QoE-aware Vertical Handover in Wireless Heterogeneous Networks

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***Abstract*—Deployment of next-generation network (4G) begins to spread throughout the world. With variety of network technologies and QoS restrictions on emerging applications; it becomes difficult for a user to select the best access network to request for connection. Even though many schemes have been proposed in the literature but very few of them take into account quality of experience (QoE) perceived by user for making decision. As QoE represents perception experienced by the user, it is thus an essential indicator for network evaluation, especially with multimedia communications nowadays. Therefore, in this paper we propose a novel network selection mechanism that takes quality of experience into consideration for decision making. It is a user-based and network-assisted approach thus a compromise solution between user and network benefit. The main idea is to use quality of experience of ongoing users in candidate networks as an indicator to select the best network for connection. We have implemented and tested our mechanism in network simulator NS-2. The obtained results illustrate that with a QoE-aware mechanism we can significantly improve user experience of mobile node and load balancing between networks.**

I. Introduction

Currently, enormous progress has been made on heterogeneous environment. In addition to wired networks, the evolution of wireless network has led to deployment of various wireless technologies, namely, Cellular Networks, Wireless Local Area Network (IEEE 802.11), Digital Video Broadcasting, or Broadband Wireless Communication (IEEE 802.16). Recently, heterogeneous networks are becoming accessible and user terminals with more than one network interface can access simultaneously to these networks and can benefit from all available choices of technologies. Besides, the rising number of Internet users has pushed the deployment of many applications. Among them, multimedia applications such as video conference and voice over IP (VoIP) are becoming increasingly famous. However, multimedia applications have tight QoS requirements in order to achieve good perception at end-users. This introduces us to network selection issue, an important concern in today's heterogeneous environment.

From the literature [1], there are two main approaches for network management. The first one is called *network-centric* approach, in which decisions are made at network operator and they are principally based on network operator's profit. On the contrary, the second approach called *user-centric* makes decision based on user's profit, generally, without considering network load-balancing or other users. It can be noticed that user-centric approach has the main drawback on load balancing issue, which can be caused when users only consider their own benefit while making decision. It could result in bad performance of the overall network.

For evaluating multimedia applications, a recent concept called *Quality of Experience (QoE)* [2] has been introduced. It defines how user rates the perception of the running application. Hence, QoE is the relevant quality indicator for multimedia applications. QoE can be evaluated in terms of Mean Opinion Score (MOS) as following: 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), 1 (Bad). However, it is difficult to ask people to mark the score and then adjust network parameters accordingly in real time. The evaluation process is very complex and time-consuming, it also needs manpower. Thus, it is not practical for real-time usage and an automatic QoE assessment tool is needed.

In this paper, we will focus on network selection using user-centric approach while being compromised between user's profit and overall network condition. In order to overcome different limitations mentioned above, we propose in this paper a novel network selection mechanism with following contributions:

1) We provide the network selection mechanism being aware of a critical factor, *quality of experience*, which is one of the most important factors for multimedia users nowadays. In addition, the QoE assessment is done in real time using PSQA technique [3].
2) We deploy *user-centric* approach meaning that the most important factor for our scheme is user satisfaction. However, we balance the trade-off between user's profit and overall network condition by taking into account overall user satisfaction when making decision. Hence, we called it *user-based* and *network-assisted* approach.

The rest of this paper is organized as follow. We begin in section II with a comprehensive summary of related works that presents recent schemes having as objective the network selection in heterogeneous environment. We continue with the proposed scheme in section III and numerical results in section IV. Then we describe simulation setup and present the results in section V. Finally, we give conclusions and future works in section VI.

II. Related Works

The emergence of heterogeneous network has pushed the research in this area to progress very rapidly. Many schemes have been proposed. We begin here with Yang et al. [4] who proposed *Customer Surplus* function to deal with non real-time transmission. In this protocol, users first survey their network interfaces and determine the list of available access networks. Next, they predict the transfer rate of each available network taking the average of the last five data transfers and then derive completion times. After that, they compute predicted utility, which is the relationship between the budget and the user's flexibility in the transfer completion time. Finally, for each candidate network, users compute consumer surplus, which is the difference between utility and cost charged by the network and they choose the best one to request for connection. It can be noticed that this scheme works fine in non real-time traffic but not for real-time multimedia service that is the most popular nowadays.

