Seamless Mobile Data Offloading in Heterogeneous Wireless Networks based on IEEE 802.21 and User Experience

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Abstract — **The increase on smartphone usage has brought the burden of data traffic with it. Operators are looking for cost-effective solutions to overcome the problem of 3G infrastructure for high contention traffic scenarios. Several schemes were offered to save the moment, and they brought some extra costs including deploying femtocell or WiMax, LTE, LTE-Advanced systems along with their expensive equipment. On the other hand, operators are expanding their networks with 802.11 technologies such that they can exploit the free-band communication. Meaning the data traffic can handover between WLAN and UMTS interchangeably. By using NS-2 simulator, we implemented IEEE 802.21 WG's Media Independent Handover (MIH) module by combining with Channel Quality Indicator (CQI) values collected from user equipment (UE) and observed a recovered throughput for both medium. We found that there is a tradeoff among energy efficiency, delay tolerance and cost. Furthermore, in this study, we integrated a Quality of Experience (QoE) metric during real-time handover decision process so that with this type of collaborative solution, an operator will be unique in terms of user happiness and heterogeneous network management.**

Keywords— **Channel Quality Indicator (CQI), Mobile Data Offloading (MDO), IEEE 802.21, Media Independent Handover (MIH)**

I. INTRODUCTION

Mobile data traffic has soared drastically in the past few years. The paramount reasons for this are the increasing smartphone usage, the availability of flat-rate voice and data bundles, and higher demand for entertainment services. Currently, operators and television networks come together to implement their IPTV services. In parallel, smartphone producers introduce technologies such as Full HD screens to their users. This increment in data traffic would accelerate, and place greater pressure on network capacity. Furthermore, there is also greater competition for subscribers, with a corresponding downward pressure on revenue per subscriber. This means mobile network operators need solutions that help them reduce network congestion while also helping them reduce costs and retain customers.

There are several solutions that can be applied to improve operators' network performance including traffic management, backhaul and infrastructure upgrades. However, operators realize that such options provide short-term relief and only apply as long as its user stays inside the operator's network. They would like a comprehensive solution that addresses user behavior in the real-world, i.e. which supports roaming from one network type to another, and allows users to receive and enjoy quality services from their operator regardless of their location and choice of network access.

At this point, mobile data offloading provides a solution with real business value. Significant cost reductions and improvement of the operator's reach to its customers gives a competitive edge to it. In this study, we will evaluate and simulate collaborative type of mobile data offloading scheme for real-time network (RTN) systems.

In this paper, we have proposed a Quality of Experience (QoE) based collaborative vertical handover method for real-time heterogeneous wireless networks. For this method, we exploited the MIH capabilities as presented by IEEE 802.21 WG, and a multiple attribute decision making (MADM) algorithm. In summary, the following major contributions have been made:

(i) User preference as a QoE metric during handover decision making has been integrated into the developed MADM algorithm.

(ii) Handover execution has been handled not only based on link-quality including QoS values but also based on subjective measures.

(iii) Network traffic of the heterogeneous wireless networks (HWNs) has been improved and managed based on user experience. Upon request, the complete simulation data will be made available. This would help the research community develop novel handover algorithms for HWNs.

The remainder of this paper is organized as follows. In Section II, we introduce related works and applications in industry. We present QoE Model in section III. In section IV, we will mention about the simulation and its results. Finally, in section

V, we will provide a conclusion regarding the collaborative vertical handover solution for RTNs.

II. RELATED WORK

Heterogeneous Wireless Networks or WiFi integrated cellular networks could be optimized by user-centric models, network-centric models or collaborative schemes. Even though user-centric models are easier to implement than collaborative and network-centric-models, for the overall performance and complexity-wise of the both networks (3GPP and non-3GPP), the network-centric models provide the most efficient solutions. Collaborative solutions, on the other hand, introduce a little bit complexity; however, in return, offers a drastic performance difference with respect to network-centric solutions.

