutual characteristics.

- *Conflict can exist among the criteria* – Take designing a laptop as a simple example, the objective of low production cost may sacrifice part of the performance.
- *Criteria are of incommensurable units* – Each criterion has its own unit of measurement. In the same example, cost is indicated by dollars, battery life is measured by minutes while processor speed is expressed by gigahertz (GHz).
- *Either design or selection is the target* – The goal of MCDM is either to design the optimal alternative or to choose the best one from the predefined alternatives.

The last characteristic actually offers us a way to classify the MCDM problems. Because of the diversity of the purpose, two alternative sets are in existence: one is a finite field with finite elements, and the other one is an infinite field with infinite elements (elements here refer to alternatives). For instance, in a car selection problem, a customer who wants to purchase a car only has limited choices, since the number of models of cars for sale is finite, and these cars are predetermined, in other words, the gas mileage, level of air pollution, maintenance cost, power, and performance of brake system of a specific car can not be changed; unlike the selection problems, when designing a car, the number of options which engineers may have designed is infinite. Due to these facts, MCDM problems can be broadly classified into two categories: *multiple objective decision making* (MODM), and *multiple attributes decision making* (MADM).

Table 3.1 describes and compares the features of the two classes. In MODM problems, criteria are defined by objectives. An objective is a goal designers want to attain, or something to be pursued. In the car design example, maximizing the gas mileage, minimizing the production cost, minimizing the level of air pollution are referred to as objectives or criteria. Thus, the goal is explicit. Also, a set of well defined constraints is another distinguishing feature owned by MODM methods. Different from MODM, in MADM problems, criteria emerge as a form of attributes. Attributes are actually the performance parameters or factors that affect our choice, and alternatives are characterized by a number of attributes with a certain level of achievement. For instance, a car in the market is described by its purchasing cost, gas mileage, horsepower, brake system performance, etc., and final decision will be made by comparing the available cars based on these parameters. For MADM problem, the goal is usually not explicit, on the contrary, it is ill-defined. Maximizing the satisfaction is sometimes indicated as the goal. The constraints for MADM methods have already been incorporated into attributes.

	MODM	**MADM**
Criteria defined by	Objectives	Attributes
Goal	Explicit	Implicit
Constraint	Active	Inactive
Alternative	Infinite field	Finite field
Decision Space	Continuous	Discrete
Usage	Design	Selection/Evaluation

Table 3.1 Characteristics of MODM and MADM.

Thinking of the network selection problem, a candidate network in a network selection problem is predetermined, and it is distinguished by its data rate, network delay, bit error rate, etc., which are known as attributes in MADM. The number of available networks is definitely infinite, and the decision space is discrete. For example, if we have four candidate networks A, B, C, and D, then in regard to any attribute, say data rate, we only have four choices provided by networks A, B, C and D, so the decision space of data rate is constructed of these four discrete numbers (data rates). Thus, combined with the characteristics of network selection problem and the distinguishing features of MODM and MADM, we draw the conclusion that network selection problem should be classified into MADM category.

Decision matrix in a MADM method contains four main parts, namely: (a) alternatives, (b) attributes, (c) weights, and (d) measures of performance of alternatives with respect to the attributes [20]. In the job choosing problem, different offers are different alternatives, attributes are the factors affecting the decision making (i.e., salary, benefits, location, workload), weights are the relative importance of attributes, and performance measures are quantitative indicators of how well (or poorly) an alternative meets. The goal of MADM is to select a most satisfying alternative from a set of alternatives based on prioritized attributes that measure the performance of each alternative.

Based on the nature of MADM, some classic methods are developed: the weighted sum method (WSM), the weighted product method (WPM), the analytic hierarchy process (AHP), the elimination et choix traduisant la realit´e (elimination and choice expressing the reality) (ELECTRE), the technique for order preference by similarity to ideal solution (TOPSIS), etc. However, in most MADM methods, the general assumption is that all the criteria are independent, which may not be true in our network selection problem. As far as knowledge goes, the network delay, packet loss rate, data rate and some other criteria that we need to take into account are quite related to each other. Interdependence is a critical issue we have to deal well with. According to [19], the dependency problem was first handled in 1994. Carlsson and Fuller showed fuzzy set theory can be applied to resolve multiple criteria problems with interdependent criteria. But this method is developed in MODM environment instead of MADM. In 1996, Saaty first introduced a mathematical theory named analytic network process (ANP), which manages all kinds of dependence and feedback systematically, and it can be applied in both MODM and MADM problems. Thus, ANP is chosen to deal with part of the network selection problem.

3.2 Introduction to AHP

Before going into ANP, we have to know AHP first, because ANP is built on the AHP, which was developed by Saaty as well [21].

3.2.1 Process of AHP

AHP is a method requires pairwise comparison. Suppose we do not have any weighting instrument, can we, somehow, try to estimate the relative weights of several different objects by hands? One way is to use the lightest one as a primary standard, assume it is weighted unit (1). On the basis of that, we can guess one other object's weight by lifting the lightest one and another one at the same time and compare them. Another way is to compare the objects in pairs: lift two objects, record the estimated difference between them; then lift another pair until we are done with all the possible pairs (i.e., if we have three objects A, B and C, then we need to judge three times: A and B, B and C, A and C.). Clearly, the second way named pairwise comparison utilizes more available information. Thomas L. Saaty develops a system called AHP that transforms the pairwise comparison scores into weights of different attributes and priorities of all alternatives on each attribute to obtain the overall ranking of alternatives.

The procedure of AHP can be summarized as: 1) formulate the problem; 2) determine the relative weights of the comparison attributes; 3) compare the alternatives on each attribute; and 4) aggregate weights to produce final evaluation [22]. To understand more details about how to use AHP, we extend our discussion by means of an example. In the car purchasing problem described below, the goal is to rank the candidate cars or find out the best car [23].

1) Formulate the Problem:

   The first step in AHP is to formulate the problem. In the case of choosing the best car from three candidates (goal), first, we must decide which attributes should be used to evaluate each alternative. As shown in Fig. 3.1, handling, economy and power are chosen to be the general criteria (attributes). Then we can further decompose each attribute into several sub-attributes. In this example, braking distribution and turning radius are the sub-attributes of handling; economy is broken into purchase cost, maintenance cost and gas mileage; while power contains only one sub-attribute. AHP allows us to decompose sub-attributes into even smaller sub-sub-attributes, and so forth, to any depth.

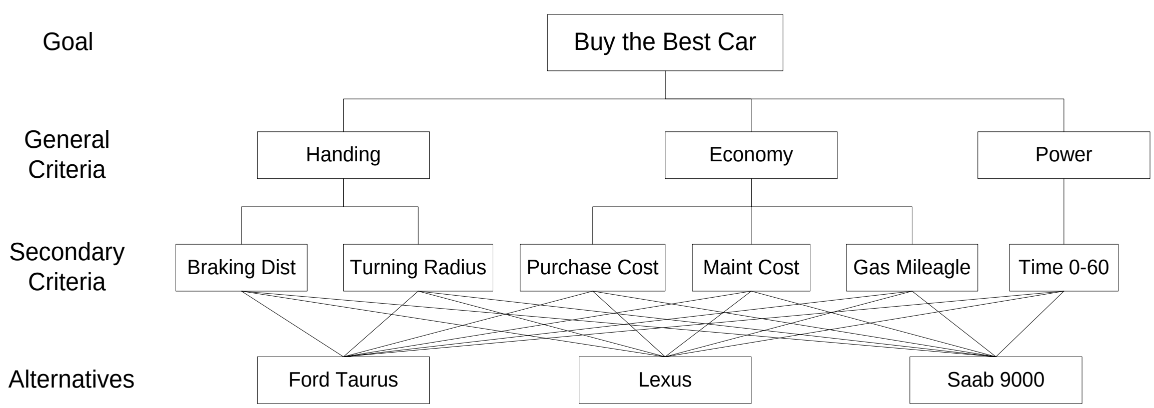

Fig. 3.1 Hierarchic representation of a car purchase problem.

2) Determine the Relative Weights of the Comparison Attributes:

   After representing the problem, the second step is to determine the relative weights of those comparison attributes that are in the same level. Two questions will be asked in each comparison: 1) Which attribute is more important?; and 2) How strongly? A fundamental 1-9 scale is used typically. Table 3.2 explains the scale. If *i* is 3 compared to *j*, that means *i* is more important than *j*, but not much; while *i* is 1/9 compared to *j* means *i* is extremely less important than *j*. Comparison usually starts with the highest-level attributes. A result matrix can be set up after a series of comparisons. In this example, three matrices are constructed for weight (importance) elicitation of attributes.

The Fundamental 1 -9 Scale		
Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance or demonstrated importance	An activity is favored very strongly over anther; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromises between the above	
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*. For instance: -if *i* is 3 compared to *j* -then *j* is 1/3 compared to *i*	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Table 3.2 1-9 scale used in pairwise comparison of AHP

Buy the Best Car	*Handling*	*Economy*	*Power*
Handling	1	2	4
Economy	½	1	2
Power	¼	½	1

Table 3.3 Comparison matrix of first level attributes with respect to the goal.

The first matrix describing the relationships among comparison attributes of the highest level is consistent, meaning that: 1) Ratings are transitive. For instance, if A is better than B and B is better than C, then A must be better than C. 2) Ratings are numerically consistent. In this car example we made 1 more comparison than we needed. We know that $H = 2E$, $H = 4P$. Thus, $2E$ should be equal to $4P$ if the weights are consistent. And in this case $E=2P$, which happens to meet the consistency requirements. Note that this type of matrix has rank = 1, therefore all rows are multiples of each other. Weights are easy to compute for consistent matrix. Using the fact that rows are multiples of each other, we can compute weighting vector by normalizing any column vector. Then, we have: $\boldsymbol{w}_1 = \{w_{1H}, \ w_{1E}, w_{1P}\} = \{0.57, 0.29, 0.14\}$, where $\boldsymbol{w}$ is the weighting vector.

Economy	*Purchase Cost*	*Maintenance Cost*	*Gas Mileage*
Purchase Cost	1	3	5
Maintenance Cost	1/3	1	3
Gas Mileage	1/5	1/3	1

Table 3.4 Comparison matrix of sub-attributes of economy.

After producing the vector of weights for the highest level of comparison attributes, we need to compute vectors of weights for each sublevel. The second matrix shows the relative importance of three sub-attributes to the buyer. Unlike the first matrix, this one is inconsistent, because it doesn't satisfy the second request of being consistent. When we encounter this kind of matrix, the most commonly used method is *eigenvalue/eigenvector* *method*. The number of nonzero eigenvalues for a matrix is equal to its rank. A consistent matrix has rank 1, so as the number of its eigenvalues, and an inconsistent matrix typically has more than 1 eigenvalue. We use the largest, λ_{max} , for consistency measurement computation.

Knowing $\boldsymbol{A} = \begin{bmatrix} 1 & 3 & 5 \\ \frac{1}{3} & 1 & 3 \\ \frac{1}{5} & \frac{1}{3} & 1 \end{bmatrix}$, we can calculate eigenvalue λ by solving $\det(\lambda \boldsymbol{I} - \boldsymbol{A}) = 0$. The maximum λ is adopted for calculations, the normalized vector of weights $\boldsymbol{w_2}$ can be obtained from the formula $\boldsymbol{A}\boldsymbol{w_2} = \lambda_{max}\boldsymbol{w_2}$: $w_{2P} = 0.64, w_{2M} = 0.26, w_{2G} = 0.10$.

Handling	***Braking Distribution***	***Turning Raduis***
Braking Distribution	1	2
Turning Raduis	1/2	1

Table 3.5 Comparison matrix of sub-criteria of handling.

It is easy to elicit weights for the handling sub-criteria, where $w_{3B} = 0.67, w_{3T} = 0.33$.

