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Network Selection Equilibrium in Heterogeneous Wireless Environment

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***Abstract*—Service delivery in a heterogeneous wireless environment requires the selection of an optimal access network. In order that users could be always connected through the optimal available network, it is necessary to develop an adequate technique for its selection. This article presents the proposal of suitable network selection technique for heterogeneous wireless environment that is based on TOPSIS method when solving the multiple criteria decision making problems. The radio access networks in this model represent the alternatives, while the network parameters (network conditions, QoS level, security level, cost of service) are considered as the triggering criteria for determining the suitable network. Through simulation studies, we show the potential of entropy based TOPSIS model in optimal network selection process.**

***Index Terms*—Heterogeneous wireless networks, network selection, QoS, seamless mobility, vertical handover.**

I. INTRODUCTION

An important characteristic of future generation wireless systems is the compositeness of communication model. The combination of different wireless technologies and architectures is used for providing a large variety of multimedia services for users to access from "any place and any time". This environment will lead to the state where users are free of being tied to one single network subscription. Wireless access technologies (WiFi, WiMAX, LTE, MobileFi, etc.) are different in terms of their general characteristics such as: coverage, bandwidth, security, cost and quality of service (QoS). However, differences can exist among networks with the same architecture. For example, two WiFi networks based on same standard can differ in terms of security and QoS as well as the cost of service.

In such heterogeneous environment, handover management is the essential issue that supports the seamless mobility from one system to another. Handover management, as one of the mobility management components, controls the change of the point of attachment (PoA) during active communications. Handover management includes mobility scenarios, metrics, decision algorithms and procedures [1]. Vertical (heterogeneous, hyper) handover can be initiated for convenience rather than connectivity reasons. Major challenges in vertical handover management are seamlessness and automation aspects in network switching. These specific requirements can refer to the Always Best Connected (ABC) concept. ABC represent a vision of fixed and mobile wireless access as an integral and challenging dimension in developmental paradigm of the next generation wireless networks [2]. It is a strategic goal to define important advancements that happen and are predicted in technologies, networks, mobile terminals, services, and future business models that include all this issues while realizing and exploiting new wireless networks. On the other hand, because users could be always connected through the optimal radio access network (RAN), it is necessary to develop an adequate mechanism for its selection. Since some other parameters must be taken into consideration, beside the traditional received signal strength (RSS) and signal to interference and noise ratio (SINR), it is possible that the problem can be pointed out from the aspect of multiple criteria decision making.

Network selection is one of the most significant challenges for the next-generation wireless heterogeneous networks. ITU's concept of Optimally Connected, Anywhere, Anytime proposed in [3] states that future wireless networks could be realized through the coalition of different RANs. According such a scenario, the heterogeneity of access networks, services and terminals should be fully exploited to enable higher utilization of radio resources. The main objective is to improve overall networks performances and QoS perceived by users.

Third Generation Partnership Project (3GPP) is defining an Access Network Discovery and Selection Function (ANDSF) [4] to assist mobile terminals in vertical handover between 3GPP and non-3GPP networks, covering both automated and manual selection as well as operator and user management.

IEEE 802.21 [5] is developing standard which enables handover and interoperability between heterogeneous link layers. This standard defines the tools required to exchange information, events and commands to facilitate handover initiation and handover preparation. IEEE 802.21 standard does not attempt to standardize the actual handover execution mechanism. Therefore, this framework is equally applicable to systems that employ mobile IP at the network layer as to systems that use Session Initiation Protocol (SIP)

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at the application layer.

This paper is organized as follows. After introductory section and brief overview of related works, a detailed description of the proposed network selection technique is provided. Then, numerical results are presented and discussed together with possibilities of model implementation in real environment. Finally, the last section is devoted to the conclusions which summarize the contribution achieved in the paper.

II. Brief Overview of Related Works

In the network selection scenario, users are always trying to seamlessly access high-quality wireless services at any speed, any location, and any time through selecting the optimal network. Therefore, ensuring a specific QoS is the objective in the process of network selection. A great number of techniques related to the handover initiation and optimal access network selection are proposed in the open literature. The suggested techniques are using different metrics and heuristics for solving the above mentioned problems [6]. Unfortunately, currently proposed vertical handover techniques do not meet all the requirements in terms of functionality and efficiency.