The common functions that need to be considered for offloading or handover mechanisms among different radio technologies are: Resource Monitoring including network discovery, decision making including network selection and decision enforcement [1] [2].

Resource monitoring helps decision maker to identify and discover the access networks along with a QoS and/or QoE mechanism when a user changes its location. The decision maker could be user-equipment (UE) or network, meaning either each cell will broadcast its connection information to UEs or UE will retrieve the cell information from both 3GPP and non-3GPP networks. In 4G networks, access network discovery could be controlled by Evolved Packet Core (EPC) along with access network discovery and selection function (ANDSF). However, 3G networks are missing such a core system and require either an additional device or an additive functionality to the existing serving nodes in the infrastructure or a user-centric approach. 3GPP or trusted/untrusted non-3GPP (WiFi) networks could be discovered and monitored by this functionality.

As for decision making functionality, UE or Mobile Network Operator (MNO) selects the access networks by considering probabilistic demands ideally.

Network related, terminal related, user related and application related metrics need to be considered pertaining to vertical handover decision. However, the paramount elements amongst them are the user-related ones as access network alters, users should approve the changes such as throughput, energy consumption of the terminal, security etc. of the suggested network. Otherwise, it would infringe on their right to privacy because for the very same application an adult's decision would differ from that of a young person, for instance, security-wise an adult might not prefer to watch videos through WEP or WPA on WiFi networks but EAP-SIM on 3GPP network. Maybe this choice could be trivial for a young person and actually he would prefer a free communication band, but considering rising security challenges of today's world, operators need to pay importance on the subject for each subscriber. [3]. We can classify the handoff decision criterias as below:

(a) Network-related: it represents network conditions: coverage, bandwidth, latency, link quality (CQI), BER (Bit Error Rate), cost, security level.
(b) Terminal-related: velocity of the user, battery power,
(c) User-related: user profile (i.e. student or businessman) and preferences (i.e. Cost or security),
(d) Service-related: service capabilities, QoS, QoE, security level [3].

The handoff decision algorithm aims at selecting a network for a particular service that can satisfy objectives based on some criteria (such as low cost, good RSS, high MOS, optimum bandwidth, low network latency, high reliability and long life battery) and taking into account the preferred access network of user. Some techniques used for network-centric solutions such as stochastic programming, game theory and utility function could be performed in this respect [1].

Stochastic linear programming obtains maximum allocation in each network by using probabilities related to allocation, underutilization, and rejection in HWNs. Game theory takes advantage of the bankruptcy game, and efficient bandwidth allocation and admission control algorithms are developed by utilizing available bandwidth in each network. In utility function, operator prioritizes users and classifies services to allocate bandwidth for the users [4-6].

In client-centric solutions, analytical hierarchy process helps ranking the networks based on QoS by checking user’s requirements and network conditions. Consumer surplus is an economical model, and could be used to find the network benefits the best-generally used for non-real-time traffic. In profit function, the difference between bandwidth gain and handoff cost for each network is computed, and the most appropriate network is found [7-9].

As for the collaborative models, fuzzy logic controller ranks the candidate networks based on the user’s selection criteria, network data rate and SNR. In objective function, user’s RSS, network’s queue delay and policy such as cost are fed as input parameters, and the function provides the allocation of services to APs and terminals [10-12]. Lastly, in TOPSIS, the best path for flow distribution on multi-homed end-hosts is computed. Also, network’s QoS (delay, jitter, and BER), user’s traffic class and most importantly QoE are checked [15].

Some other problems related to user-centric models are: a device would connect at Layer 2, but not at network layer. Also, UEs would connect one of APs available based only on signal strength, and end-up with wrong assignment such as application class or QoS requirement are not met. Adding the increasing number of interfaces such as WiMax, WiFi and cellular network, the burden of UE would extend to cover multiple interfaces.
IEEE 802.21 WG was formed to overcome the diversity in the handover mechanisms and to eliminate user-centric methods’ drawbacks, and therefore, a common MIHF (Media Independent Handover Function) was introduced. MIHF is a abstraction layer between layer 2 and layer 3. All interfaces on

L2 (cellular, WiMax, LTE, WiFi) could communicate with MIHF, and MIHF could transmit the necessary messages to L3 and above such as SIP, MIPv4, MIPv6 or HIP [13].