To handle handoff, Liu et al. [5] proposed *Profit Function*. The authors associated each handoff with a profit that is decided by a target function with two parameters: *bandwidth gain* and *handoff cost*. Parameters used in the calculation of the gain include: (i) access networks along with their maximum bandwidth provided to a single user as well as capacity utilization; (ii) application's maximum requirement on bandwidth; (iii) access networks' bandwidths used by a mobile node for handoff. Then the authors defined a handoff cost as data volume lost due to handoff delay; it corresponds to the volume of data which could have been transmitted during the handoff delay. Thus, the profit is a difference between gain and cost. At each handoff epoch, mobile node compares profit from each network and chooses the one that yields maximum profit. This scheme takes only bandwidth-related parameters into account. However, considering solely bandwidth cannot guarantee good QoE for multimedia applications.

Song and Jamalipour proposed network selection [6] using *analytical hierarchy process (AHP)* to weigh QoS factors and using *grey relational analysis (GRA)* to rank networks. With QoS factors, the authors constructed an AHP hierarchy based on their relationships. QoS is placed in the topmost level as the objective; main QoS factors describing network conditions are placed in the second level. Moreover, factors have been decomposed into sub factors and they have been arranged in the third level. Finally, available solutions are arranged in the bottommost level. User-based data is collected and processed by AHP for weight computation. At the same time, network-based data are normalized by GRA, and then ideal network performance is defined following by calculation of the grey relational coefficient (GRC) which gives grey relationship between ideal network and the other. The calculation of GRC takes the previously computed weights into account; finally, the network with the largest GRC is the most desirable. This scheme takes many technical parameters into account but still does not include QoE, an essential factor for multimedia users.

Also deploying MADM (multi-attribute decision making), Wilson et al. [7] proposed an algorithm based on *Fuzzy Logic Controller (FLC)* to evaluate fitness ranking of candidate networks. They differentiate decision making into three phases: pre-selection, discovery, and decision making. Pre-selection phase takes criteria from user, application, and network to eliminate unsuitable access networks from further selection. The authors implemented discovery phase based on fuzzy logic control, they fuzzify crisp values of the variables (network data rate, Signal to Noise Ratio (SNR), and application requirement data rate) into grade of membership in fuzzy set. Then these membership functions are used as input to the pre-defined logic rule base. Finally, overall ranking is obtained through defuzzification with weighted average method. It needs to be mentioned here that fuzzy logic control gives good result in this case of few metrics. However, if the metrics number increases, the system may become very complex and may give erroneous results.

The proposed schemes covered many aspects and have taken into account several parameters, however, it is interesting and advantageous to take into consideration QoE (a crucial quality factor) when making decision. Therefore, our objective is to combine different *technology-independent* criteria including user experience into decision mechanism, hence the contribution of this paper.

III. The Proposed Scheme

In this section, we first describe our decision mechanism. Then we explain how to obtain QoE in real time and how communication among network entities can be implemented.

A. Decision Mechanism

For decision making, we deploy one of the multi-criteria decision making (MCDM) techniques called *Technique of Order Preference by Similarity to Ideal Solution* (**TOPSIS**) [8]. In this method, two artificial alternatives are hypothesized: *ideal alternative* that has the best level for all attributes considered, and *negative ideal alternative* that has the worst attribute values. TOPSIS selects the alternative that is the closest to the ideal solution and furthest from negative ideal alternative.