In one of fundamental works [7] the authors develop a network selection mechanism for an integrated WLAN/cellular system. The design goal is to provide the user the best available QoS at any time. The proposed network selection mechanism relies on the combination of Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) of the multiple criteria decision making. This method mathematically presents a complex solution and unnecessarily takes into account a large number of QoS parameters (delay, jitter, response time, bit error rate, etc.), only for 3G and WLAN networks. Processing a large number of parameters leads to the computational time increasing, while the user's terminals and infrastructure network elements are additionally loaded. Thus, this model is theoretically interesting but not adequate for a direct implementation. These lacks are recognized in [8], but in general forms.

The decision for selection of an optimal access network is influenced by several factors. This is important aspect of service delivery in a heterogeneous wireless system. The article [9] has proposed a unique decision process that uses non-compensatory and compensatory multiple criteria decision making jointly on the network side to assist the terminal in the top candidate network selection. The steps involved in a use of a non-compensatory algorithm remove network alternatives from the candidate list that are not suited for the scenario. This process is completed before a compensatory algorithm can be used to provide network ranking. The proposed technique is more comprehensive compared to the methods previously mentioned, but also unnecessary considers too many network parameters.

New architecture capable to support ABC service together with personalized network selection scheme is proposed in [10]. There are several QoS parameters that affect access network selection. These parameters are summarized as availability, throughput, timeliness, reliability, security, and cost. Moreover, it is noted that some factors can be divided into second level factors. According to the presented scheme, users can select their personalized "best" network by changing weight factors and constraints in a single objective optimization problem. This model looks complicated from the user's point of view, while a problem of large set of criteria still exists.

For efficient network selection strategy the following important issue has to be fulfilled:

1) Only considerable parameters must be analyzed;
2) Equilibrium among users preferences, services requirements and networks performance must be achieved;
3) Technique has to be reliable and transparent to the user;
4) Algorithm has to minimize handover latency, blocking probability and number of superfluous handovers;
5) Flexible and suitable implementation in real environment is necessary.

III. Network Selection Equilibrium Technique

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [11] is one of Multi Attribute Decision Making (MADM) techniques based on a concept that the chosen alternative should have the shortest Euclidean distance (second order Minkowski's space) from the ideal solution and the longest from the non-ideal solution. Criteria can be presented in multidimensional coordinate system, where each has a coordinate axis. It is assumed that each criterion usability monotonously grows or falls, so it is easy to find an ideal solution made of all the best criterion values reached and the non-ideal solution made of the worst values. This technique is considered as a well-known and proven mathematical tool which gives an indisputable sequence of solution preference.

Network metrics are the qualities that are measured to give indication of whether or not a handover is needed. The following network parameters are particularly important for network selection and vertical handover decision and because of that fact, they will be observed in the proposed model:

1) Network conditions (D): Available bandwidth is mostly used indicator of traffic performances in the access networks and transparent parameter for the current and future users of the multimedia services. This is the measure of per user bandwidth allotted by the network operator which is dynamically changeable according the utilization of the network. The maximum theoretical bandwidth is closely related to the link capacity [12], [13]. Transition to a network with better conditions and higher performance would usually provide improved QoS. In the analyzed case, besides usual criteria, classical grade of service (GoS) parameters are pointed out. The influence of criteria D_i, i.e., network conditions for i-th one, can be analyzed through link capacity, the link capacity and traffic ratio, as well as the ratio of link capacity and blocking, link capacity and traffic losses ratio, through the available bandwidth, etc.

2) QoS level (Q): Delay, jitter, error ratio, loss ratio and other parameters can be measured in order to decide which network can provide a higher assurance of continuous connectivity. The levels of QoS should objectively be declared by the service provider based on ITU-T recommendation Y.1541 [14] and specified parameters. By declaring the QoS level in this way, we will avoid a complex examination of QoS parameters by users and the additional load of mobile terminals and other network elements.

3) Security level (S): When the information exchanged is confidential, a network with high encryption is preferred. The security level concept, sometimes called level of security (LoS), is similar to level of service in QoS management [15]. LoS is a key piece of information within a security profile and is used to determine whether user data is allowed to be transferred by a particular network or not.

4) Cost of service (C): The cost of services can significantly vary from provider to provider, but in different network environments. In some cases cost can be the deciding factor for optimal network selection, and it includes the traffic costs and the costs of roaming between heterogeneous networks. In some context cost of service is in tight relation with network conditions, QoS level, security level, but in next generation wireless environment, cost of service is fast time differentiable function dependable of many others parameters. Pricing schemes adopted by different service providers is crucial and will impact the decisions of users in network selection [16].