3) Compare the Builds on Each Attribute:

Having done with formulating the car purchasing problem and determining the vectors of weights for the comparison attributes, the third step in the AHP is to perform comparisons of all alternatives based on every lowest level of the comparison attributes. In this example, we need to compare alternative Ford Taurus versus alternative Lexus versus alternative Saab 9000 on each of the six comparison attributes: braking distribution, turning radius, purchase cost, maintenance cost, gas mileage and time 0-60. The alternative comparison process is exactly the same as the attribute comparison process. With respect to braking distribution performance, by comparing every possible pair of alternatives using the 1-9 scale in Table 3.2, we get the following values:

Braking Dist	*Ford Taurus*	*Lexus*	*Saab 9000*
Ford Taurus	1	3	5
Lexus	1/3	1	2
Saab 9000	1/5	½	1

Table 3.6 Comparison matrix of alternatives with respect to braking distribution.

In other words, we determine/suppose the braking distribution performance for Ford Taurus is somewhat better than it is for Lexus, the performance for Ford Taurus is definitely better than that for Saab 9000, and the performance for Lexus is slightly better than that of Saab 9000. Applying the largest eigenvalue algorithm as in the previous section, we establish the braking distribution performance ranking vector $\boldsymbol{w_B} = \{\mathbf{0.65, 0.23, 0.12}\}^{\mathrm{T}}$.

Using the same process for the remaining five lowest level attributes to compare alternatives, ranking vectors can be computed as shown in Table 3.7. Every row is a ranking vector with respect to a certain attribute.

	Ford Taurus	*Lexus*	*Saab 9000*
Turning Radius	0.57	0.29	0.14
Purchase Cost	0.44	0.39	0.17
Maintenance Cost	0.64	0.09	0.27
Gas Mileage	0.22	0.68	0.10
Time 0-60	0.30	0.26	0.44

Table 3.7 Ranking vectors for alternatives with respect to each attribute.

4) Aggregate Weights to Produce Final Evaluation:

With the attribute weighting vectors and the alternative performance ranking vectors, we may aggregate all the intermediate data to produce the final evaluation metrics. Table 3.8 is established based on the data received in previous steps.

<table>
<tr><th rowspan="2">Alternatives</th><th colspan="2">Handling
(0.57)</th><th colspan="3">Economy
(0.29)</th><th>Power
(0.14)</th></tr>
<tr><th>Braking Distribution
(0.67)</th><th>Turning Radius
(0.33)</th><th>Purchase Cost
(0.64)</th><th>Maintenance Cost
(0.26)</th><th>Gas Mileage
(0.10)</th><th>Time 0-60
(1.00)</th></tr>
<tr><td>Ford Taurus</td><td>0.65</td><td>0.57</td><td>0.44</td><td>0.64</td><td>0.22</td><td>0.30</td></tr>
<tr><td>Lexus</td><td>0.23</td><td>0.29</td><td>0.39</td><td>0.27</td><td>0.68</td><td>0.26</td></tr>
<tr><td>Saab 9000</td><td>0.12</td><td>0.14</td><td>0.17</td><td>0.09</td><td>0.10</td><td>0.44</td></tr>
</table>

Table 3.8 Summary of previous steps.

The final quality metric for each alternative according to AHP is the weighted sum of its attribute rankings. Having this table, it is easy for us to compute the final overall value for each alternative. The final overall value for Ford Taurus is:

(.57)(.67)(.65) +

(.57)(.33)(.57) +

(.29)(.64)(.44) +

(.29)(.26)(.64) +

(.29)(.10)(.22) +

(.14)(1.00)(.30) = 0.534

In the same way, the final overall value for Lexus is 0.291, and the final overall value for Saab 9000 is 0.175.

3.2.2 Disadvantages of AHP

AHP has drawn a lot of attention since it came out. It is mainly due to the fact that AHP is easy to use, its fundamental theory is not difficult to understand and it can apply to various application fields. However, though it has gained much popularity, it is controversial on both of its theoretical and practical soundness.

While it is being widely used, it must be used carefully. The first problem is that the hierarchic architecture used to build additive value function for calculation actually requires independence among all those attributes that are in the same hierarchy level. In many cases, the AHP is misused by not maintaining the independence among elements of hierarchy. The second controversy of AHP is called rank reversal. The meaning of rank reversal can be explained in two cases: 1) Assume after calculated by AHP, the order of preference is, for example, A, B, C then D, but if C is eliminated for other reasons, the order of A and B could be reversed so that the resulting priority is B, A, then D [24]. 2) A, B, C and D are ranked according to the criteria, say, W, X, Y, adding another criterion about which A, B, C, and D are equal, should have no bearing on the ranks. Yet, Perez et al prove in [25] that ranking change is possible in this case by using AHP. A simple example below is used to verify the existence of the rank reversal in AHP.

Suppose there are three alternatives A1, A2, A3, and four criteria/attributes a, b, c, d in the first place. Comparison matrices are constructed as shown in Table 3.9, and normalized eigenvectors are shown in Table 3.10. Further assume all criteria are weighted equally, meaning weights are all ¼. Hence, AHP scores for A_1= 1/4(1/18) + 1/4(9/11) + 1/4(1/14) + 1/4(3/9) = 0.320, A_2 = 1/4(9/18) + 1/4(1/11) + 1/4(9/14) + 1/4(1/9) = 0.336* (* represents the highest score), and A_3 = 1/4(8/18) + 1/4(1/11) + 1/4(4/14) + 1/4(5/9) = 0.320, so as a result, the ranking is $\mathbf{A_2 > A_1 = A_3}$. Now we add the fourth alternative, and redo the computation, we get A_1= 0.264*, A_2 = 0.243, A_3 = 0.246, and A_4 = 0.246. This time, the result is $\mathbf{A_1 > A_3 = A_4 > A_2}$.

	Alternatives		
Criteria	A1	A2	A3
A	1	9	8
B	9	1	1
C	1	9	4
D	3	1	5

Table 3.9 Comparison matrices of three alternatives with respect to each criterion.

	Alternatives		
Criteria	A1	A2	A3
A	1/18	9/18	8/18
B	9/11	1/11	1/11
C	1/14	9/14	4/14
D	3/9	1/9	5/9

Table 3.10 Normalized eigenvectors for each comparison matrix.

Criteria	Alternatives A1	A2	A3	A4
A	1	9	8	4
B	9	1	1	1
C	1	9	4	8
D	3	1	5	5

Table 3.11 Comparison matrices after adding a new alternative.

Regarding to the independence problem, Thomas L. Saaty has developed an advanced method named *analytic network process* (ANP). Aiming at solving the decision problems which can not be structured hierarchically on account of the interaction and dependence of higher-level elements on lower-level elements as well as elements in the same level, a feedback network like structure is proposed. Actually, AHP is a special case of ANP, where all the elements maintain independence. In next section, an example is cited to illustrate the usage of ANP. Nonetheless, the second problem of AHP: rank reversal also occurs in ANP. Rank reversal is a flaw does not just happen in AHP, it is a typical problem of many MADM methods (e.g., TOPSIS, ELECTRE). To avoid rank reversal, we decide to use ANP to assign weights to the attributes only, but not to score the alternatives, which avoids pairwise comparison between alternatives.

3.3 The Process of Using ANP for Weight Elicitation

As a matter of convenience, we use the same car purchase example to explain the steps added in ANP. And we will not talk about changes of the last two steps in AHP, by reason that to avoid rank reversal, ANP is only used for weight elicitation [38].

Assumptions listed as following and the arrows signed in Fig. 3.2 indicate the dependent relationships between criteria.

- Handling is influenced by economy and power.
- Economy is influenced by handling.
- Power is influenced by economy.
- Maintenance cost is influenced by purchase cost.
- Braking distribution is independent with turning radius.

- Purchase cost, maintenance cost, and gas mileage are independent.

1) Formulate the Problem:

   In ANP, the criteria and alternatives construct a network as shown in Fig. 3.2. Handling, economy, and power are considered as control criteria in ANP, and each of them has its own components (e.g. handling is composed of braking dist and Turning radius). The control criterion with its components is regarded as a cluster, so as the alternatives. There are totaling three clusters in the car purchase problem, and we assume they are influenced by each other, meaning they are inter-dependent. Also, we assume sub-criteria within the same cluster are independent, or in other words, every cluster is inner-independent.

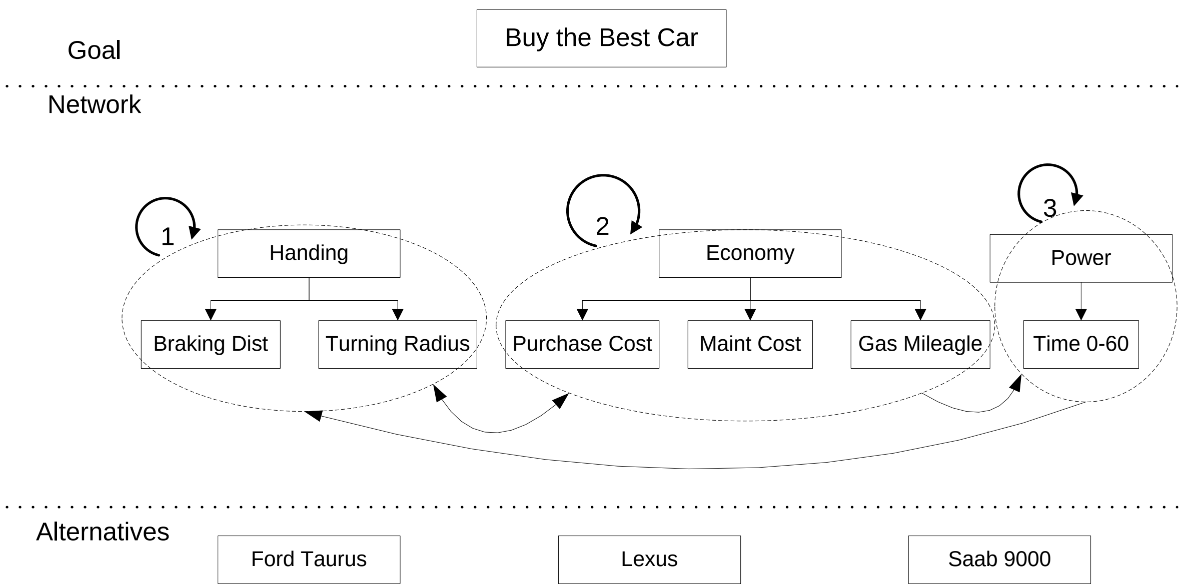

Fig. 3.2 Network structure of a car purchase problem.

2) Determine the Relative Weights of the Attributes:

   First, we use the same method applied in AHP to attain the weighting vector of handling, economy, and power, which is $\boldsymbol{w}'_1 = \{0.57, 0.29, 0.14\}^T$. Next, the effects of the interdependence between the clusters are resolved. The group members will examine the impact of all criteria on each other by pair-wise comparisons too. Two questions to be answered by making pairwise comparison are: "Which cluster will influence cluster 1 more: cluster 2 or cluster 3? And how much more?". Various pairwise comparison matrices are constructed for each cluster. These pairwise comparison matrices are needed for identifying the relative impacts of criteria interdependent relationships. The normalized principal eigenvectors for these matrices are calculated and expressed as column components in interdependence weighting matrix **B**, where zeros are assigned to those with no interdependent relationship between them. Table 3.12 - 3.14 are the interdependence comparison matrices of three clusters with respect to various clusters. Table 3.15 is the weighting matrix **B**, expressing the dependent relationships among three clusters.

Handling	***Handling***	***Economy***	***Power***	***Weights***
Handling	1	7	3	0.682
Economy	1/7	1	1/2	0.102
Power	1/3	2	1	0.216

Table 3.12 Interdependence comparison matrix with respect to handling.

Economy	***Handling***	***Economy***	***Weights***
Handling	1	1/7	0.125
Economy	7	1	0.875

Table 3.13 Interdependence comparison matrix with respect to economy.

Power	***Economy***	***Power***	***Weights***
Economy	1	1/2	0.333
Power	2	1	0.667

Table 3.14 Interdependence comparison matrix with respect to power.

