Wireless Connection Steering for Vehicles

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***Abstract*—This paper designs a complete framework that anticipates QoS/QoE (Quality of Experience) degradation and proactively defines policies for LTE-connected cars (UEs) to select the most adequate radio access out of WiFi and LTE. For a particular application, the proposed framework considers the application type, the mobility feature (e.g., speed, user mobility entire/partial path, user final/intermediate destination), and the traffic dynamics over the backhauls of both LTE and WiFi networks in order to predict and allow the UE to select the best network that maximize user QoE throughout the mobility path. Simulations are conducted to evaluate the performance of the proposed framework in achieving its design objectives and encouraging results are obtained.**

I. Introduction

Current trends show a growing number of large-scale WLAN network deployments for mobile services, owned and administrated by mobile operators or by a third party, and that is mainly due to their numerous benefits. Indeed, public Wi-Fi hotspot networks represent a viable way to offload significant amounts of traffic and alleviate congestion at macro network [6]. It is therefore more likely to have, in many parts of a city, areas that are covered with WiFi, LTE and other access types, as shown in Fig. 1. With this regard, smart vehicles are also envisioned to be equipped with different access types, including interfaces to a mobile network (e.g., UMTS Universal Mobile Telecommunications System, LTE – Long Term Evolution, etc) and V2I – (Vehicle to Infrastructure) oriented IEEE WLAN interfaces [1] [2].

The usage of WiFi as a backup network for mobile operator networks would become less attractive if the fixed broadband connection cannot keep up with the quality of service (QoS) that the cellular network should provide. Therefore, the quality of mobile services provided at WiFi depends not only on the WiFi radio link quality, but also on the level of congestion on the backhaul link. A solution to the backhaul segment may deceptively appear simple by increasing the backhaul capacity. However, resource overprovisioning is certainly not a cost-efficient solution mainly in developing markets where wireless is amazingly less expensive than cable or DSL [7]. An agile admission control framework that anticipates QoS/QoE (Quality of Experience) degradation and proactively defines policies for LTE-connected cars (UEs) to select the most adequate radio access out of WiFi and LTE, for a particular application, taking into account the application type, the mobility features, and the traffic dynamics over the backhauls of both LTE and WiFi networks, and also enable IP flow mobility between WiFi and macro LTE networks would be of vital importance. The design and evaluation of such framework defines the focus of this paper.

The remainder of this paper is structured as follows. Section II highlights some related research work. Section III describes the proposed framework and highlights the distinct operations and entities that it incorporates. Section IV portrays the simulation philosophy and discusses the simulation results. Finally, the paper concludes in Section V.

II. Related Work

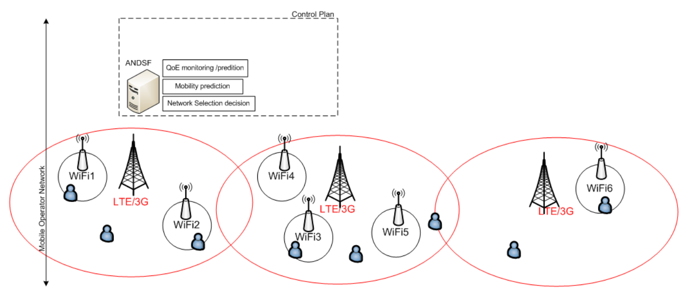

Fig. 1. Envisioned mobile network architecture.

Internetworking VANETs with 3GPP mobile systems or connecting vehicles directly to 3GPP networks have been gaining a great deal of momentum over the past few years. In [3], the NG Connect program is considering direct communication of cars to the LTE network. In [4], a heterogeneous integration of VANET and 3G networks using mobile gateways (i.e., vehicles) is introduced. However, as discussed in the introduction, due to the huge mobile traffic volumes, far beyond the original mobile network capacity, mobile operators will not be offering mobile IP connectivity through only 3GPP networks [5]. They are also considering the usage of WiFi networks. The availability of several wireless access technologies, for connecting vehicles (e.g., highly mobile UEs) to the Internet, introduces the need to have efficient network selection mechanisms when UE is invoking vertical handover. This mechanism must be enforced either by network operators or user preferences [12][13][14]. The vertical handover schemes proposed in the literature covered many aspects and have taken