After the definition of the convenient parameters, the question often arises is how to transfer the metrics information from the network entities to the user's multimode terminals. Through the End to End Reconfigurability (E^2R) project, concepts and solutions for a cognitive pilot channel (CPC) were developed [17]. It was concluded that CPC will be able to bring enough information (for example proposed parameters) to the terminals for network selection, when users are preceding either initial connection or handover.

Network selection criteria are mainly represented in the form of decision (performance) matrix

$$\mathbf{D} = \left\| x_{ij} \right\|_{m \times n}, \tag{1}$$

where x_{ij} represents performance of i-th RAN (i = 1, … , m), related to j-th criteria (j = 1, …, n). Here, m is a set of available RANs, and n is a set of observed criteria (n = 4 in this case). In order to compare the criteria of different values and different measurement units, normalization is treated as a necessary step for most of the network selection techniques. In normalization process starting matrix (1) moves into normalized matrix $\left\| r_{ij} \right\|_{mxn}$, where r_{ij} is defined as normalized performance rating, obtained as

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2}, \; r_{ij} \in [0,1] \cdot \tag{2}$$

Once the decision criteria have been determined, the next step is to define their importance, i.e., weight, of each one of them in the final outcome. Weights are differentiated based on context, since each user or application type may bear different requirements. The user's preferences and services requirements play an important role in the decision mechanism and they can be used to weight the involved criteria. Many methods for the criteria weight estimation are developed in the theory. In certain cases encountered in the literature, the weights of the selection criteria are defined through the derivation and the analysis of questionnaires, which capture the user's overall perception of a service. However, these approaches depend only on user's feedback to determine the relative weights and thus cannot be considered precise, since user's perception and opinion is subjective. Obviously, this approach is adequate when subjective criteria are considered.

As an exact and objective approach, the entropy method can be applied. The Shannon's entropy is a measure of uncertainty in information formulated in terms of probability theory. Entropy weight is a parameter that describes how much different alternatives approach one another in respect to a certain attribute. The greater the value of the entropy means the smaller entropy weight. Then the smaller the different alternatives in this specific attribute and the less information the specific attribute provides, leads to the fact that this attribute becomes less important in decision making process.

While some modifications of TOPSIS method are applied for network selection algorithms [9], the entropy based modification concerning subjective weights estimation is first time introduced in [18]. The weights set based on its attribute entropy within the same criterion and range within all criterion models can be combined with the weights that are given by the decision bearer (in this case the user) based on the preferences. The algorithm of entropy method for defining the weighted coefficients consists of the following steps:

Step 1. It is necessary to transform the model so that all criteria become the types of maximization. The relations in the model stay unchanged, but the nature of criterion cost is changing (min→max) in the following operation $x_{i4}^* = 1 - x_{i4}$, for each i-th RAN.

Step 2. Determining the entropy for every of j-th criteria based on relation

$$e_j = \left[-1/\ln(m)\right] \cdot \sum_{i=1}^{m} \left[r_{ij} \ln(r_{ij})\right], \; j \in \{1, \dots, n\}. \tag{3}$$

Step 3. Determining the deviation within each criterion $d_j = 1 - e_j$.

Step 4. Determining the weight coefficients

$$W_j = d_j w_j / \sum_{j=1}^{4} d_j w_j \cdot \tag{4}$$

In the objective approach, the user equally prefers all the parameters, and because of that w_j = 1. Otherwise, if the user determines the subjective weights, $w_j = (1 + p)/5p$ for the preferred parameter (p is a number of preferred parameters),

w_j = 0.2 for other parameters.

After criteria weights estimation, in general, normalized matrix moves into the weighted matrix

$$\mathbf{V} = \left\| W_j r_{ij} \right\|_{m\times n} = \left\| v_{ij} \right\|_{m\times n}. \quad (5)$$

Considering the weighted matrix defined by (5) and min→max transformation provided in weight coefficients estimation, the ideal and worst solutions are representing the sets:

$$\begin{cases} A^{+} = \{\max_{1\le i\le m} v_{ij} \mid j = 1,...,n\} = \{v_1^{+},...,v_n^{+}\}, \\ A^{-} = \{\min_{1\le i\le m} v_{ij} \mid j = 1,...,n\} = \{v_1^{-},...,v_n^{-}\}. \end{cases} \quad (6)$$