In IEEE 802.21 framework, there are several factors to determine the handover decision including service continuity, application class, QoS, network discovery and selection, security, power management, and handover policy. In Fig. 5, MIHF architecture is showed. The most important advantage MIHF brings is not only to provide both L2 and L3 handover but also to allow running make-before-break soft handover mechanism which in return supply us MOS calculation time before the final break execution with the connected access network.

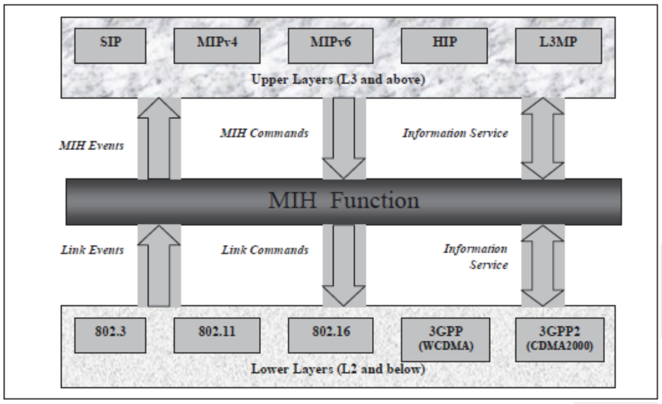

Figure 1 - MIHF Architecture

III. QOE MODEL

Service delivery and user experience are strongly related items for operators in terms of radio resource management. Technical aspects targeting this issue relate to QoS parameters that can be handled by the platform, at least partially. Subjective psychological issues and human cognitive aspects are typically unconsidered aspects and they directly determine the QoE.

It does not matter how smoothly packets move through your network, if the users find out that services and applications don't meet expectations. Planning must address the factors that underlie QoE for each service that runs on the network, as well as any interactions or inconsistencies between them. For this work, we do not consider the problems due to the application's packetization and/or encoding/decoding schemes which could also affect QoE, but only focus on the optimization of the network traffic for the heterogeneous networks.

In this study, we used TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [15], due to its easy implementation, as a way of selecting the best target network for a given user's video application. The decision to use this algorithm was made based on the other multiple attribute decision making (MADM) algoritms' performance comparison results. In [14], four different MADM algorithms (MEW, SAW, GRA, TOPSIS) were evaluated and it was concluded that they all performed very similar. By using this algorithm, we trigger the MIH events such as connect-link or disconnect-link to execute the handover seamlessly. For this purpose, first, we created a decision matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}$$

In mxn A matrix refers to decision points such as link quality, MOS of the target network for the given application, user preference (cost security), and m refers to the target networks which are UMTS or WLAN. In second step, we formed a normalized decision matrix by using the following equation [15]:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{1}$$

We obtained the R matrix:

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

Then, we created a weighted normalized decision matrix by multiplying each column of the matrix by corresponding weight w_i where $\sum_{i=1}^{n} w_i = 1$ by using the following equation:

$$v_i = w_i * r_i \tag{2}$$

TOPSIS method assumes that each evaluation factor has a monotonically increasing or decreasing tendency. Next, we formed the positive (A^*) and negative (A^-) solutions by using the following formula:

$$A^* = \left\{ (\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} \middle| j \in J' \right\} \tag{3}$$

$$A^- = \left\{ (\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} \middle| j \in J' \right\} \tag{4}$$

For both (3) and (4) , J refers to benefit (max), and J' refers to lost (min) and the number of evaluation factor consists of m elements.