B	***Handling***	***Economy***	***Power***
Handling	0.682	0.125	0
Economy	0.102	0.875	0.333
Power	0.216	0	0.667

Table 3.15 Interdependence weighting matrix B**.**

Now we can obtain the interdependence priorities of the criteria by synthesizing the results from the previous two activities as follows:

$$\boldsymbol{w_1} = \boldsymbol{B_1}\boldsymbol{w_1'} = \begin{bmatrix} 0.682 & 0.125 & 0 \\ 0.102 & 0.875 & 0.333 \\ 0.216 & 0 & 0.667 \end{bmatrix} \cdot \begin{bmatrix} 0.57 \\ 0.29 \\ 0.14 \end{bmatrix} = \begin{bmatrix} 0.425 \\ 0.359 \\ 0.216 \end{bmatrix}.$$

We then calculate the relative weights of the elements inside a cluster by the same token: $w_E = B_E w_E' = \{0.692, 0.208, 0.1\}^{\mathrm{T}}$. Relative weights of braking dist and turning radius remain the same, since they are independent with each other.

After recalculation with interdependence considered, the final weight of each attribute becomes: $w = \{w_{1H}\boldsymbol{w_H}^{\mathrm{T}}, w_{1E}\boldsymbol{w_E}^{\mathrm{T}}, w_{1P}\boldsymbol{w_P}^{\mathrm{T}}\}^{\mathrm{T}}$

$$= \{0.285, 0.140, 0.248, 0.075, 0.036, 0.216\}^{\mathrm{T}}.$$

3.4 Introduction to RTOPSIS

As it is mentioned in previous section, rank reversal is a lethal problem occurring in lots of MADM methods, including AHP, ANP, TOPSIS, ELECTRE, etc [26, 27, 28]. To prevent it from happening, ANP is only adopted for weight elicitation, while instead, an improved TOPSIS methodologies is employed to score the alternatives [29, 37].

Yoon and Hwang developed the *technique for order preference by similarity to ideal solution* (TOPSIS) [30] with the goal of finding the alternative with the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution.

RTOPSIS [29] insists on the same goal and shares the first three steps with TOPSIS. Assume *m* alternatives with *n* attributes need to be evaluated, and a set of weights $w = \{w_1, w_2, \dots, w_j, \dots, w_n\}$, $\sum_{j=1}^{n} w_j = 1$, for the attributes is received. The process of RTOPSIS is as following.

Step 1: All the original attributes receive tendency treatment to construct a decision matrix **D**.

Two different types of criteria may coexist, namely cost criteria and benefit criteria respectively. From the name, we can easily tell for cost criteria, the less the better; on the contrary, for benefit criteria, the larger, the better. Thus, in order to unify their bases, we need to transform the benefit criteria into cost criteria by taking the inverse of the outcomes, or vice versa. We usually treat cost criteria as benefit criteria. Let x_{ij}' denote the outcome of the

i^{th} alternative with respect to the j^{th} attribute X_j before transformation, and $\mathbf{x_{ij}}$ denote the outcome after transformation. The details are shown as follows;

If X_j is a benefit criterion, then $x_{ij} = x'_{ij}$;

else if X_j is a cost criterion, then

a) $x_{ij} = \frac{1}{x'_{ij}}$ (the reciprocal ratio method), refers to the absolute criteria; or

b) $x_{ij} = 1 - x'_{ij}$ (the difference method), refers to the relative criteria.

After tendency treatment, we construct the decision matrix **D**, where A_i = the i^{th} alternative considered, X_j = the j^{th} attribute considered, and x_{ij} = the numerical outcome of the i^{th} alternative with respect to the j^{th} attribute after transformation.

$$\mathbf{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} X_1 & X_2 & \cdots & X_j & \cdots & X_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots & & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \end{array}$$

Step 2: Construct the normalized decision matrix **R**.

In order to allow comparison across the attributes, tendency treatment is not enough. We also have to transform the various dimensional attributes into non-dimensional attributes. Taking the outcome of each criterion divided by the norm of the total outcome vector of the criterion at hand is one way to achieve the goal. An element r_{ij} of the normalized matrix **R** can be computed as

$$r_{ij} = x_{ij} / \sqrt{\textstyle\sum_{i=1}^{m} x_{ij}^2}.$$

Consequently, thus each attribute has the same unit length of vector.

Step 3: Calculate the weighted normalized decision matrix **V**.

Weighting vector $\boldsymbol{w}$ is given.

$$\mathbf{V} = \begin{bmatrix} v_{11} & \cdots & v_{1j} & \cdots & v_{1n} \\ v_{21} & \cdots & v_{2j} & \cdots & v_{2n} \\ \vdots & \ddots & \vdots & & \vdots \\ v_{i1} & \cdots & v_{ij} & \cdots & v_{in} \\ \vdots & & \vdots & & \vdots \\ v_{m1} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & \cdots & w_j r_{1j} & \cdots & w_n r_{1n} \\ w_1 r_{21} & \cdots & w_j r_{2j} & \cdots & w_n r_{2n} \\ \vdots & \ddots & \vdots & & \vdots \\ w_1 r_{i1} & \cdots & w_j r_{ij} & \cdots & w_n r_{in} \\ \vdots & & \vdots & & \vdots \\ w_1 r_{m1} & \cdots & w_j r_{mj} & \cdots & w_n r_{mn} \end{bmatrix}$$

Step 4: Determine the positive ideal and negative ideal solutions.

In original TOPSIS, two artificial alternatives A^+ and A^- are defined as

$$\mathrm{A}^+ = \{\max_{1\le i\le m} v_{ij} \mid (j = 1, 2, \dots, n)\} = \{v_1^+, v_2^+, \dots, v_n^+\} \text{ and}$$

$$\mathrm{A}^- = \{\min_{1\le i\le m} v_{ij} \mid (j = 1, 2, \dots, n)\} = \{v_1^-, v_2^-, \dots, v_n^-\} \text{ , respectively.}$$

They are considered as the most preferable alternative and the least preferable alternative, respectively. However, this step is actually the cause of rank reversal, for the ideal solutions change when the alternatives change. Imagine an alternative being deleted or a new alternative being added, what will happen? The ideal solutions will probably change, and so as to the Euclidean distances of alternatives away from the ideal solutions. [29] suggested introducing a pair of absolute ideal solutions instead of the relative ideal solutions in original TOPSIS. [37] claimed the rank reversal problem had been solved by using their approach, however, rank reversal still happens because they did not delete the cause of the rank reversal. This pair of absolute ideal solution can be determined by experts in related field, or simply set as

$$\mathrm{A}^+ = \{v_1^+, v_2^+, \dots, v_n^+\} = \{w_1, w_2, \dots, w_n\} \text{ and}$$

$$\mathrm{A}^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \{0, 0, \dots, 0\}.$$

Step 5: Calculate the separation measures.

In TOPSIS, the separation between each alternative and the absolute ideal solution can be measured by the n-dimensional Euclidean distance. The separation from the absolute positive ideal solution is given by

$$S_i^+ = \sqrt{\textstyle\sum_{j=1}^{n} \left(v_j^+ - v_{ij}\right)^2}, i = 1, 2, \dots, m.$$

The separation from the absolute negative ideal solution is given by

$$S_i^- = \sqrt{\textstyle\sum_{j=1}^{n} \left(v_j^- - v_{ij}\right)^2}, i = 1, 2, \dots, m.$$

Wei Chen found another flaw in this step [29]. Let z_{ij} denote the variable corresponding to the j^{th} attribute, then when $|(z_j^- - z_{ij})| = |(z_i^- - z_{ik})|$, $\frac{\partial S_i^- / \partial z_{ij}}{\partial S_i^- / \partial z_{ik}} = (\frac{w_j}{w_k})^2$. It is not in accord with the concept of weight, which should represent the relative importance across the attributes. Hence, in RTOPSIS, the separation from the absolute ideal solutions are defined as

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \frac{\left(v_j^+ - v_{ij}\right)^2}{w_j}}, i = 1, 2, \dots, m \text{ and}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \frac{\left(v_j^- - v_{ij}\right)^2}{w_j}}, i = 1, 2, \dots, m.$$

In this way, $\frac{\partial S_i^- / \partial z_{ij}}{\partial S_i^- / \partial z_{ik}} = \frac{w_j}{w_k}$.

Step 6: Calculate the relative distance to the ideal solution.

The relative closeness from attribute A_i to A^+ is defined as

$$C_i^* = S_i^- / (S_i^+ + S_i^-), 0 \le C_i^* \le 1, i = 1, 2, \dots, m.$$

Step 7: Rank the preference order.

It is obvious from the last two steps that when $A_i = A^+, C_i^* = 1$; when $A_i = A^-, C_i^* = 0$; and also the larger the C^*, the more we prefer.

3.5 Conclusion

According above stated, we propose the hybrid model of combining ANP and RTOPSIS as a novel solution for MADM problems. It eliminates the interdependence impact across the attributes, and addresses the severe rank reversal flaw happening in MADM algorithms.

Chapter 4
Hybrid ANP and RTOPSIS Model for Network Selection

In general, handover can be divided into three main phases: *handover initiation*, *handover preparation*, and *handover execution* [10]. In handover initiation phase, new links are searched, and also, network discovery, network selection, and handover negotiation happen in the first phase. MAC and IP layer connectivity are carried out during handover preparation phase. After setting up new link, in last phase, handover signaling, context transfer, and packet reception are executed, and the handover is then completed. The network selection issue in phase one has recently attracted a lot of attention due to the drive for a converged network system. Especially after the emergence of IEEE 802.21, which is proposed to support vertical handover as a standard, the network selection problem becomes more urgent than before, because though IEEE 802.21 has defined three services and MIH function to help with network selection, the specific algorithm applied for network selection is just beyond its scope. This chapter proposes a new algorithm combining three MCDM technologies to select the most proper network.

Normally, there are three different types of strategies to handle the handover problem: 1) terminal controlled, 2) terminal initiated and network assisted, 3) network initiated and network controlled. Terminal controlled method is a strategy with which terminal has the highest controllability to choose a network, but also network resources are wasted the most. Is it worth to sacrifice the limited network resources (i.e., bandwidth) to trade for user's control power? Or do most users need such a high level controllability to choose the network? Most users are not specialists in telecommunication, and they probably want intelligence and automation more than free choice regarding to the network selection problem. The second tactic uses quite the same network resources to the third one for handover information transmission. However, the second strategy gives terminal users more freedom to choose the network. Thus, we prefer the terminal initiated and network assisted model than the other two.

4.1 Network Selection Process

We formulate the network selection problem into a MADM problem with certain constraints. Before we get into the details, some definitions in the decision making context are specified:

- *Alternative*: an alternative is one of the possible decisions from which a decision maker can choose.
- *Criteria*: criteria are quantitative or qualitative standards by which the alternatives are judged.
- *Compensatory Criteria*: a compensatory criterion is one of the criteria which is not absolutely required to be met; rather, it can be “traded off” (compensated) with other criteria. In other words, all the compensatory criteria are considered, and there are no absolute constraints imposed.
- *Non-compensatory Criteria*: a non-compensatory criterion is one of the criteria that have to be met for any alternative being considered. Those alternatives for which any one of the non-compensatory criteria is not satisfied will be eliminated in the decision process.
- *Attribute*: attribute is the smallest element of data. It is a single piece of data containing a value for a record in a table. Each alternative has its own set of attributes. In our case, the candidate networks are the alternatives, the criteria are the factors that impact the network selection.

4.2 Information Collection

We assume IEEE 802.21 standards are in place. Under the IEEE 802.21 *media independent handover function* (MIHF), current network connecting with the terminal can easily collect the useful information of its neighboring networks by registering for MIH services.

Most information are static (i.e., network ID, link type, service types available in a network), so current network can collect them once it senses the new neighboring network or any other time, and store them in its own database. Unlike the static ones, some information are dynamic, changing with time (i.e., available bandwidth, packet loss rate). Current network sends the dynamic information request to neighboring networks after it finds out the link between itself and the terminal is going down and the handover is going to be triggered. How to deal with the collected information to select the best new network for the terminal to hand over is explained in details below.