Euclidean distances of all alternatives, in relation to the ideal and worst solution, can be calculated from:

$$\begin{cases} D_i^{+} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{+})^2}, \\ D_i^{-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{-})^2}, \quad i = 1,...,m. \end{cases} \quad (7)$$

Lastly, the ranking of networks can be done through the relative closeness (*RC*) to the ideal solution in the form

$$RC_i = \frac{D_i^{-}}{D_i^{-} + D_i^{+}}, RC_i \in (0,1). \quad (8)$$

where the optimal network is the one with the largest *RC*. This merit function evaluates networks performances by integrating the measured parameters with their corresponding weights assigned according to the users preferences and services requirement, and can be contemplated as measure of network quality. *RC* factor can be used for vertical handover initiation to highest ranked RAN taking into account that

$$RC_{candidate} > RC_{curent} + \theta. \quad (9)$$

Here θ represents predefined threshold which goal is to minimize the influence of undesirable effect of frequent superfluous handovers and also can be used in admission control mechanism if operators need to control or influence which target network the users select. A handover is considered as superfluous when a mobile terminal back to the previous PoA is needed within certain time duration ("ping-pong" effect), and such handovers should be minimized. The larger the threshold value, the smaller the number of handovers, however there is a longer handover initiation delay. On the other hand, the smaller the threshold value, the shorter the handover initiation delay but the larger the number of handovers. Handover initiation delays lead to an increase in the call dropping probability, especially in the case of highly mobile users. Moreover, frequent handovers cause an increase in signaling overhead and in the network load. Therefore, the determination of the threshold value is very important in terms of mobility performance. The algorithm for the proposed model is shown on Fig. 1 and it is possible to test it in real environment as well as by using the generated network parameters through the simulated model.

User's decision about the selection of network by multifunctional terminal can be made through several levels that provide efficiency while accessing. It is possible to organize the levels in the following way:

1st *level.* The decision is made according to the name of the given network. Users choose directly one of the available networks based on their own experience and knowledge of its characteristics.

2nd *level.* Users manually decide about the network selection based on parameters provided by the network and in our case they are: network conditions, QoS level, security level and cost of service.

3rd *level*. Users automatically make the decision about the network selection based on optimized algorithm and adopted weight coefficients for the basic available network parameters (from the second level).

4th *level*. Advanced users choose to make the decision by activating the algorithm similar to the previous one during which they choose the selection of weight coefficients for the basic network parameters and some supplementary parameters (e.g., battery consummation).

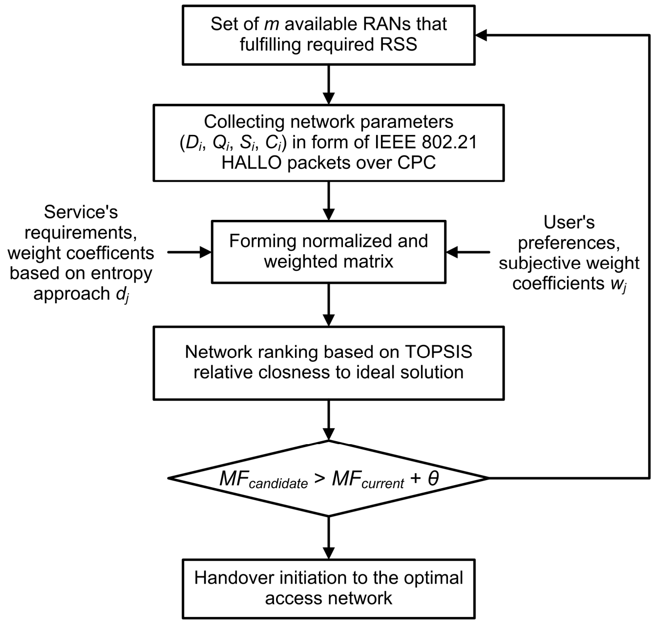

Fig. 1. Proposed algorithm for network selection equilibrium.

IV. TESTING MODEL RESULTS

In this section we present the results of the simulations conducted to highlight the benefits of the proposed network selection technique. Results demonstrate the process of finding a trade-off between user's preferences, services requirements and networks performances. A software application is developed for testing the algorithm with source code written in C++ environment. The source code can be implemented in mobile terminals with the adequate graphic user interface (GUI) so that the user can be provided with a faster and simpler way for connection to the optimal access network. Testing model results are shown through representative scenarios for three available access networks. The mobile terminals follow Poisson distribution with average velocity of 0 to 30 m/s with applied random walk model. The movements are considered as stochastic process.