Input to TOPSIS

- TOPSIS assumes that we have m alternatives (options) and n attributes/criteria and we have the score of each option with respect to each criterion.
- Let x_{ij} be score of option i with respect to criterion j
- We have a matrix $X = (x_{ij})$, $m \times n$ matrix.
- Let J be the set of benefit attributes or criteria (more is better)
- Let J' be the set of negative attributes or criteria (less is better)

Steps of TOPSIS

1) *Construct normalized decision matrix:*
   This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria. Data is normalized as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \text{ for } j = 1, ..., n.$$

2) *Construct the weighted normalized decision matrix:* Assume we have a set of weights for each criteria w_j for $j = 1, ...n$. We multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is: $v_{ij} = w_j * r_{ij}$.
3) *Determine the ideal and negative ideal solutions:* Ideal solution is $A^* = \{v_1^*, ..., v_n^*\}$, where

$$v_j^* = \begin{cases} max_i(v_{ij}) & \text{if } j \in J \\ min_i(v_{ij}) & \text{if } j \in J'. \end{cases}$$

Negative ideal solution is $A^{'} = \{v_1^{'}, ..., v_n^{'}\}$, where

$$v_j^{'} = \begin{cases} min_i(v_{ij}) & \text{if } j \in J \\ max_i(v_{ij}) & \text{if } j \in J'. \end{cases}$$

4) *Calculate the separation measures for each alternative:* The separation from the ideal alternative is $S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}$ for $i = 1, ..., m$. Similarly, the separation from the negative ideal alternative is $S_i^{'} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{'})^2}$ for $i = 1, ..., m$.
5) *Calculate the relative closeness to the ideal solution:* $C_i^* = \frac{S_i^{'}}{(S_i^* + S_i^{'})}, 0 < C_i^* < 1$, for $i = 1, ..., m$ Select the option with C_i^* closest to 1.

B. Obtaining QoE in Real Time

As mentioned earlier, it is very difficult to obtain subjective evaluation (QoE) in real time. However, there exist some techniques that enable real-time assessment. We briefly describe the techniques called PSQA (Pseudo-Subjective Quality Assessment) [3] deployed in our scheme below.

PSQA is based on statistic learning using random neural network (RNN). The idea is to train the RNN to learn the mapping between QoE score and technical parameters so that we can use a trained-RNN as a function to give QoE score in real time. In order to use this tool, three steps need to be done beforehand. We summarize them as follow [9].

1) Configuration: We first choose configurations (sets of quality affecting parameters along with their ranges of values) that will be used for the RNN training. Then we take several video sequences to be distorted with the chosen configurations. For this scheme, selected parameters are loss rate and mean loss burst size at IP level. The latter captures the way losses are distributed in the flow, a crucial factor for QoE.
2) Training: We ask for a panel of human observer to evaluate the distorted videos then configurations and corresponding MOSs are stored into two databases: *training* and *validation*. After that, RNN is trained to learn the mapping of configurations and scores as defined in the training database. Once it has been trained, we have a function $f()$ that can map any value of parameters into MOS as in Fig.1.
3) Validation: Trained RNN is validated by comparing value given by the $f()$ at the point corresponding to each configuration in the validation database (not seen before by RNN). If the values are closed enough, the RNN is validated; otherwise, we have to review chosen configurations.

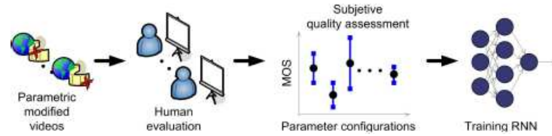

Fig. 1. Training PSQA

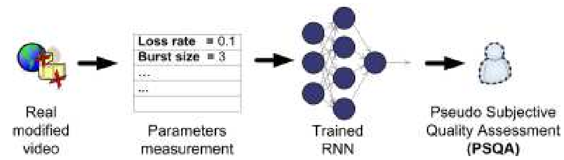

Fig. 2. Using PSQA

Once RNN has been validated, PSQA can be used anywhere in real time without interaction from human (Fig.2). It needs values of technical parameters as input and it gives scores (in MOS) as if there were real humans marking the playing media. In our scheme, PSQA runs at point of attachment level.

