QoE-aware Network Selection in Wireless Heterogeneous Networks

Kandaraj Piamrat, César Viho, Adlen Ksentini, Jean-Marie Bonnin

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

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Mécanisme de sélection de réseau d'accés basé sur la qualité d'expérience dans les réseaux sans-fil hétérogène

Kandaraj Piamrat*, César Viho†, Adlen Ksentini‡, Jean-Marie Bonnin§

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Résumé : Le réseau de prochaine génération (4G) commence à se déployer à travers le monde. Avec une variété de technologies de réseau et des restrictions de qualité de service sur les nouvelles applications multimédia, il est plus difficile pour les utilisateurs de sélectionner le meilleur réseau d'accès pour demander une connexion. Même si de nombreux mécanismes ont été proposés dans la littérature pour la prise de décision, aucun d'eux ne prend en compte la qualité d'expérience (QdE) perçue par l'utilisateur. Comme QdE représente la perception perçue par l'utilisateur, notamment avec les communications multimédias de nos jours, il est donc un indicateur essentiel pour l'évaluation du réseau. Par conséquent, dans ce document, nous proposons un mécanisme de sélection de nouveaux réseaux qui prend en considération la qualité d'expérience pour la prise de décision. Il s'agit d'une approche basée sur l'utilisateur avec l'assistance de réseau ainsi une solution de compromis entre approche basée sur l'utilisateur et sur l'opérateur de réseau. L'idée principale est d'utiliser la qualité d'expérience des utilisateurs en cours dans les réseaux d'accès potentiels comme un indicateur pour sélectionner le meilleur réseau pour la demande de connexion. Nous avons implémenté et testé notre mécanisme dans le simulateur de réseau NS-2. Les résultats obtenus montrent que, même avec un mécanisme simple, nous pouvons considérablement améliorer la QoE de noeud mobile et l'équilibrage de charge entre les réseaux.

Mots-clés : Qualité d'Expérience, Mécanisme de Sélection, Réseaux d'Accs, Réseaux Hétérognes

* kandaraj.piamrat@irisa.fr
† cesar.viho@irisa.fr
‡ adlen.ksentini@irisa.fr
§ jm.bonnin@telecom-bretagne.eu

Centre de recherche INRIA Rennes – Bretagne Atlantique
IRISA, Campus universitaire de Beaulieu, 35042 Rennes Cedex
Téléphone : +33 2 99 84 71 00 — Télécopie : +33 2 99 84 71 71

QoE-aware Network Selection in Wireless Heterogeneous Networks

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 is more difficult for users to select the best access network to request for connection. Even though many schemes have been proposed in the literature but none of them takes 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 even with a simple mechanism; we can significantly improve QoE of mobile node and load balancing between networks.

Key-words: Quality of Experience, Network Selection, Access Networks, Heterogeneous Networks

1 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 most relevant quality indicator for multimedia applications. QoE can be evaluated in terms of Mean Opinion Score (MOS) shown in Table 1. 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.

TAB. 1 – Mean Opinion Score - MOS

MOS	**Quality**	**Impairment**
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

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 a novel network selection mechanism based on a critical factor, *quality of experience*, which is the most important factor for multimedia users nowadays. In addition, the QoE assessment is done in real time.
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 network users' 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 2 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 3. Then we describe test setup and present the results in section 4. Finally, we give conclusions and future works in section 5.

2 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. [3] 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. [4] 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 [5] 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. [6] 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.

Even though all proposed schemes have covered many aspects and have taken into account several parameters, they cannot guarantee users' satisfaction since none of them is interested in quality of experience metric, which is the most prominent factor in multimedia networking today. It is the reason why we conduct this investigation and on which our solution is positioning.

3 The Proposed Scheme

In this section, we first describe our decision mechanism. Then we give summary about how we obtain quality of experience in real time.

3.1 Decision Mechanism

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 users. We decide to diffuse 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) [7].