4.3 Candidate Networks Determination

The information that the neighboring networks provide to the current network are called criteria or factors in a network selection problem. We separate these information into two categories: non-compensatory information and compensatory information. The non-compensatory information is employed as a trigger to start the process of dealing with the compensatory criteria. Table 4.1 lists the non-compensatory criteria and the minimum requirements a candidate network has to meet. Note that for simplicity, we assume each network has only one PoA. If there are more than one PoA in place, then treating different PoAs as different networks will remove the impact of this assumption. The current network checks non-compensatory information the neighboring network has sent to it, and decides whether they all meet the minimum requests (such as the current network and the new network have to have at least one authentication agreement, the terminal device must have the interface to support the new network's access technology, etc). If all the requirements to non-compensatory information are satisfied, the current network determines the new network has the ability to be a candidate, and then the compensatory information are taken into consideration to calculate the overall score of the new network.

Type	Criteria	Description	Requirement
Network Identifier	Operator ID	The operator of a network. RADIUS Operator-Name attribute defied in draft-ietf-geoprivradius-lo-05.txt.	N/A
Non-compensatory Criteria	RSS (if wireless network)	Received signal strength.	RSS should be strong enough for transmission.
	Link Type	e.g., Ethernet, IEEE 802.11, IEEE 802.16, UMTS, GPRS	Terminal has interface to connect with this type of link.
	Roaming partners	This information specifies the operators with which this network operator has direct roaming agreements.	Current network operator connected to terminal should be one of the partners.
	Authentication Method	Authentication mechanism used by the network (e.g., SIM or user ID/password).	Terminal supports the authentication mechanism.
	Services Capability	Higher layer services such as Emergency Services, IMS Services, etc.	Network is able to provide the required service.

	Admission Control	Admission control information for realtime traffic such as audio calls or video calls.	This network is capable to accept the incoming traffic from terminal.

Table 4.1 Non-compensatory criteria list.

Type	Criteria	Description
Connection Cost	Cost	Indication of cost for service or network usage. Provided on per Kbytes basis.
Security	Network Security	Security level of the link layer. Range from 0 to 10.
QoS Subcriteria	Packet Transfer Delay	Average packet transfer delay in ms. (If class of service is in place, then network needs to provide information of all the classes). Valid range for average packet transfer delay: [0..65535] ms
	Packet Transfer Delay Jitter	Packet transfer delay jitter for the class in ms. Valid range for average packet transfer delay: [0..65535] ms
	Packet Loss Rate	Indicates the fraction of packets lost or detected as erroneous. A value equal to integer part of the result of multiplying -100 times the log10 of the ratio between the number of error packets and the total number of packets transmitted in the class population of interest.
	Max Bitrate	The maximum information transfer rate achievable in the class population of interest. This value can be constant, if there is only wired links involved; or it can be time varying at different scales, at is the case for segments involving wireless links. It is measured in kbps
	Guaranteed (Min) Bitrate	The minimum information transfer rate in the class population of interest. It is measured in kbps.

Table 4.2 Compensatory criteria list.

4.4 Weight Elicitation

Before ranking the networks according to the compensatory criteria, we need to know the relative importance/weight of each criterion. In network selection problem, some algorithms are proposed using AHP for weight elicitation [17, 18, 31, 32]. Despite the pairwise comparison characteristic and the hierarchic expression make AHP an easy and clear way to elicit weights of the criteria, it may not be suitable. As mentioned in chapter 4, independence between any two criteria in the same hiararchy level is required. However, considering the delay, delay jitter and packet loss rate, we find that they have strong interdependence between any pair of them. For instance, a sequence of negative jitters can result in congestion in router so as to increase packet loss rate, and a sequence of positive jitters can lead into excessive delays of consecutive packets [35]. Also, sacrificing some reliability such as rise the packet dropping rate through decreasing the buffer size can help us decrease the latency. To address this problem, we decide to use ANP for weight elicitation. Interdependence is considered in several fuzzy MCDM algorithms [33], but they actually aiming at handling the interdependence issue in MODM problems instead of MADM problems. Most weight elicitation methods for MADM do not consider interdependent criteria such as SMART, Swing Weights Pair Wise Ordinal Comparison of Criteria, etc. However, thanks to MIH function and related services, there is no fuzzy data involved, thus we can apply ANP directly to assign weights for our compensatory criteria. The weight elicitation process is described as following.

We divide the criteria into three parts: QoS, security and cost. Below the QoS, there are four sub-criteria: bitrate, packet loss rate (PLR), delay, and delay jitter. The relative importance of the three first level criteria can be elicited by user, while the importance of each QoS sub-criterion is predefined. Different traffic has different characteristics, determining they have different demands on the QoS criteria. Thus, weights are elicited by traffic type. We classify the traffic into four categories according to the class of services (TS23.107) defined by 3GPP:

- Conversational Traffic: The typical applications of this class are VoIP and video conferencing. Real-time conversation is always performed between peers (or groups) of live (human) end-users. This is the only traffic where the required QoS characteristics are strictly given by human perception.
- Streaming Traffic: When the user is looking at (listening to) real-time video (audio), the scheme of real-time streams applies. The real-time data flow is always aiming at a live (human) destination. It is a one-way transport.

- Interactive Traffic: When the end-user, that is either a machine or a human, is online requesting data from remote equipment (e.g. a server), this type of traffic applies. Examples of human interaction with the remote equipment are: Web browsing, database retrieval, server access. Examples of machines interaction with remote equipment are: polling for measurement records and automatic database enquiries (tele-machines).
- Background Traffic: When the end-user, that typically is a computer, sends and receives data-files in the background, this type of data transmission is called background traffic. Examples are background delivery of e-mails, SMS, download of databases and reception of measurement records.

Then we assign the weights to criteria based on the specific characteristics of the traffic type.

4.4.1 Conversational Traffic

Fig. 4.1 exhibits the compensatory criteria we taking into account and their sub-criteria. Four actions are taken to elicit weights: 1) Assign weights to level-1-criteria. For QoS, security and cost are in three different areas, AHP is utilized to decide the weights for them. 2) Allocate raw weights to QoS sub-criteria. 3) Eliminate the interdependence impact of QoS sub-criteria. Interdependence matrix referred in ANP is constructed to solve the interdependence problem. 4) Decide final weights.

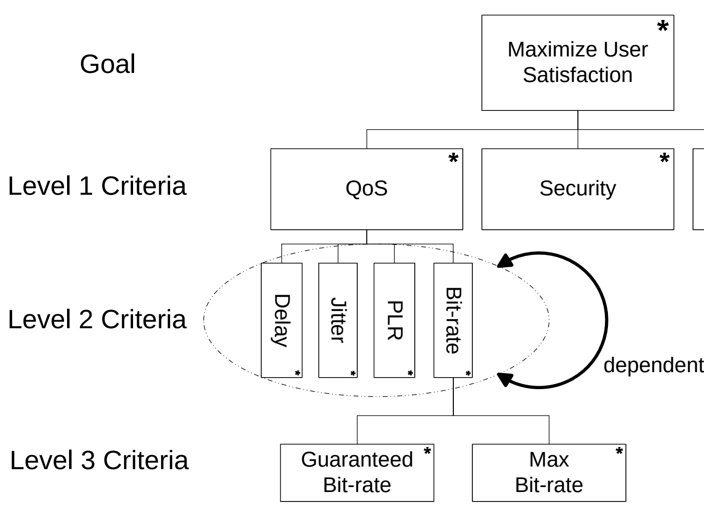

Fig. 4.1 Compensatory criteria of conversational traffic.

Activity 1:   Weight Elicitation for Level 1 Criteria

As shown in Fig. 4.1, we separate the compensatory criteria into three categories: QoS, security and cost. Either user assigns the weights to these three factors or default weights apply. By reason of relatively low total bits being transferred compared with other type of traffic, the cost may not be as significant as QoS (Assume the cost is calculated on per kbyte basis). Table 4.3 displays the judgments for Level 1 compensatory criteria. Using the largest eigenvalue method, the weights are calculated and shown in Table 4.3.

Compensatory Criteria	*QoS*	*Security*	*Cost*	***Weights***
QoS	1	4	7	0.705
Security	1/4	1	3	0.211
Cost	1/7	1/3	1	0.084

Table 4.3 Comparison matrix and weighting vector of level 1 criteria of conversational traffic.

However, due to the fact that the relative importance of these three criteria can vary wildly from diverse users, the weights are assumed to be $w_{1QoS}, w_{1Security}, w_{1Cost}$ for the three criteria respectively, where the summation of $w_{1Qos}, w_{1Security}, w_{1Cost}$ is equal to 1.

Activity 2:   Weight Elicitation for QoS Sub-criteria

We allot the weights for the sub-criteria of QoS based upon the characteristics of conversational traffic. The limit on acceptable transfer delay is very strict, as failure to provide low enough transfer delay will result in unacceptable lack of quality. Imagine you are having a phone call, and every time after you finish your word, you have to wait for response for more than 2 seconds, that will be a disaster. Jitter can change the inter-arrival times of neighboring packets, which leads into audio/video distortion, or, cause packet reordering which makes audio/video unrecognizable, due to these facts, jitter is also vital to conversational traffic. With respect to packet loss rate, intensive packet loss could give rise to voice gap or screen freezing and blanking, but humans are still able to tell the conversation contents or the main objects in a video with some isolated packet loss. In other words, conversational traffic can bear a certain level of packet loss. Hence, though PLR is quite important, it is not as critical as delay or jitter. By reason that the conversational traffic are not bursty (usually constant), and the encoding rates are relatively low (usually 4-64kbps typical data rates for conversational voice, and 16-384kbps data rates for video phone), the requirement on data rate supported by a candidate network is of less importance compared with other criteria.

Based on these natures of conversational traffic, we use the 1-9 scale to build the comparison matrix $\boldsymbol{C_1}$ in Table 4.4. Largest eigenvalue method is applied to obtain the original weighting vector $\boldsymbol{w}_1''$. Here, the largest real eigenvalue of this comparison matrix is 4.016, and hence, the corresponding eigenvector:

$$\boldsymbol{C_1 w_1'''} = \lambda \boldsymbol{w_1'''} \Longrightarrow \boldsymbol{w_1'''} = \left(w_{1Delay}''', \ w_{1Jitter}''', w_{1PER}''', w_{1GBr}'''\right)^{\mathrm{T}}$$

And the normalized weighting vector is given by

$$\begin{aligned}\boldsymbol{w_1''} &= \left(w_{1Delay}'', w_{1Jitter}'', w_{1PER}'', w_{1GBr}''\right)^{\mathrm{T}} \\ &= \left(\frac{w_{1Delay}'''}{w_{1total}''}, \frac{w_{1Jitter}'''}{w_{1total}''}, \frac{w_{1PER}'''}{w_{1total}''}, \frac{w_{1GBr}'''}{w_{1total}''}\right)^{\mathrm{T}} \\ &= (0.420, 0.306, 0.223, 0.051)^{\mathrm{T}},\end{aligned}$$

where $w_{1total}'' = w_{1Delay}''' + w_{1Jitter}''' + w_{1PER}''' + w_{1GBr}'''$.

QoS	*Delay*	*Jitter*	*PLR*	*Bitrate*	***Weights***
Delay	1	1	2	7	0.370
Jitter	1	1	2	7	0.370
PLR	1/2	1/2	1	6	0.214
Bitrate	1/7	1/7	1/6	1	0.046

Table 4.4 Comparison matrix and weighting vector of QoS subcriteria of conversational traffic.

For conversation traffic and streaming traffic, sometimes two different values of bitrate are provided by networks: guaranteed bitrate and maximum bitrate. However, the guaranteed bitrate is much more important than max bitrate regarding to conversational traffic from the QoS perspective. About those networks that do not provide OoS assurance for realtime traffic, their guaranteed bitrates are set to be zero.

Bitrate	*Weights*
Guaranteed Bitrate	0.95
Max Bitrate	0.05

Table 4.5 Weights for bitrate subcriteria of conversation traffic.