In the first example of model testing the user did not have specific preferences for any parameters so $W_1 = 0.44$ is determined for the weight coefficient of parameter D purely based on service demands (entropy). Beside the network conditions, the safety parameter ($W_3 = 0.30$) has also proved to be important for this application while the Q and C are of less importance in this case ($W_2 = 0.10$ and $W_4 = 0.16$). The RAN_1 is determined as an optimal network because it is much better than any of the two networks according to all its parameters, except cost of service (Table I).

TABLE I. THE EXAMPLE OF TESTING MODEL RESULTS – 1ST SCENARIO.

	D	*Q*	*S*	*C*
		Normalized matrix		
RAN_1	0.881	0.310	0.418	0.419
RAN_2	0.884	0.161	0.080	0.776
RAN_3	0.626	0.192	0.058	0.234
W_j	0.44	0.10	0.30	0.16
		Weighted matrix		
RAN_1	**0.392**	**0.031**	**0.124**	0.067
RAN_2	0.375	0.016	0.024	**0.123**
RAN_3	0.278	0.019	0.017	0.037

According to second scenario, the user's preferable parameter is network conditions and for that parameter the weight coefficient $W_1 = 0.44$ is determined through the entropy method in combination with user's preferences. According to the result of simulation (Table II) RAN_3 is declared as optimal network, although RAN_2 is better as for as all the other parameters, but the difference between the value parameters Q, S, and C has proved to be marginal comparing to the significance of parameter D.

TABLE II. THE EXAMPLE OF TESTING MODEL RESULTS – 2ND SCENARIO.

	D	*Q*	*S*	*C*
		Normalized matrix		
RAN_1	0.498	0.286	0.389	0.088
RAN_2	0.089	0.828	0.944	0.695
RAN_3	0.872	0.458	0.821	0.614
W_j	**0.44**	0.12	0.27	0.17
		Weighted matrix		
RAN_1	0.218	0.034	0.105	0.015
RAN_2	0.039	**0.098**	**0.255**	**0.121**
RAN_3	**0.381**	0.054	0.221	0.107

For the third model testing scenario the lowest cost of service is required from user and so for this parameter the weight coefficient $W_4 = 0.58$ is set in the combination with service requirements. It can be concluded from the results that RAN_2 has the lowest cost of service (Table III). However, RAN_1 is declared as optimal because it provides higher level of QoS and security. RAN_2 also offers a greater network conditions ($D_2 > D_1$), but that parameter is less important in this case.

TABLE III. THE EXAMPLE OF TESTING MODEL RESULTS – 3RD SCENARIO.

	D	*Q*	*S*	*C*
		Normalized matrix		
RAN_1	0.169	0.869	0.681	0.976
RAN_2	0.254	0.132	0.269	0.993
RAN_3	0.056	0.229	0.878	0.274
W_j	0.12	0.15	0.15	**0.58**
		Weighted matrix		
RAN_1	0.020	**0.132**	0.103	0.567
RAN_2	**0.030**	0.020	0.041	**0.577**
RAN_3	0.007	0.035	**0.132**	0.159

In order to perform some efficiency evaluation, proposed technique is compared with RSS [19], cost function [20] and AHP&GRA [7] based techniques. The average blocking probabilities of RSS, cost function, AHP&GRA and proposed technique when velocity of mobile terminals varies are presented in Fig. 2. The simulation results show that MADM based techniques (AHP&GRA, TOPSIS) provide lower handover blocking probabilities than that of the RSS and cost function based techniques. It also shows that blocking probability has no obvious relationship with the mobile terminal velocity.

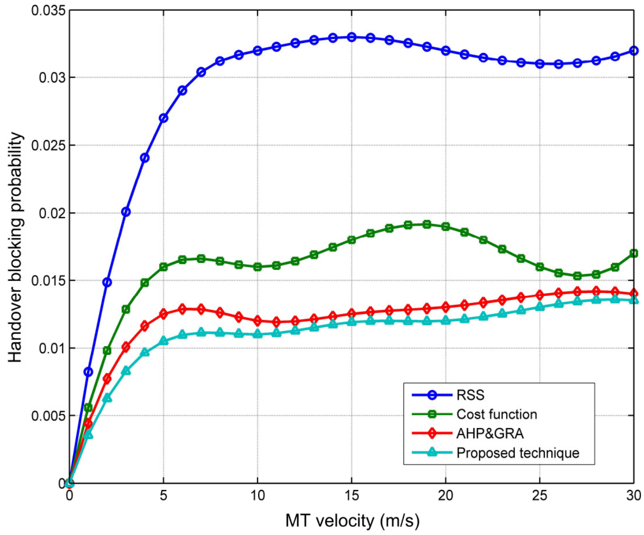

Fig. 2. Handover blocking probability when MT velocity varies.