Let OF be the objective function to be computed for each network. It is calculated by the sum of each criterion (C_i) times their weight (w_{ci}). Weight can be set as desired by users (all weights are equal by default). Hence, OF can be written as in equation (1) below.

$$OF = \sum_{i=1}^{n} C_i * w_{ci} \text{ ; where } \sum_{i=1}^{n} w_{ci} = 100 \qquad (1)$$

The value of C_i is normalized by its maximum value, which gives C_i value in a range [0..1]. The sum of all weights is equal to 100, thus the score of each network is in a range of [0..100]. After having computed OF for all available networks, the mechanism selects the network that has the highest score for requesting connection. The other networks are arranged in a ranking table. If the connection request of the first choice network cannot be satisfied by network operator, the station tries the next one in the table respectively.

Taking an example, we assume that a mobile node or MN is multi-mode ; it is equipped with Ethernet, WLAN and 3G interfaces. Major factors influencing user decisions in network/handover selection are quality of experience (qoe), cost ($cost$), and mobility (mob). Hence, the OF can be written as equation (2), where k is network technology.

$$OF(k) = C_{qoe} * w_{qoe} + C_{cost} * w_{cost} + C_{mob} * w_{mob} \quad (2)$$

Table 2 presents an example of criteria scoring. It can be noticed that QoE is the only parameter to be measured, the other two can be taken directly from the table.

Tab. 2 – Criteria Scoring

Technology	**Quality of Experience**	**Cost**	**Mobility**
Ethernet	to be measured ($x/5$)	free (5/5)	none (1/5)
WLAN	to be measured ($y/5$)	low (3/5)	low (3/5)
UMTS	to be measured ($z/5$)	high (1/5)	high (5/5)

To have some guarantees on QoE, we propose *threshold-based* mechanism, the threshold indicates a border beyond which the quality of experience may not be guaranteed. This step is done after network ranking to ensure that the winning network can suit user satisfaction. For that, the mobile user sets its threshold MOS (mos_{th}) then compares it with minimum score (mos_{min}) obtained from the winning network. We define this threshold as the acceptable MOS plus an absorber ; i.e. $mos_{th} = mos_{acpt} + mos_{abs}$. If the minimum score is higher or equal to this threshold, then the connection is launched. Otherwise, the mobile node may revise its weight assignment or QoE expectation. One exception exists, in which we called it *forced handover*. The connection is launched even when the minimum score is less than threshold. For instance, when the candidate network is the only available network in the area ; if handover is not executed, the mobile node will lose its connectivity. Please note that the absorber is very delicate to define as we deal with quality of experience. To ensure high quality of experience, user may set this absorber to a high value but the trade-off is that it may not find an appropriate candidate if the expectation is too high.

3.2 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) [8] 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.

1. Configuration : We first choose configurations, which are 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 configurations previously chosen. For this scheme, parameters are loss rate and mean loss burst size at application frame level.
2. Training : We ask for a panel of human observer to evaluate the distorted videos and then we store the configurations and corresponding MOS into two databases : training and validation databases. After that, we train the RNN to learn the mapping of configurations and scores as defined in the training database. Once the tool has been trained, we have a function $f()$ that can map any value of parameters into MOS.
3. Validation : Trained RNN is validated by comparing value given by the $f()$ at the point corresponding to each configuration in the validation database. If the values are closed enough, the RNN is validated ; otherwise, we have to review chosen configurations.

Once RNN has been validated, PSQA can be used anywhere in real time without interaction from human. 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.

4 Performance Evaluation

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 interface, following by WLAN, and UMTS technology respectively. This classification is implemented in real Mobile IP tool such as Segco Mobile IP [9] as well as in NS-2 from NIST [10]. The reason for this classification is very high bandwidth and no 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 test setup along with our testbed configuration and topology, and then we continue with the obtained results.

4.1 Implementations in Network Simulator NS-2

We based our implementation on NS-2 with NIST add-on [10] (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 [11]. 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.

4.2 Test Setup

The scenario is presented in Fig.1. 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. The MN moves during the connection until it enters WLAN coverage (after 24s). There are two possibilities, either MN stays in the same network or MN hands over to WLAN.