C. Communications between PoA and users

To provide information to users for decision making, a point of attachment (PoA) in our scheme broadcasts QoE information to all users within its range. The embedded MOS is the minimum score among all ongoing users of this PoA or perfect score if there is no ongoing user. We decide to broadcast the minimum score because we want the mobile node to be aware of what the worst quality it can get after the connection request. This can be done via signaling messages in IEEE 802.21 MIH (media independent handover) [10].

IV. Numerical results

We assume that a mobile node or MN is multi-mode, it is equipped with WLAN and 3G interfaces. Major factors influencing user decisions in network/handover selection are quality of experience, cost, and mobility. We consider metrics that are independent of technologies, which are appropriate for such heterogeneous environment. In this example, we do not consider security assuming that the running contents are not sensitive. However, if the issue becomes crucial, the algorithm can be applied to security criteria as well.

Table I presents an example of criteria scoring. It can be noticed that QoE is the only parameter to be measured/varied, the other two can be taken directly from user preferences/policy.

TABLE I
Example of Criteria Scoring

Technology	Quality of Experience	Cost	Mobility
WLAN	to be measured ($x/5$)	low (3/5)	low (3/5)
UMTS	to be measured ($y/5$)	high (1/5)	high (5/5)

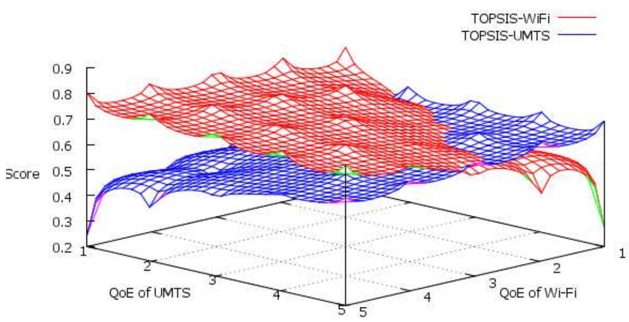

Fig. 3. Score computation of TOPSIS with the above example.

Fig.3 presents the scores processed by TOPSIS method when considering different values of QoE in WLAN and UMTS networks. It can be noticed that with this configurations of criteria the user will select WLAN network most of the time. However, there are some regions in the graph that indicate better scores for UMTS. In the next section, this example will be simulated so that we can observe network throughput and user satisfaction with our method.

V. Simulation Results

We compare our proposition with a scheme, called *Priority-based*, in which the decision making is based on priority classification. This priority concerns network interface technology/type. Highest priority goes to Ethernet, following by WLAN, and UMTS technology respectively. This classification is implemented in real Mobile IP tool such as Segco Mobile IP [11] as well as in NS-2 from NIST [12]. The reason for this classification is very high bandwidth and very low cost of Ethernet, following by medium bandwidth and low cost of WLAN, and low bandwidth and high cost of UMTS regardless of its high mobility. In this section, we first describe the implementation and scenario then we continue with the obtained results.

A. Implementations in Network Simulator NS-2

We based our implementation on NS-2 with NIST add-on [12] (mobility extension: IEEE 802.21 model and 802.11), which enables simulations of heterogeneous environments. This simulation platform incorporates a variety of access networking technologies to run jointly.

We have integrated three other modules into NS-2:

- `videotrace`: this module is used for enabling video streaming application in NS-2. It enables transmission of parsed traces from real video sequences within NS-2.
- `rnn`: this module is used for PSQA functioning. We have developed this module based on RNN source code from colleagues in our research group. The basic code contains all functionalities necessary for using RNN such as creation, training, and validation. The interactions between RNN and NS-2 have been implemented to enable communications of RNN input/output with NS-2.
- `handover`: in NS-2 from NIST, 802.21 module provides network and handover selection according to priority. The terminal connects to the new network if it is better than the current one according to the order of technology. We modified this module in order to add the decision making based on quality of experience as previously described.