Activity 3: Eliminate the Interdependence Impact for QoS Sub-criteria

Weight elicitation using AHP is based on the strong assumption that all the attributes are independent. As we can see, this assumption may not be applied in our case, since end-to-end delay, delay variation, packet loss rate, and bitrate, they are related. Thus, the effects of the interdependence between the criteria are resolved in action 2. The impact of all criteria on each other will also be examined by pair-wise comparisons. Two questions: "Which criterion will influence criterion *delay* more: *PLR* or *jitter*? And how much more?" are answered. Various pair-wise comparison matrices are constructed for various criteria. These pair-wise comparison matrices are needed for identifying the relative impacts of criteria interdependent relationships. The eigenvectors for these matrices are normalized and expressed as column components (the summation of all the components in the same column is 1) of interdependence weight interdependence matrix **B** as shown in Table 4.9. And zeros are assigned to the left elements of **B**.

Fig. 4.2 explains the influence relationship among these criteria. Low bitrate can result in congestion, which either causes packet loss and/or a variation in latency. Packet loss can also be introduced by excessive jitter or a sequence of negative jitter, while a sequence of positive jitter leads into longer average transfer delay during a period time of interest [35].

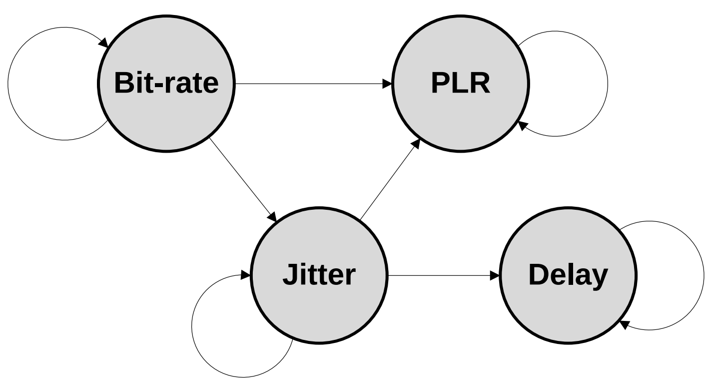

Fig. 4.2 Interdependence of QoS factors for conversational traffic.

Delay	*Delay*	*Jitter*	***Weights***
Delay	1	6	0.857
Jitter	1/6	1	0.143

Table 4.6 Interdependence comparison matrix with respect to delay of conversational traffic.

Jitter	*Jitter*	*Bitrate*	***Weights***
Jitter	1	3	0.750
Bitrate	1/3	1	0.250

Table 4.7 Interdependence comparison matrix with respect to jitter of conversational traffic.

Congestion caused by limited bitrate can result in successive packet loss, while jitter usually brings about single packet loss only. Packet loss occurs in burst is a lot more harmful than isolated packet loss, so we decide bitrate is of more importance than delay.

PLR	*Jitter*	*PLR*	*Bitrate*	***Weights***
Jitter	1	1/7	1/6	0.071
PLR	7	1	1.5	0.538
Bitrate	6	1/1.5	1	0.391

Table 4.8 Interdependence comparison matrix with respect to PLR of conversational traffic.

Thus, the interdependence matrix **B** is defined as following:

Interdependence matrix	*Delay*	*Jitter*	*PLR*	*Bitrate*
Delay	0.857	0	0	0
Jitter	0.143	0.750	0.105	0
PLR	0	0	0.637	0
Bitrate	0	0.250	0.258	1

Table 4.9 Interdependence comparison matrix B of conversational traffic.

The final weights for QoS sub-criteria are calculated as following.

$$\boldsymbol{w}_1' = \mathbf{B}\boldsymbol{w}_1'' = \begin{bmatrix} 0.857 & 0 & 0 & 0 \\ 0.143 & 0.750 & 0.071 & 0 \\ 0 & 0 & 0.538 & 0 \\ 0 & 0.250 & 0.391 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0.370 \\ 0.370 \\ 0.214 \\ 0.046 \end{bmatrix} = \begin{array}{c} \begin{bmatrix} 0.317 \\ 0.346 \\ 0.115 \\ 0.222 \end{bmatrix} \end{array} \begin{array}{c} \text{delay} \\ \text{jitter} \\ \text{PLR} \\ \text{Bitrate} \end{array}$$

Activity 4: Decide Overall Weights for Attributes

Now the overall weight is resolved for every attribute according to ANP. Weighting vector $\boldsymbol{w}_1 = w_{1Q} \cdot \boldsymbol{w}_1'$, thus, weights of delay, jitter, PLR, guaranteed bitrate are $w_{1Delay} = w_{1Delay}' \cdot w_{1Q}, w_{1Jitter} = w_{1Jitter}' \cdot w_{1Q}, w_{1PER} = w_{1PER}' \cdot w_{1Q}, w_{1GB} = 0.9 \cdot w_{1Bitrate}' \cdot w_{1Q}$,

and $w_{1MB} = 0.1 \cdot w_{1Bitrate}' \cdot w_{1Q}$ respectively. Weights of security $w_{1Security}$ and cost w_{1Cost} remain the same.

$$\boldsymbol{w}_1 = \begin{bmatrix} 0.317 \cdot w_{1Q} \\ 0.346 \cdot w_{1Q} \\ 0.115 \cdot w_{1Q} \\ 0.95 \cdot 0.222 \cdot w_{1Q} \\ 0.05 \cdot 0.222 \cdot w_{1Q} \\ w_{1Security} \\ w_{1Cost} \end{bmatrix} \begin{array}{c} \text{Delay} \\ \text{Jitter} \\ \text{PLR} \\ \text{GB} \\ \text{MB} \\ \text{Security} \\ \text{Cost} \end{array}$$

4.4.2 Streaming Traffic

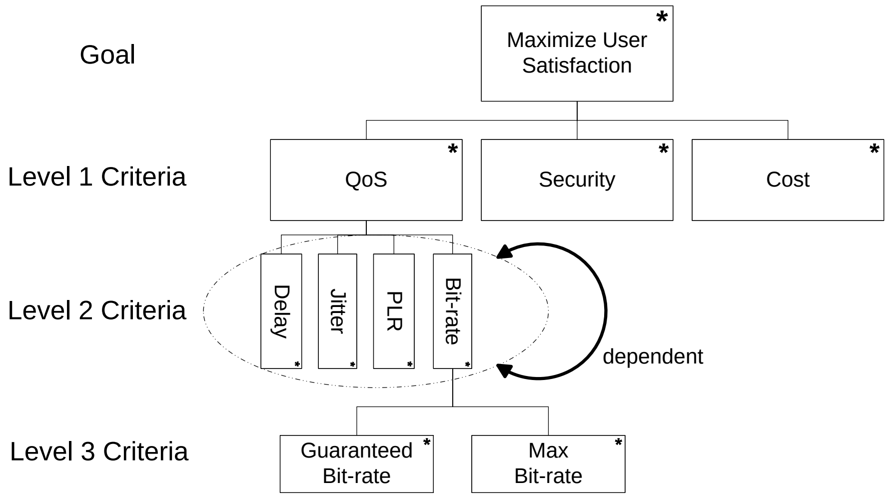

Fig. 4.3 Compensatory criteria of streaming traffic.

Activity 1: Weight Elicitation for Level 1 Criteria

Similarly, level 1 weights are assigned by users. Assume the weights for level one criteria of streaming traffic are: w_{2Qos}, $w_{2Security}$, and w_{2Cost}.

Activity 2: Weight Elicitation for QoS Sub-criteria

For this type of traffic are not interactive, the end-to-end delay is not that vital as it is for conversational traffic or interactive traffic. Nevertheless, the delay variation of the end-to-end flow must be limited, to preserve the time relation (variation) between information entities of the stream. As the stream normally is time aligned at the receiving end (in the user equipment), the highest acceptable delay variation over the transmission media is given by the capability of the time alignment function of the application. Acceptable delay variation is thus much greater than the delay variation given by the limits of human perception, so as PLR. For the sake of high quality video streaming application, researchers have developed schemes in which encoding rate varies according to the available bandwidth, the higher the bandwidth, the better the quality. In this case, not only minimum bitrate, but also maximum data rate a network is capable to provide needs to be taken into account. Table 4.10 and Table 4.11 denote the comparison matrices of QoS sub-criteria and bitrate sub-criteria, respectively.

QoS	*Delay*	*Jitter*	*PLR*	*Bitrate*	***Weights***
Delay	1	1/4	1/5	1/7	0.058
Jitter	4	1	1/1.5	1/2	0.215
PLR	5	1.5	1	1/1.5	0.299
Bitrate	7	2	1.5	1	0.428

Table 4.10 Comparison matrix and weighting vector of QoS subcriteria of streaming traffic.

Bitrate	*Guaranteed Bitrate*	*Max Bitrate*	***Weights***
Guaranteed Bitrate	1	5	0.833
Max Bitrate	1/5	1	0.167

Table 4.11 Comparison matrix and weighting vector of bitrate subcriteria of streaming traffic.

Activity 3: Eliminate the Interdependence Impact for QoS Sub-criteria.

Interdependence matrix **B** is the same for each type of traffic. Hence $\boldsymbol{w}_2'$ is given by

$$\boldsymbol{w}_2' = \mathbf{B}\boldsymbol{w}_2'' = \begin{bmatrix} 0.857 & 0 & 0 & 0 \\ 0.143 & 0.750 & 0.071 & 0 \\ 0 & 0 & 0.538 & 0 \\ 0 & 0.250 & 0.391 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0.058 \\ 0.215 \\ 0.299 \\ 0.428 \end{bmatrix} = \begin{array}{c} \begin{bmatrix} 0.049 \\ 0.191 \\ 0.161 \\ 0.599 \end{bmatrix} \end{array} \begin{array}{c} \text{delay} \\ \text{jitter} \\ \text{PLR} \\ \text{bitrate} \end{array}$$

Activity 4: Decide Overall Weights for all Attributes

Table 4.10 explains calculation of overall weighting vector $\boldsymbol{w}_2$.

Attributes	*Weights*
Delay	0.049× w_{2Qos}
Jitter	0.191× w_{2Qos}
PLR	0.161× w_{2Qos}
Guaranteed Bitrate	0.599×0.833× w_{2Qos}
Max Bitrate	0.599×0.833× w_{2Qos}
Security	$w_{2Security}$
Cost	w_{2Cost}

Table 4.12 Overall weighting vector for streaming traffic.

4.4.3 Interactive Traffic

Interactive traffic is one of the classical data communication types, and it is characterized by the request response pattern of the end-user. At the message destination there is an entity expecting the message (response) within a certain time. Delay is therefore one of the key attributes. Another characteristic is that the content of the packets must be transparently transferred (with low BER). Jitter affects little in this case, and because of the burstness of this type of traffic, guaranteed bitrate is not required.

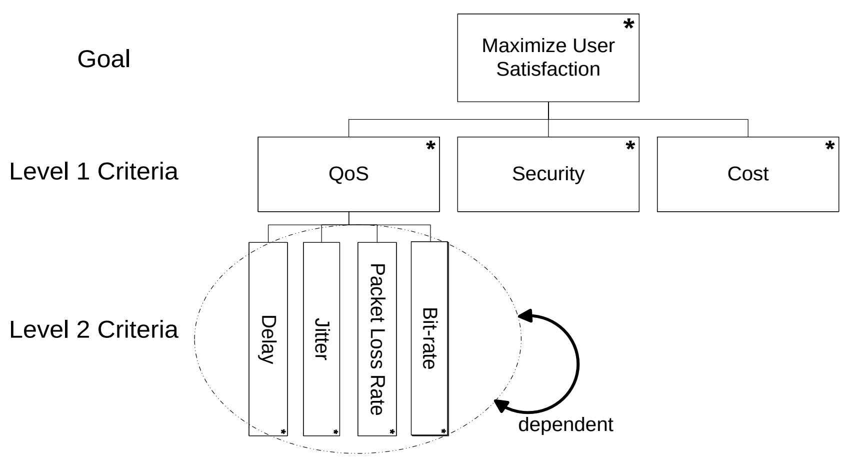

Fig. 4.4 Compensatory criteria of interactive traffic.