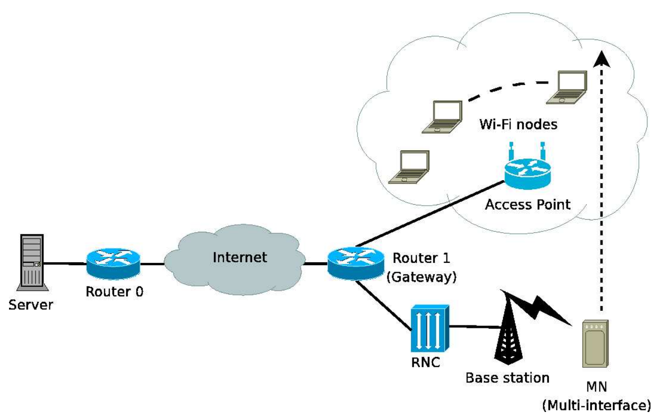

FIG. 1 – Network Topology

We deploy $mos_{acpt} = 3$ because this value is the standard acceptable level of QoE for video streaming application. As for mos_{abs}, we have conducted some tests with different values (2.0, 1.5, 1.0, 0.5, 0.0) in order to see how network behaves with its variation. Fig.2 shows how quality of experience and throughput behave with decreasing values of absorber. As mentioned before, if this value is high and an appropriate network exists then quality of experience will be very good. However, if we analyze closer we can see that throughput in this type of network is very low; the reason is because network dedicates the whole bandwidth to only a few connections. In addition, as the expectation is high hence it is difficult to find an appropriate network. On the contrary, if the value of absorber is lower, the quality of experience decreases and the throughput of the network increases accordingly. Considering all criteria mentioned above, we deploy $mos_{abs} = 1.0$ and thus $mos_{th} = mos_{acpt} + mos_{abs} = 4$.

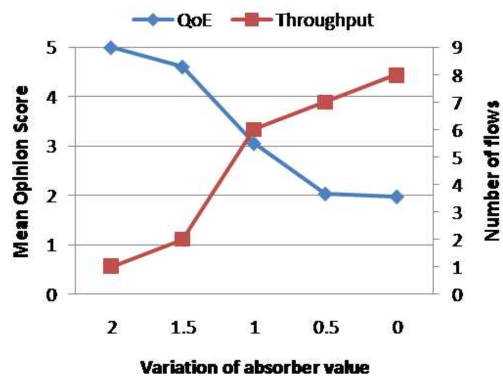

FIG. 2 – Network behavior with different absorbers

We illustrate scenario 1 with moderate network condition and scenario 2 with worst condition. We would like to show that if everything is doing fine, we do not need to have any precaution or management mechanism. However, when the condition degrades, some adaptations needs to be done in order to alleviate the situation. In our case, we show how our proposed mechanism can guarantee mobile node having good quality of experience. We also provide the preliminary result for introducing admission control, which can be done by network operator to also ensure quality of ongoing users.

4.3 Results

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

4.3.1 Moderate condition

The most important metric is user satisfaction. For measuring user satisfaction of the running application, we consider the quality of experience in terms of MOS as previously described. Fig.3 presents the quality of experience perceived by ongoing connections within the Wi-Fi network. The graph presents the lowest scores among all Wi-Fi users in time. It can be noticed that QoE-based scheme performs slightly better than the priority-based scheme but there is not much difference. Nevertheless, minimum scores obtained with QoE-based scheme stays above 4 (*Good* quality) most of the time and does not decrease below 3 (*Fair* quality). On the contrary, scores obtained with priority-based scheme go below 3 (*Fair* quality) and reaches 2 (*Poor* quality) twice. Regarding the quality of experience obtained at MN, we can clearly observe improvement obtained with QoE-based scheme in Fig.4. Since there is not any other traffic in

UMTS, MN would rather stay in the same network and get perfect score than hand over to WLAN and get fluctuating scores. However, the fluctuation in this case is not crucial as it stays above 4 all the time.