The average handover blocking probabilities of observed techniques under different traffic conditions are shown in Fig. 3.

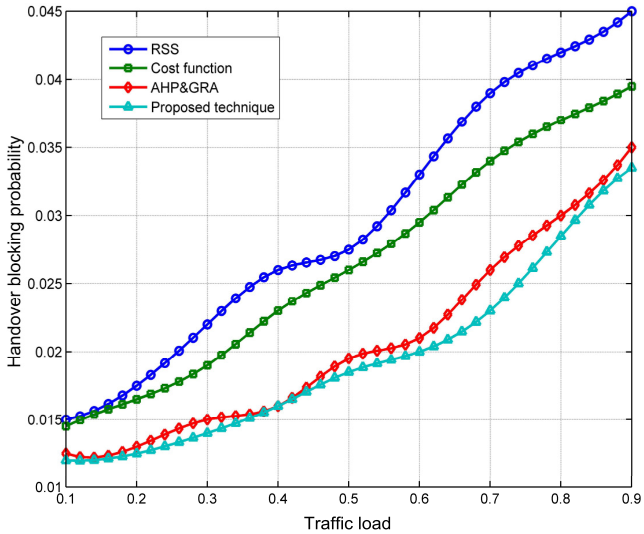

Fig. 3. Handover blocking probability with different traffic load.

Because the MADM based techniques consider more normalized networks parameters than the RSS and cost function based heuristics, the simulation results show that MADM techniques provide much lower blocking probability. Moreover, the blocking probability of the proposed technique provides about 4% improvement to the

AHP&GRA method. The results also show that the blocking probability is directly proportional to the traffic load. The blocking probability of all schemes increases as the traffic becomes heavier.

V. Possibilities of Model Implementation

For model functionality on the application layer it is important to implement network selection (NS) software modules based on the proposed algorithm into the network infrastructure elements. Suitable elements are mobile terminals, as well as QoS brokers that would interact with Authentication Authorization Accounting (AAA) servers (Fig. 4). Model implementation can provide the significant improvement of perceived QoS and overall system performance.

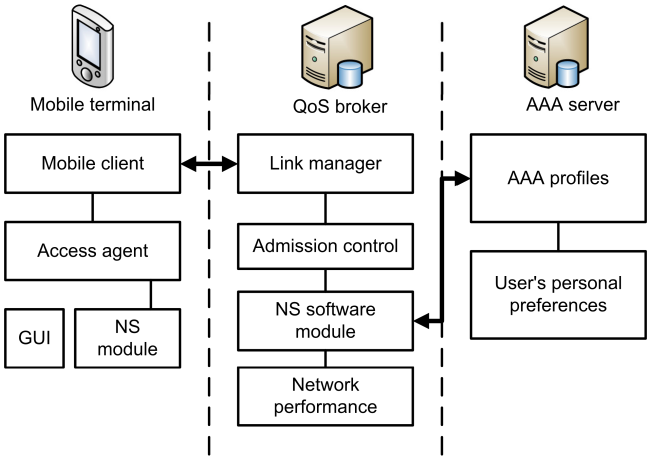

Fig. 4. Model implementation architecture.

VI. Conclusions

Current proposed network selection techniques in heterogeneous environment require more significant challenges to be overcome before they can successfully deployed in real systems. Following the principles of heterogeneous networking, a mobile terminal may choose among multiple available connectivity alternatives based on the criteria related to networks performances, users preferences and services requirements. In this paper we developed a network selection equilibrium technique for heterogeneous wireless environment. We integrated network conditions, QoS level, security level and cost of service as trigger parameters. Through simulation studies, multi criteria analysis is envisaged as promising tool especially when TOPSIS method is used. The proposed model finds simply and effectively the equilibrium between the users preferences, services requirements and networks condition. The solution is realistic and not very complex to implement in mobile terminals and other network elements.

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