QoS	*Delay*	*Jitter*	*PLR*	*Max Bitrate*	***Weights***
Delay	1	8	1	3	0.409
Jitter	1/8	1	1/8	1/2	0.055
PLR	1	8	1	3	0.409
Max Bitrate	1/3	2	1/3	1	0.127

Table 4.13 Comparison matrix and weighting vector of QoS subcriteria of interactive traffic.

And by the same token, the overall weights are computed, and listed in Table 4.14.

Attributes	***Weights***
Delay	$0.409 \times w_{3Qos}$
Jitter	$0.055 \times w_{3Qos}$
PLR	$0.409 \times w_{3Qos}$
Max Bitrate	$0.127 \times w_{3Qos}$
Security	$w_{3Security}$
Cost	w_{3Cost}

Table 4.14 Overall weighting vector for interactive traffic.

4.4.4 Background Traffic

Background traffic is the other classical data communication where an overall level is characterized by the absence of any parameter at the destination expecting to receive the data within a certain time limit. The scheme is thus more or less delivery time insensitive. Another characteristic is that the content of the packets must be transparently transferred (with low BER). No bitrate is guaranteed for background traffic, so bitrate only refers to max bitrate here.

QoS	*Delay*	*Jitter*	*PLR*	*Max Bitrate*	***Weights***
Delay	1	1	1/5	1/9	0.060
Jitter	1	1	1/5	1/9	0.059
PLR	5	5	1	1/3	0.265
Bitrate	9	9	3	1	0.616

Table 4.15 Comparison matrix and weighting vector of QoS subcriteria of background traffic.

Attributes	***Weights***
Delay	$0.051 \times w_{4Qos}$
Jitter	$0.072 \times w_{4Qos}$
PLR	$0.143 \times w_{4Qos}$
Max Bitrate	$0.734 \times w_{4Qos}$
Security	$w_{4Security}$
Cost	w_{4Cost}

Table 4.16 Overall weighting vector for background traffic.

4.5 Ranking

RTOPSIS is applied for rating the candidate networks. Process of ranking the networks for conversation traffic is specified in this section. The processes for the other types of traffic are just about the same. Assume *m* networks have complemented the requirements for non-compensatory criteria, and have been decided to be the candidates. The weighting vector of the six attributes (delay, delay jitter, PLR, guaranteed bitrate, security, and cost) for conversation traffic is $\boldsymbol{w} = \boldsymbol{w_1}$.

Step 1: All the original attributes receive tendency treatment to construct a decision matrix **D**.

Delay, delay jitter, PLR and cost are cost criteria, so we need to transform them into benefit criteria. Let D, J, PLR, GB, S, and C denote the attributes, respectively. The i^{th} network N_i can be represented as a row vector $\{d'_i, j'_i, plr'_i, gb'_i, s'_i, c'_i\}$, where each element is the raw value with respect to certain attribute of this network. $\mathbf{D}'$ is the original decision matrix before transformation, and $\mathbf{D}$ is constructed based on $\mathbf{D}'$. In matrix $\mathbf{D}$, for $i = 1, 2, \ldots, m$, $d_i = 1/d'_i$, $j_i = 1/j'_i$, $plr_i = 1/plr'_i$, $c_i = 1/c'_i$, and all the other elements remain the same.

$$\mathbf{D}' = \begin{array}{c} \\ \mathrm{N}_1 \\ \mathrm{N}_2 \\ \vdots \\ \mathrm{N}_i \\ \vdots \\ \mathrm{N}_m \end{array} \begin{array}{c} \begin{array}{cccccc} \mathrm{D} & \mathrm{J} & \mathrm{PLR} & \mathrm{GB} & \mathrm{S} & \mathrm{C} \end{array} \\ \begin{bmatrix} d'_1 & j'_1 & plr'_1 & gb'_1 & s'_1 & c'_1 \\ d'_2 & j'_2 & plr'_2 & gb'_2 & s'_2 & c'_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ d'_i & j'_i & plr'_i & gb'_i & s'_i & c'_i \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ d'_m & j'_m & plr'_m & gb'_m & s'_m & c'_m \end{bmatrix} \end{array}$$

$$\mathbf{D} = \begin{array}{c} \\ \mathrm{N}_1 \\ \mathrm{N}_2 \\ \vdots \\ \mathrm{N}_i \\ \vdots \\ \mathrm{N}_m \end{array} \begin{array}{c} \begin{array}{cccccc} \mathrm{D} & \mathrm{J} & \mathrm{PLR} & \mathrm{GB} & \mathrm{S} & \mathrm{C} \end{array} \\ \begin{bmatrix} d_1 & j_1 & plr_1 & gb_1 & s_1 & c_1 \\ d_2 & j_2 & plr_2 & gb_2 & s_2 & c_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ d_i & j_i & plr_i & gb_i & s_i & c_i \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ d_m & j_m & plr_m & gb_m & s_m & c_m \end{bmatrix} \end{array}$$

Step 2: Construct the normalized decision matrix **R**.

For example, element r_{s_i} of the normalized matrix **R** is computed as below:

$$r_{s_i} = s_i / \sqrt{\textstyle\sum_{i=1}^{m} s_i^2}.$$

So are the other elements. Thus each attribute has the same unit length of vector.

Step 3: Calculate the weighted normalized decision matrix **V**.

Weighting vector $\boldsymbol{w}$ is given:

$$
\mathbf{V} = \begin{bmatrix} v_{d_1} & v_{j_1} & v_{plr_1} & v_{gb_1} & v_{s_1} & v_{c_1} \\ v_{d_2} & v_{j_2} & v_{plr_2} & v_{gb_2} & v_{s_2} & v_{c_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{d_i} & v_{j_i} & v_{plr_i} & v_{gb_i} & v_{s_i} & v_{c_i} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{d_m} & v_{j_m} & v_{plr_m} & v_{gb_m} & v_{s_m} & v_{c_m} \end{bmatrix}
$$

$$
= \begin{bmatrix} w_D r_{d_1} & w_J r_{j_1} & w_{PLR} r_{plr_1} & w_{GB} r_{gb_1} & w_S r_{s_1} & w_C r_{c_1} \\ w_D r_{d_2} & w_J r_{j_2} & w_{PLR} r_{plr_2} & w_{GB} r_{gb_2} & w_S r_{s_2} & w_C r_{c_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_D r_{d_i} & w_J r_{j_i} & w_{PLR} r_{plr_i} & w_{GB} r_{gb_i} & w_S r_{s_i} & w_C r_{c_i} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_D r_{d_m} & w_J r_{j_m} & w_{PLR} r_{plr_m} & w_{GB} r_{gb_m} & w_S r_{s_m} & w_C r_{c_m} \end{bmatrix}.
$$

Step 4: Determine the absolute positive ideal and negative ideal solutions.

This pair of absolute ideal solution can be simply set as

$$
\mathrm{A}^{+} = \left\{v_D^{+}, v_J^{+}, v_{PLR}^{+}\ v_{GB}^{+}, v_S^{+}, v_C^{+}\right\} = \{w_D, w_J, w_{PLR}, w_{GB}, w_S, w_C\} \text{ and}
$$

$$
\mathrm{A}^{-} = \left\{v_D^{-}, v_J^{-}, v_{PLR}^{-}\ v_{GB}^{-}, v_S^{-}, v_C^{-}\right\} = \{0, 0, 0, 0, 0, 0\}.
$$

Step 5: Calculate the separation measures.

The separation from the absolute ideal solutions are calculated as

$$
S_i^{+} = \sqrt{\frac{\left(w_D - v_{d_i}\right)^2}{w_D} + \frac{\left(w_J - v_{j_i}\right)^2}{w_J} + \frac{\left(w_{PLR} - v_{plr_i}\right)^2}{w_{PLR}} + \frac{\left(w_{GB} - v_{gb_i}\right)^2}{w_{GB}} + \frac{\left(w_S - v_{s_i}\right)^2}{w_S} + \frac{\left(w_C - v_{c_i}\right)^2}{w_C}},
$$

$$
S_i^{+} = \sqrt{\frac{\left(w_D - v_{d_i}\right)^2}{w_D} + \frac{\left(w_J - v_{j_i}\right)^2}{w_J} + \frac{\left(w_{PLR} - v_{plr_i}\right)^2}{w_{PLR}} + \frac{\left(w_{GB} - v_{gb_i}\right)^2}{w_{GB}} + \frac{\left(w_S - v_{s_i}\right)^2}{w_S} + \frac{\left(w_C - v_{c_i}\right)^2}{w_C}},
$$

and $\mathrm{i} = 1, 2, \dots, \mathrm{m}$.

Step 6: Calculate the relative distance to the ideal solution.

The relative closeness from attribute A_i to A^{+} is defined as

$$
C_i^{*} = S_i^{-} / (S_i^{+} + S_i^{-}),\ 0 \le C_i^{*} \le 1,\ i = 1, 2, \dots, m.
$$

Step 7: Rank the preference order.

The larger the C^*, the more we prefer. Hence, the candidate network with the largest C^* will be chosen as the target network to hand over.

By the same token, we can rank the candidate networks for the other types of traffic.

4.6 Conclusion

In this chapter, we have presented the process of the proposed network selection algorithm. Firstly, we attain the useful information of neighboring networks from IEEE 802.21 MIH service. Secondly, we use the non-compensatory criteria (information) to pick out the capable networks. Thirdly, we apply ANP to assign the weights to these compensatory attributes depends on the nature of a specific type of traffic. And finally, RTOPSIS is employed to calculate the final score of each candidate network.

Chapter 5

Evaluation of RTOPSIS for Network Selection

5.1 Case Study of RTOPSIS based Scheme

In this chapter, 3 cases are studied to verify the validity and usability of our proposed hybrid ANP and RTOPSIS model. Moreover, a comparison study for our proposed model and a TOPSIS based model will be presented in Section 5.2. Compensatory information provided by four heterogeneous networks are listed in Table 5.1. We will use these information for network selection in the following scenarios. Also, we make an assumption that all the listed networks meet the non-compensatory criteria requirements.

Candidate Networks		Delay (ms)	Jitter (ms)	PLR	GB (Mbps)	MB (Mbps)	Security (level)	Cost (per kbyte)
#1 UMTS	Conversational	100	10	10^{-4}	0.2	1	9	9
	Streaming	280	10	10^{-3}	0.2	1	9	
	Interactive	800	70	10^{-6}	0	2	9	
	Background	800	70	10^{-6}	0	2	9	
#2 WiMAX	Conversational	60	15	10^{-3}	0.1	20	6	6
	Streaming	350	20	10^{-3}	0.1	20	6	
	Interactive	500	70	10^{-5}	0	20	6	
	Background	1000	100	10^{-5}	0	20	6	
#3 WLAN	No CoS	200	30	10^{-3}	0	10	5	1.5
#4 WLAN	No CoS	400	80	10^{-3}	0	3	5	1
#5	No CoS	1000	100	10^{-2}	0	1	1	10

Table 5.1 Attribute values for scenarios 1, 2 and 3.