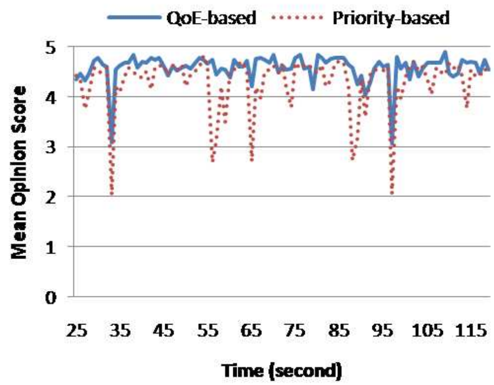

Fig. 3 – Quality experienced by WLAN nodes under moderate condition

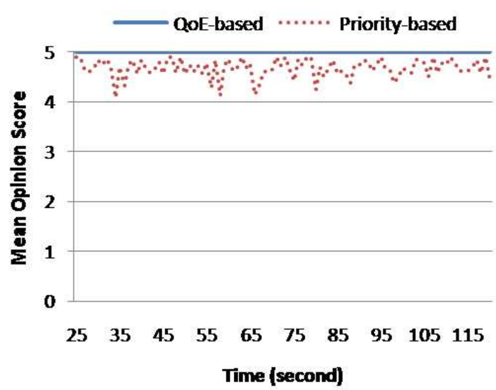

Fig. 4 – Quality experienced by MN under moderate condition

Fig.5 and Fig.6 present bandwidth utilization in UMTS and WLAN respectively. It can be seen that QoE-based scheme provides a better balance of load between the two networks. This is because load is automatically distributed by MOS indicator. User selects network with higher MOS, which is generally low-loaded, and hence load is better distributed. On the contrary, when using priority-based, the scheme does not take any concern of quality into account and blindly change user into WLAN expecting larger bandwidth and lower cost.

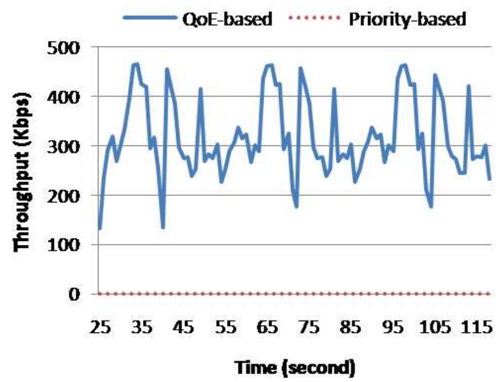

FIG. 5 – Throughput in UMTS network

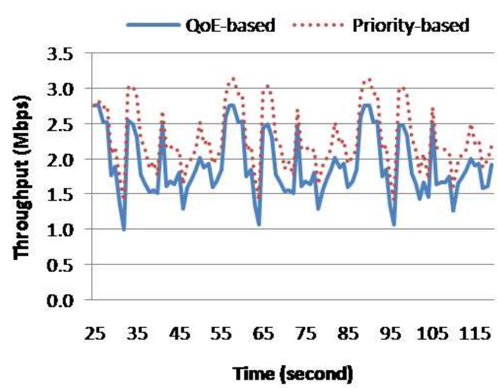

FIG. 6 – Throughput in WLAN under moderate condition

4.3.2 Critical condition

In order to show how the situation can become much worst, we illustrate in this scenario the case when load in WLAN is increasing in time. The MN decides whether to execute or not a handover in this situation.

Fig.7 presents quality of experience of ongoing connections in WLAN. The blue curve results from QoE-based scheme, in which the MN decided not to enter WLAN after seeing MOS condition of ongoing users. The red curve results from priority-based scheme, in which the MN continues to make a handover 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 other hand, 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.8. MN obtains perfect scores along the session with our QoE-based mechanism. On the contrary, it obtains a very fluctuating score with priority-based scheme and sometimes it drops closed to 1 (*Bad* quality).

For bandwidth utilization, the result of UMTS load distribution is similar to Fig.5 as we leave the UMTS network with no previous traffic. On the other hand, the WLAN throughput of priority-based scheme is shifted up a little as can be seen in Fig.9. This is because WLAN has more traffic flows in the network. 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. In general, network operator wants to take the most profit from available bandwidth and sometimes ignores the result in quality experienced by users. We can see from this example (red curves) that when bandwidth utilization is high in WLAN (Fig.9), the QoE of ongoing users becomes poorer (Fig.7 and Fig.8).