B. Scenario

The scenario is presented in Fig.4. Our system model considers the coexistence of two types of wireless access networks. The first network is a CDMA based WWAN with omni directional antenna and cell coverage $= 50m$ and the second one is a TDMA based WLAN with omni directional antenna and cell radius $= 200m$. Mobile node (MN) is a multi-interface terminal. It is equipped with UMTS and WLAN interfaces. At the beginning, the only available network present is UMTS so the MN starts its connection via UMTS. Mobile node moves randomly from point A to point B with the velocity of $1m/s$. The MN enters WLAN coverage (after $24s$). There are two possibilities, either MN stays in the same network or MN hands over to WLAN.

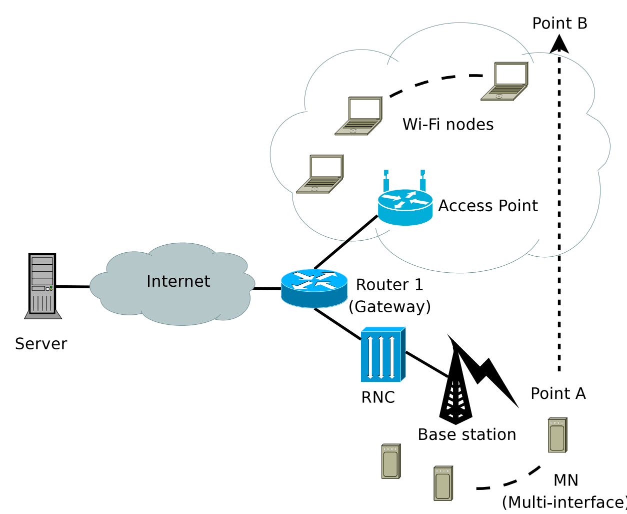

Fig. 4. Network Topology

C. Results

We present results from the previously described scenario in terms of quality of experience (MOS) and bandwidth utilization (throughput).

The first important metric we consider is user satisfaction. For measuring user satisfaction of the running application, we consider the quality of experience in terms of MOS. Fig.5 presents the quality of experience perceived by ongoing connections within the WLAN. The graph presents the lowest scores among all WLAN users in time. The red curve results from our scheme, in which the MN decided not to enter WLAN after observing TOPSIS score (computed via MOS condition of ongoing users). The green curve results from priority-based scheme, in which the MN makes a handover