We ended up with the respective sets of $A^* = \{v_1^*, v_2^*, ..., v_n^*\}$ and $A^- = \{v_1^-, v_2^-, ..., v_n^-\}$

Then, we calculated the Euclidean distance S_i^* of each alternative a_i from the positive point and S_i^- of each alternative a_i from the negative point A^-. Both positive and negative set consists of the number of evaluation factor, that is, m elements. The calculations are shown respectively as below:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{5}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{6}$$

In the next step, we calculated the relative similarity of the alternatives from the positive and negative point which is done in the following manner:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{7}$$

where $0 \le C_i^* \le 1$

If C_i is close to value 1 the solution is closer to ideal.

IV. PERFORMANCE RESULTS

For our simulation, we used NS 2.29 simulator integrated with EURANE, NIST and EVALVID packages to evaluate the video performances in a heterogeneous network during a handover execution where the TOPSIS algorithm results were utilized. Decision parameters of TOPSIS are as follows:

(i) MOS: Mean Opinion Score is considered as a subjective measure. Currently, it is more often used to refer to one or another objective approximation of subjective MOS. Although all "MOS" metrics are intended to quantify QoE performance and they all look very similar (values between one and five with one or two decimal places), the various metrics are not directly comparable to one another. ITU P.800 and P.830 define the MOS scale as showed in Table 1.

(ii) PSNR (dB): The peak signal-to-noise ratio is used as an objective measurement of the restored image quality. PSNR is most commonly used to measure the quality of reconstruction of lossy compression codecs which is in our case MPEG-4.

$$PSNR = 20\log\frac{Vpeak}{MSE} \tag{8}$$

Vpeak = $2^k - 1$ where k is equal to number of bits per pixel (luminance component). MSE is mean squared error.

(iii) CQI: Channel quality indicator is reported by UE and is calculated using BLER and SNR values. It is a vital parameter to estimate the UMTS air interface quality. The UE type that is assumed in the simulator is 3GPP UE category 1 to 6. In our simulation, the highest CQI value was accepted as 22. However, it varies between 1 and 22.

(iv) QoS: Quality of service level of the access point (AP) is utilized in the algorithm to determine the link-quality of WiFi network. Voice = Platinum = 6, Video = Gold = 5, Best Effort = Silver = 3, Background = Bronze = 1

(v) Security Policy used in WiFi network: WPA or WPA2 cannot be used for a seamless solution. EAP-SIM is required to do so.

(vi) Channel Utilization: It is a WiFi network parameter, and is monitored for a stable traffic level and to prevent under or over utilization.

(vii) Client SNR: Signal-to-noise ratio is a critical and widely used metric to obtain the experienced Wi-Fi quality per user.

(viii) User Preference: For a businessman security and quality level could be extremely important whereas for a student the cost is of the utmost importance.

Table 1 - ITU-R Quality and Impairment Scale

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

QoE assessment could be performed with subjective tests with humans, but by using this scheme we cannot make a handover execution in real-time, other approaches to the problem of QoE assessment includes utilizing objective testing to predict the MOS value of a service. These solutions need original signals (for real time applications e.g., ITU-T objective measurement standards like PESQ (P.862), E-model (G.107) etc.) and are computationally complex [16-17]. Therefore, we calculated the PSNR frame by frame and map it to the corresponding MOS value as in Table 2.

Table 2- PSNR to MOS mapping

PSNR [dB]	MOS
> 37	5 (Excellent)
31 - 37	4 (Good)
25 - 31	3 (Fair)
20 - 25	2 (Poor)
< 20	1 (Bad)

When simulating our heterogeneous network in tight-coupling architecture, we used a case where a video is downloaded in the beginning. Our user was connected to an UMTS network and in this network throughput was 45Kb/s which is not even acceptable for voice networks since 64Kb is used for bearer payload whereas 16Kb needs to be used for signaling purposes in each direction, making a total of 80Kb/s at least for a good quality voice traffic. Considering our traffic, video requires a lot more throughput for an acceptable communication. As a result, we obtained the following frames in Figure 2.