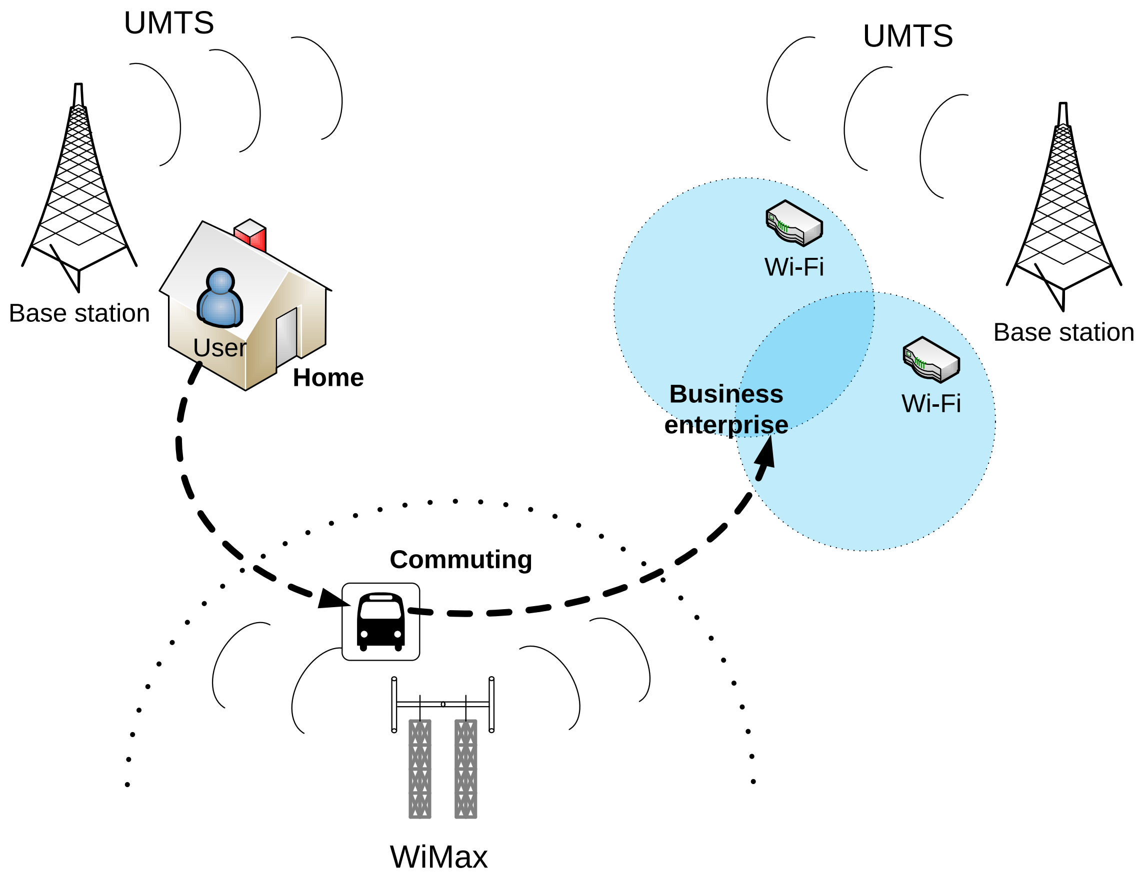

Fig. 5.1 The network selection simulation scenario.

Scenario 1: User is watching a streaming video at home under the service of network #1. As shown in Fig. 6.1, only the signal from network #1 is sensed in this case. Even though the signal strength is not very good, handover won't be trigger owing to no other choice.

Scenario 2: After a while, user leaves home for work. He gets on the bus and when it is running on the highway, a signal form network #2 is received. User manually starts the network selection program. According to the weights of *QoS*, *security* and *cost* which user has set and stored in the user profile (suppose the weights for QoS, security and cost are 0.5, 0.1, and 0.4 respectively), network #2 is determined to be the server. Set weight for security as 0.1, in Fig. 6.2, we can see that changing the relative importance between QoS and cost does affect the results: the greater the importance for cost, the higher chance network #2 wins, since network #2 offers better price than the other networks.

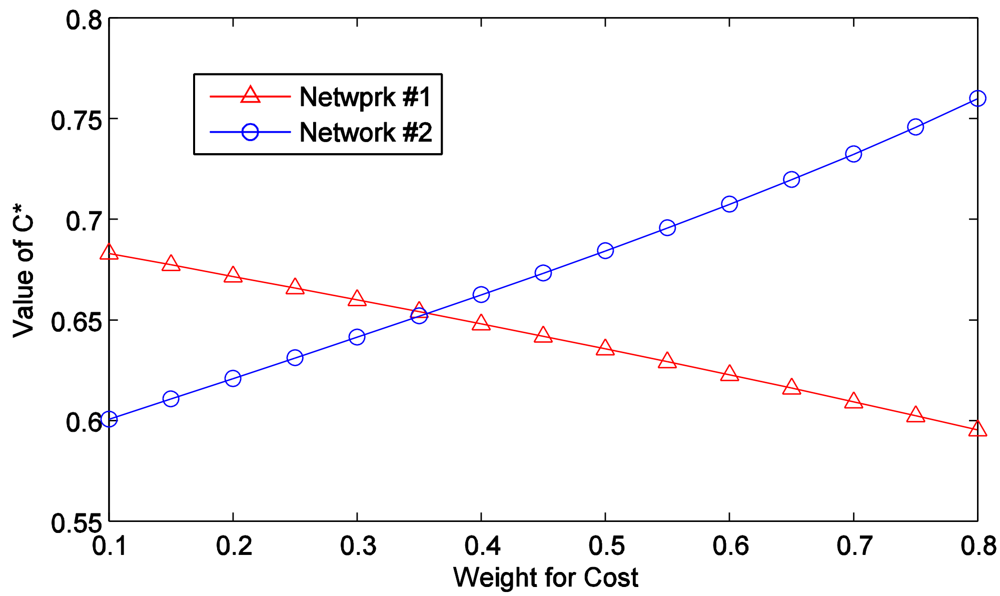

Fig. 5.2 Value of C* for Network #1 and Network #2 with respect to weight for cost (set the weight for security unchanged as 0.1).

Scenario 3: In this scenario, as demonstrated in Fig. 5.1, user is sitting in his office and having a VoIP conference call. Somehow, two different Wireless LANs (network #3 and network #4) and a UMTS (network #1) are available. By reason of the high requirements on QoS and security for a business call, UMTS is chosen.

Table 5.2 gives the C* values for scenario 2 and scenario 3.

	Weights for Level 1 Criteria	Networks	Value of C*	Result
Scenario2	{0.5, 0.1, 0.4}	#1	0.6478	N2>N1
		#2	0.6625	
Scenario3	{0.4, 0.5, 0.1}	#1	0.7086	N1>N3>N4
		#3	0.3917	
		#4	0.3773	

Table 5.2 Values of C* for scenario 2 and scenario 3, and the ranking result.

5.2 Comparison Study with TOPSIS based Scheme

If a TOPSIS based scheme [13] is applied in the selection system, some unfavorable situations will happen.

5.2.1 Relationship between Weight and Score

For scenario 2, we drew a figure about value of C* with respect to weight of cost. Fig. 5.3 is the same as Fig. 5.2, while in Fig. 5.4 we use TOPSIS to calculate the value of C*. By comparing the two pictures, we can easily find out that: in Fig. 5.3, the value of C* is linearly proportional to the weight for cost, exhibiting a linear relationship. In Fig. 5.4, the relationship of the value of C* and the weight for cost is not linear.

Score changes proportionally with weight is a desirable feature for scoring system. However, in literature, not only [13], which adopted a TOPSIS based scheme for network selection, though [16, 17, 18, 31] tried to use other methods to score the networks, they all suffer the same problem. Thus, this RTOPSIS based model makes an improvement in network selection area.

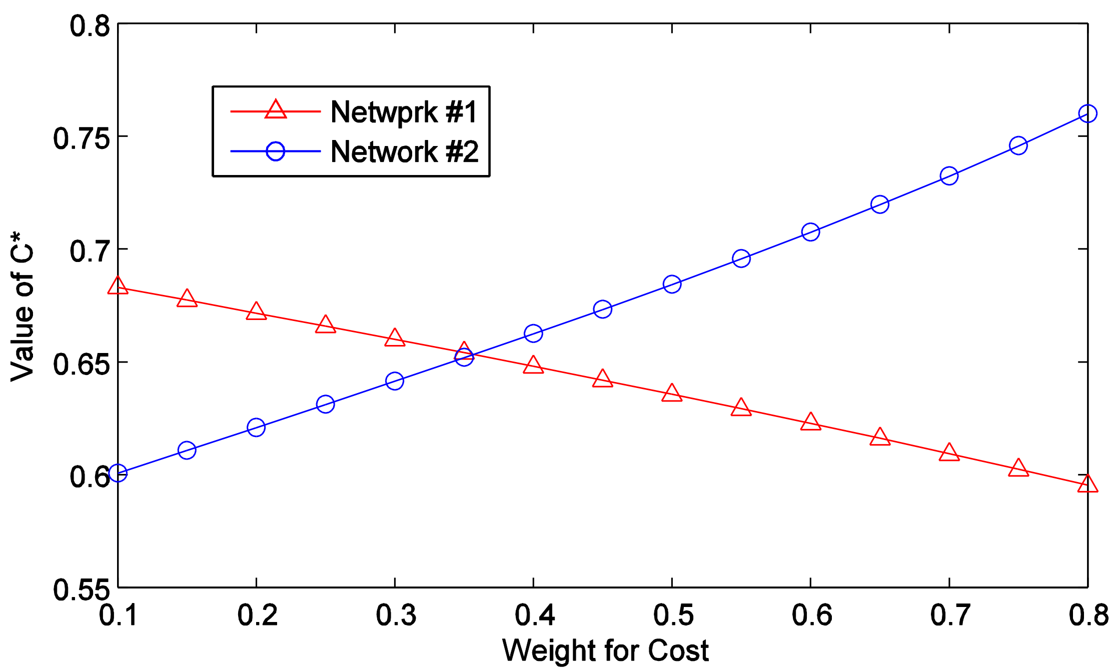

Fig. 5.3 Set weight of security as 0.1, the value of C* for network #1 and network #2 with respect to weight of cost using RTOPSIS.

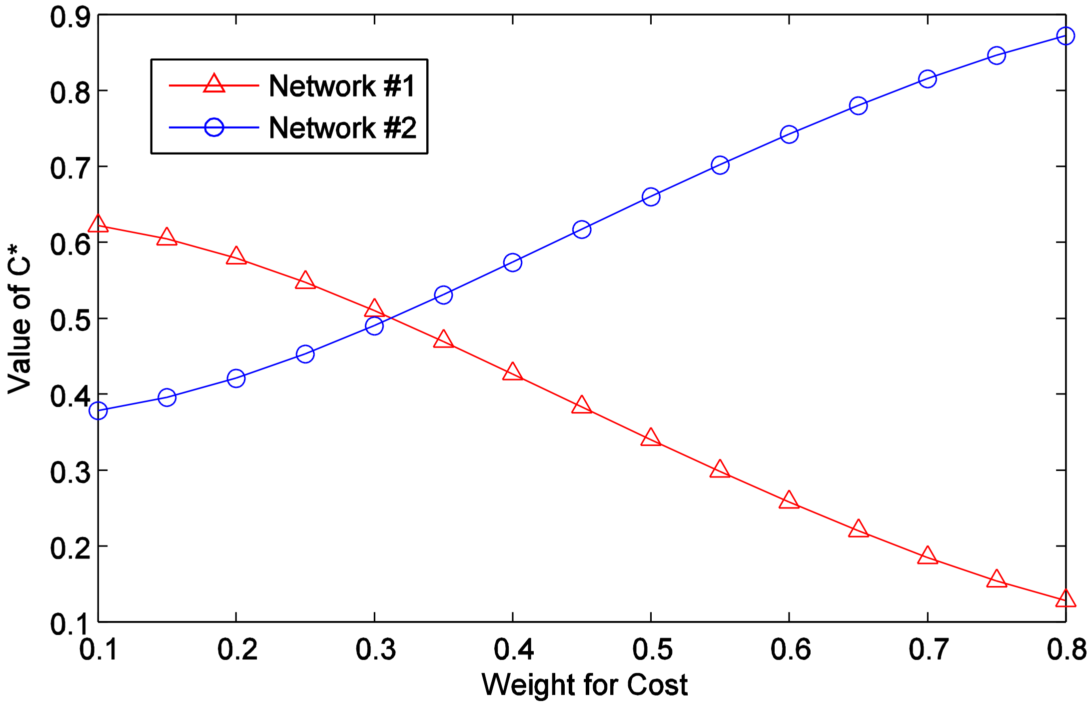

Fig. 5.4 Set weight of security as 0.1, the value of C* for network #1 and network #2 with respect to weight of cost using TOPSIS

5.2.2 Rank Irregularity

In scenario 3, rank irregularity or rank reversal could happen if user changes the relative weights across the level 1 criteria. In first case, we only have three networks as it is in scenario 3, except we set the weighting vector as {0.2, 0.1, 0.7}. Now we add one more network as a candidate, say network #5, and keep all the other conditions unchanged, then the result provided by our approach is consistent on N1>N4>N3. However, in a TOPSIS based approach, the preference for N3 and N4 is reversed. An even worse situation happens in TOPSIS is shown in Table 5.4. In this case, the top ranked network changes. The worst choice (N1) reverses into the best one after a new network being added. In both scenarios, our proposed model works well.