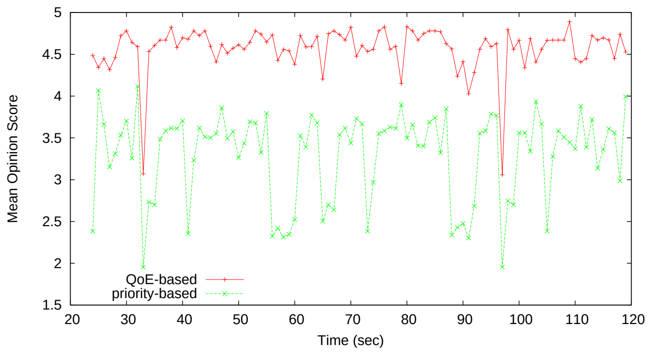

Fig. 5. Quality experienced by WLAN nodes

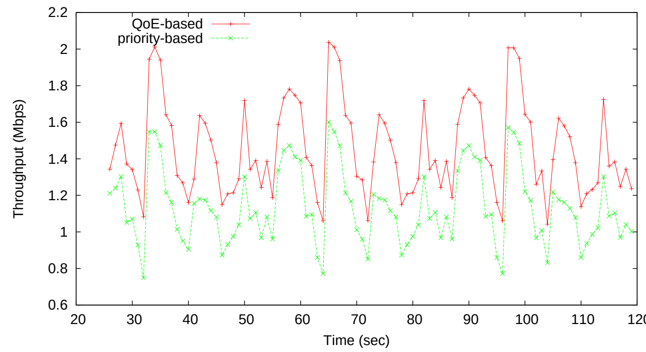

Fig. 7. Throughput in UMTS network

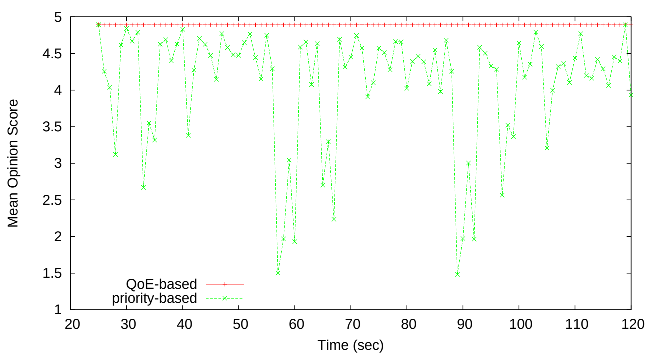

Fig. 6. Quality experienced by MN

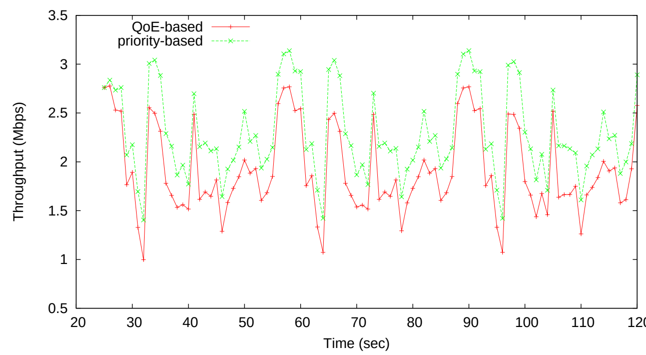

Fig. 8. Throughput in WLAN

to WLAN regardless of current WLAN condition. It can be noticed that our scheme outperforms priority-based scheme by providing good quality of experience, minimum MOS is close to 5 (*Excellent* quality) most of the time. On the contrary, minimum MOS of priority-based scheme performs badly. Even though, majority of score is above 3 (*Fair* quality) but it drops close to 2 (*Poor* quality) many times. As for MN, its quality of experience has a great improvement as we can observe in Fig.6. MN obtains very good scores along the session with our QoE-aware mechanism. On the contrary, it obtains very fluctuating scores with priority-based scheme and sometimes the drops are closed to 1 (*Bad* quality).

Fig.7 and Fig.8 present bandwidth utilization in UMTS and WLAN respectively. We can observe higher throughput with our scheme in UMTS and higher throughput with priority-based scheme in WLAN. It can be remarked here that there is always a trade-off between bandwidth utilization in a network, load balancing between different networks, and quality of experience. We can see from this example (green curves) that when bandwidth utilization is high in WLAN (Fig.8), the QoE of users becomes poorer (Fig.5 and Fig.6). With this reasoning, our scheme illustrates a better load balance between the two networks. Load is better distributed via MOS indicator since user selects network with higher MOS, which is generally low-loaded. On the contrary, priority-based does not take any concern of quality into account and blindly change user into WLAN expecting larger bandwidth and lower cost.

VI. Conclusion

We have proposed a network selection mechanism being aware of user experience. This metric represents how ongoing users face with current network condition. We compare our scheme with priority-based scheme currently in use on many Mobile IP implementations. The obtained results show that our scheme performs better in order to guarantee both quality of handover user (MN) and ongoing users in target network. The load distribution is also better in our case as UMTS network can gain throughput from MN. This preliminary results show that even with simple mechanism, we can see improvement in the results. In the future, we planned to improve our network selection process and more sophisticate mechanism will be proposed. In addition, more complex scenario will be deployed to compare QoE-aware scheme with other handover schemes such as QoS handovers.

Also, it is important to mention that network selection alone may not be sufficient. It only helps mobile user to select the best network at the entrance phase, however it cannot guarantee that network condition will not change after the selection process is executed. Therefore, mechanism of ongoing control is also necessary in order to maintain good quality at users during the whole connection. This can be done via, for instance, admission control mechanism that filters connection according to current condition of users or adaptation mechanism that reacts/provisions on changes of network condition.

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