(a) (b)

Figure 2 - (a) Transmitted Common Intermediate Format (CIF) 352x288 MPEG-4 XviD (b) Received CIF 352x288 MPEG-4 XviD

One UE's speed was 1m/s, and after 2 seconds where video is transmitted with a rate of 30fps, the MIH module discovered the WLAN network and requested the target WLAN network's metrics regarding QoS (jitter, delay, packet loss) and also user preference such as security (i.e. EAP-SIM or WPE) along with MOS. Based on the TOPSIS algorithm, user was attached to the target WLAN network by using MIH functionality at frame of 60. Between frames 60 and 300, user experienced MOS values between four and five. You can find the graphical representation of the scenario in Figure 3.

Furthermore, we calculated the packet loss rates in percentage for the same scenario while user experiences different throughput rates in UMTS network. The loss rates were measured to check the impact of an UMTS network before the handover execution and the impact of these losses for the full transmission. Our encoded video is composed of two distinctly different types of frames; Intracoded (I) frames, predictive (P) frames with a group of pictures (GOP) length of 30 frames with no B-frames. The frame losses are shown in Figure 4.

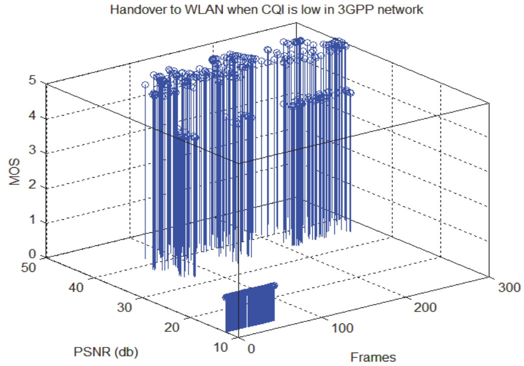

Figure 3 - Handover to WLAN when CQI is low in 3GPP network

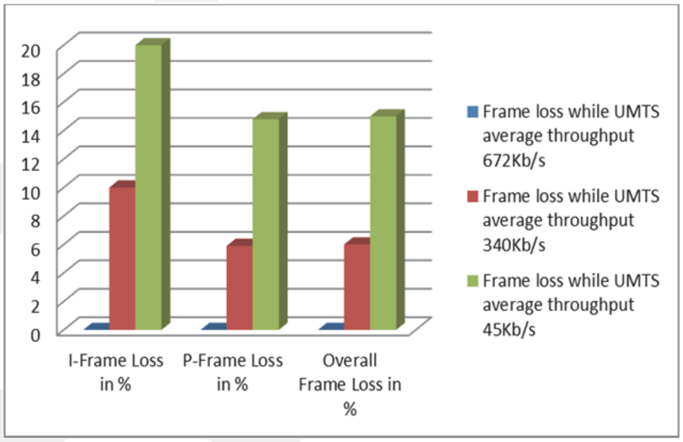

Figure 4 - Impact of the frame losses due to UMTS network on the full transmission

V. CONCLUSIONS AND FUTURE WORKS

Due to the data traffic volume growth of smartphone users every year, operators need to either evolve their both wireline and wireless networks; for instance, from UMTS to LTE, or offload the traffic to an existing WLAN network as a less costly solution. In this study, the interaction between a 3G network and a WLAN network to make a seamless offload was analyzed and simulated. 802.21 MIH module allowed us to handover on both layer 2 and layer 3, thus, we had almost seamless handover solution, but to make it even better, we used CQI values obtained from UEs so that the handover could occur based on the policies and/or QoE agreements between users and operators such as a high MOS value. QoE include both terminal end applications' behavior such as the used codec for the transmission and container and the network traffic health. In this study, we only focused on the network improvement and user preferences such as cost or security, and considered the HWN where UMTS and WLAN are coupled. Based on the results, we achieved a high MOS value during the video transmission and better user experience. The main drawback that could be taken into account is the power consumption causing by the neighbor discovery (ND) module. In this solution, the periodical router advertisement (RA) and router solicitation (RS) messages would eat up the limited battery power, but this needs to be tested as a future work.

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