Weights			RTOPSIS	TOPSIS	Results
{0.2, 0.1, 0.7}	Case 1	#1	0.6331	0.6694	RTOPSIS: N1>N4>N3 TOPSIS: **N1>N4>N3**
		#3	0.4166	0.3121	
		#4	0.4373	0.3304	
	Case 2	#1	0.6318	0.6878	RTOPSIS: N1>N4>N3 TOPSIS: **N1>N3>N4**>N5
		#3	0.4152	0.3527	
		#4	0.4360	0.3433	
		#5	0.0822	0	

Table 5.3 Rank Irregularity Example of TOPSIS

Weights			RTOPSIS	TOPSIS	Result
{0.335, 0.1, 0.565}	Case 1	#1	0.5515	0.4950	RTOPSIS: N1>N4>N3 TOPSIS: **N4>N3>N1**
		#3	0.4507	0.4264	
		#4	0.5132	0.5049	
	Case 2	#1	0.5503	0.5182	RTOPSIS: N1>N4>N3>N5 TOPSIS: **N1>N4>N3**>N5
		#3	0.4492	0.4471	
		#4	0.5118	0.5115	
		#5	0.0834	0	

Table 5.4 Rank reversal example of TOPSIS.

5.3 Conclusion

In this chapter, we consider 3 different scenarios to show the usability of our proposed network selection algorithm. Moreover, we compare this RTOPSIS based scheme with a TOPSIS based scheme. When rank reversal happens in the TOPSIS based scheme, RTOPSIS still works well. Thus, this simulation results and comparison study verify the invalidity and superiority of our proposed ANP and RTOPSIS based scheme.

Chapter 6
Conclusion

6.1 Summary

Network selection is vital in future highly integrated pervasive 4G networking environment. A traditional way to select a target network which is only based on the received signal strength (RSS) is not effective enough to make the best choice for those multimedia applications. The traffic characteristics, the user preference, and the network conditions should all be considered to maximize consumer satisfaction. Though some existing schemes do consider multiple criteria (e.g. QoS, security, connection cost, etc.) for network selection, there are still several problems unsolved. In this study, we obtain the necessary information of neighboring networks via IEEE 802.21 MIHF, and classify the information into two categories; then we use the non-compensatory information as a trigger of checking the compensatory information; at last, taking the compensatory information as input, we propose a hybrid ANP and RTOPSIS model to rank the candidate networks. We not only provide a comprehensive way to select the optimal network, but also solve the rank irregularity problem. This proposed approach can be applied in handover scenarios, and also, for a terminal that allows using multiple network interfaces simultaneously, this network selection model can be employed to choose the best link for a specific traffic flow.

6.2 Future Work

IEEE 802.21 is in its early stage. This thesis is based on the draft standard produced by IEEE 802.21 working group in March 2006 and the working group's regular meeting documents posted on its website. Since the final version may have a lot differences with the draft standard, the criteria that we have considered in this report will also be updated. However, the basic selection process and model will probably be the same.

Since IEEE 802.21 draft standard only concerns about infrastructure based single-hop networks, the extension of this thesis to multi-hop networks will be the future study.

Besides network selection decision making, the proposed hybrid ANP and RTOPSIS model can also be applied in other decision making areas, for example, whether we should hand over to another network or stay in current network, where to localize the relay station decision, and routing decision making issue. All these problems should consider multiple factors to make a comprehensive decision.

Bibliography

[1] Draft IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services. IEEE P802.21/D01.00. March 2006. Available from IEEE.

[2] IEEE 802.21 Working Group. [online] http://www.ieee802.org/21/.

[3] J. Stein, "Survey of IEEE802.21 Media Independent Handover Services," [online] http://www.cs.wustl.edu/~jain/cse574-06/handover.htm.

[4] [Buddhikot03] M. Buddhikot et al, "Design and Implementation of WLAN/CDMA2000 Interworking Architecture", *IEEE Communication*, Volume 41, Number 11, Page 90-100, November 2003.

[5] Wikipedia, *IEEE 802.11k*, http://en.wikipedia/wiki/ IEEE 802.11k (as of Oct. 10, 2007).

[6] J. Mark, and W. Zhuang, *Wireless Communications and Networking*, Prentice Hall, 2002.

[7] Imago Communications Limited, *IP 06 Survey*. [online] http://www.ipexpo.co.uk/files/IP06SurveyBriefing1_Wireless.pdf, July 2006.

[8] L. Garber, "Will 3G really be the next big wireless technology", *Computer*, Volume 35, Number 1, Page 26–32, 2002.

[9] ITU-T. Recommendation Q.1701: Framework for IMT-2000 networks.

[10] IEEE 802.21 Tutorial, http://www.ieee802.org/21/.

[11] H. Jia, Z. Zhang, P. Cheng, H. H. Chen and S. Li, "Study on Network Selection for Next-Generation Heterogeneous Wireless Networks," in *Proc. of IEEE PIMRC'06,* Helsinki, Finland, September 2006.

[12] M. Wu, Y. Chen, T. Chung and C. Hsu, "A Profile-Based Network Selection with MIH Information Service," in *Proc. of ICS'06,* Samos Island, Greece, August/September 2006.

[13] F. Bari and V. C. M. Leung, "Automated network selection in a heterogeneous wireless network environment," *IEEE Network*, Volume 21, Page 34-40, January/February 2007.

[14] F. Bari and V. C. M. Leung, "Service Delivery over Heterogeneous Wireless Networks: Network Selection Aspects," in *Proc. of ACM IWCMC*, Vancouver, Canada, July 2006.

[15] F. Bari, and V. C. M. Leung, "Multi-Attribute Network Selection by Iterative TOPSIS for Heterogeneous Wireless Access", in *Proc. IEEE CCNC'07* Las Vegas, NV, USA, January 2007.

[16] W. Zhang, "Handover Decision Using Fuzzy MADM in Heterogeneous Networks," in *Proc. of IEEE WCNC'04*, Atlanta, GA, USA, March 2004.

[17] E. Stevens-Navarro and V. Wong, "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks," in *Proc. of IEEE VTC'06-Spring*, Melbourne, Australia, May 2006.

[18] Q. Song, A. Jamalipour, "Network Selection in an integrated wireless LAN and UMTS environment using mathematical modeling and computer techniques." *IEEE Wireless Communication Magazine*; Volume 12, Number 3, Page 42-48, 2005.

[19] Z. Ozturk, "A Review of Multi Criteria Decision Making with Dependency between Criteria", in *Proc. of MCDM 2006*, Chania, Greece, June 2006.

[20] V. M. R. Tummala, *Introduction to Decision Making in the Manufacturing Environment*, Springer, June 2007.

[21] T. L. Saaty, *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation.* Mc-Graw Hill, 1980.

[22] V. K. Thomas, *PhD dissertation, Georgia Institute of Technology*, May 2007.

[23] Decision and Risk Analysis: [online] http://classweb.gmu.edu/rganesan/AHP.ppt

[24] T. L. Saaty and L. Vargas, *Decision Making with the Analytic Network Process: Economic, political, social and technological applications with benefits, opportunities, costs and risks.* Springer, 2006.

[25] J. S. Dyer, "Remarks on the Analytic Hierarchy Process." *Management Science,* Volume 36 Number 3, Page 249-258, 1990.

[26] X. Wang, and E. Triantaphyllou, "Some ranking irregularities when the ELECTRE method is used for decision-making," in Proc of *IERC'04*, Houston, TX, USA, May 2004.

[27] D. M. Buede, and D. T. Maxwell, "Rank Disagreement: A Comparison of Multi-criteria Methodologies", *Journal of Multi-Criteria Decision Analysis*, Volume 4, Number 1, Page 1-21, 2006.

[28] T. Hiroyuki, S. Yosuke, and T. Koichi, "A Normalization Procedure and Proof of Convergence of ANP Revised with Aspiration Level", *Proceedings of the Annual Conference of the Institute of Systems, Control and Information Engineers*, Volume 43, Pages 501-502, 1999.

[29] W. Chen, "On the Problem and Elimination of Rank Reversal in the Application of TOPSIS Method", *Operations Research and Management Science*, Volume 14, Number 5, October 2005.

[30] C. Hwang, and K. Yoon, “Multiple attribute decision making: methods and applications”, Springer, New York, 1981.

[31] Q. Song and A. Jamalipour, “Quality of Service Provisioning in WirelessLAN/UMTS Integrated Systems Using Analytic Hierarchy Process and Grey Relational Analysis,” in *Proc. of IEEE GLOBECOM*, Dallas, TX, USA, Nov./Dec. 2004.

[32] M. Tam, V. M. R. Tummala “An application of the AHP in vendor selection of a telecommunications system.” *Omega*, Volume 29, Number 2, Page 171-182, April 2001.

[33] C. Carlsson, R. Fuller, “Fuzzy Multiple Criteria Decision Making: Recent Developments”, *Fuzzy Sets and Systems*, Volume 78, Number 2, Page 139-153, March 1996.

[34] T. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, 2001.

[35] L. Zheng, L. Zhang, D. Xu, “Characteristics of Network Delay and Delay Jitter and its Effect on Voice over IP (VoIP),” *IEEE International Conference on Communications*, Volume: 1, Page 11-14, June 2001.

[36] M. Emmelmann, S. Wiethoelter, A. Koepsel, C. Kappler and A. Wolisz, “Moving towards Seamless Mobility: State of the Art and Emerging Aspects in Standardization Bodies,” *in Proc. of IEEE WPMC’06*, San Diego, CA, USA, September 2006.

[37] L. Ren, Y. Zhang, Y. Wang, and Z. Sun, “Comparative Analysis of a Novel M-TOPSIS Method and TOPSIS”, *Applied Mathematics Research eXpress*, Volume 2007, Article ID abm005, 10 pages, June 2007.

[38] J. Lee, and S. Kim, “Using Analytic Network Process and Goal Programming for Interdependent Information System Project Selection”, *Computers & Operation Research*, Volume 27, Number 4, Page 367-382, April 2000.

[39] Wikipedia, IEEE 802.11r, http://en.wikipedia/wiki/ IEEE 802.11r (as of Oct. 10, 2007).

[40] M. Katz, and F. H.P. Fitzek, “Cooperative Techniques and Principles Enabling Future 4G Wireless Networks”, *EUROCON 2005*, Serbia & Montenegro, Belgrade, November 2005.

[41] SPG Media Ltd., “4G: Challenges and Opportunities”, *Global Semi-conductor Forum*, February 2007.

[42] V. Gazis, N. Alonistioti, and L. Merakos, “Toward a Generic “Always Best Connected” Capability in Integrated WLAN/UMTS Cellular Mobile Networks,” *IEEE Wireless Communications*, Volume 12, Page 22-29, June 2005.

[43] A. Iera, A. Molinaro, C. Campolo, M. Amadeo, “An Access Network Selection Algorithm Dynamically Adapted to User Needs and Preferences”, *Proceedings of IEEE PIMRC’06*, Helsinki, Finland, September 2006.

[44] A. Iera, A. Molinaro, C. Campolo, “New Concept Platforms for QoS Management in Future Telecommunication Scenarios”, *International Journal of Wireless Information Networks*, Volume 14, Page 79-91, 2007.