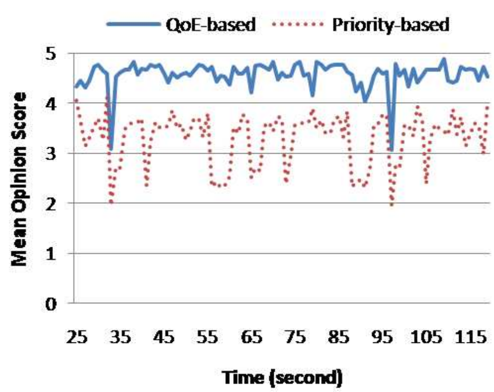

Fig. 7 – Quality experienced by WLAN nodes under critical condition

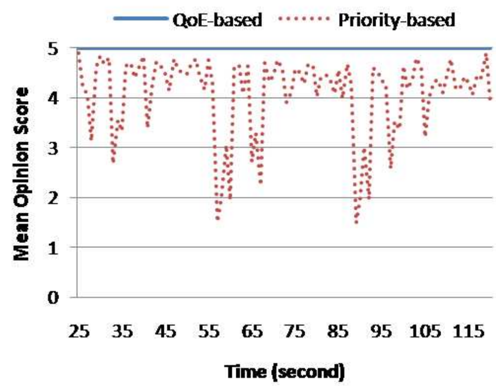

FIG. 8 – Quality experienced by MN under critical condition

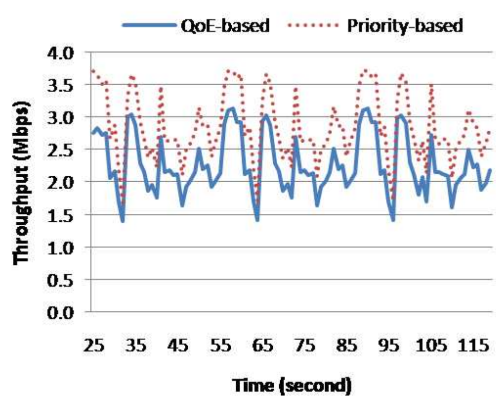

FIG. 9 – Throughput in WLAN under critical condition

4.3.3 Discussion

It can be seen that network selection mechanism is useful for making decision when entering the network. However, it should be mentioned here that this procedure only guarantee the entrance phase. A bad result can still be obtained later even with our network selection mechanism. This is the case in which WLAN load continues to increase after the handover of MN. In such a case, quality of experience can continue to degrade until very bad performance.

We investigate deeper to see how the quality of experience can be influenced by network load. We present in Fig.10, MOS evaluation with increasing number of traffic in WLAN. The blue curve presents average MOS in time whereas the red curve presents the lowest MOS in time. It can be seen that MOS decreases when network load increases. In this situation, network operator needs to take an action in order to maintain quality of experience at acceptable level. Management mechanism such as admission control can be used for that. For instance, the network operator can filter incoming connection with, for example, MOS of ongoing users. This can help in maintaining good quality of experience for everyone.

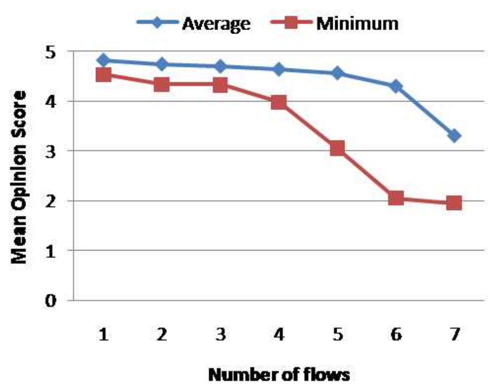

FIG. 10 – Quality experienced by WLAN nodes with increasing traffic

5 Conclusion

We have proposed a novel network selection mechanism based on quality of experience. This quality 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 some throughputs 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-based scheme with other handover schemes such as QoS handovers.

One thing we have remarked here is that when everything is fine, whatever mechanism can provide correct quality of experience (as in scenario1). But when network condition degrades (scenario 2), an efficient selection mechanism is necessary in order to obtain good QoE performance hence our proposed scheme.

Also, we try to illustrate that network selection alone is not enough. It can only help mobile user to select the best network at the moment but it cannot guarantee that network condition will not change after the selection process is finished. We give the primary result of quality evaluation with increasing number of flows. This shows that at some points, admission control is necessary in order to maintain good QoE for all users. In the future, we plan to investigate admission control issue as well.

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