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into account several parameters [19]. However, it is interesting and advantageous to take into consideration QoE (a crucial quality factor) when making decision, as in [15]. To facilitate the implementation of vertical handover between 3GPP and WLAN networks, and assist UEs in selecting the optimal radio access out of many available ones, current discussion within 3GPP regards whether WLAN can be considered as a trusted non-3GPP or Non-trusted non-3GPP access. For an efficient interworking between WLAN and LTE, many operators and vendors are in favor of qualifying WLAN as a trusted non-3GPP. There are also ongoing standards activities on enabling seamless WLAN-based offload vs. non-Seamless WLAN-based offload [8] and on location based selection of gateways for seamless WLAN-based offload. Whilst ANDSF (Access Network Discovery and Selection Function) was initially designed for the selection between 3GPP and non-3GPP accesses such as WLAN [9], further standards work consider the extension of ANDSF functionalities to the selection of PDN (Packet Data Network) connection from within the 3GPP domain and enabling UEs to steer IP flows among the available PDN connections (Operator Policies for IP Interface Selection – OPIIS [10]). Other ongoing standards activities focus on defining metrics for the identification of a data flow/application [11] to enable per IP flow offload. Some of the envisioned metrics are domain name and application unique ID, and others such as throughput, content size, and behavioral statistics are still discussed. Based on the identification of the application type, an operator may enforce policies that would force a UE to steer the relevant flow via WiFi or LTE.

III. Proposed Scheme

Fig. 1 portrays the envisioned network architecture and its main components. The mobile network consists of a number of wireless domains; each comprising a number of access points using the same or different wireless access technologies (i.e., 4G networks). On the control plane, ANDSF (or alike node) is used to assist UEs to discover available access networks and to select the best network access following policies defined, a priori or dynamically/on demand, by the mobile operator and enforced by UEs, in a transparent manner to users. A number of monitoring agents are deployed over the entire mobile network to assess the QoE experienced by users at each access point within the urban wireless domains. As in [19], QoE is assessed in the form of a metric that indicates average user satisfaction level (i.e., Mean Opinion Score – MOS). Information on user satisfaction is collected explicitly from users when they handout from an access network. Users that are requested to score their satisfaction level can be selected, randomly or following a defined logic such as only users that received a particular service/application type, video or only users that have been connecting to an access network for a time exceeding a specific threshold. Users may be given incentives for scoring the service. A users satisfaction level can be, for example, a score from ω_{min} to ω_{max}, with ω_{max} indicating an excellent perceived quality and ω_{min} indicating a poor service. There may be different ways for computing the average user satisfaction level using any function that takes the following metrics as inputs, namely the score ω_i indicated by a customer i, the duration θ_i during which the user was connected to an access network, the types of applications/services received by the customer, and the average throughput λ_i achieved by the customer while being connected to an access network. The user satisfaction indicators (ω_{min}, ω_{max}, θ_i, λ_i) values are then reported to a QoE profiling unit at the ANDSF (or another relevant node) in order to build/update the user satisfaction profile for the different access points AP_k. As depicted in

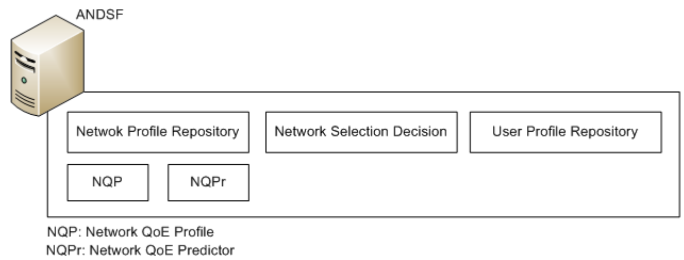

Fig. 2. Proposed additional components to ANDSF or alike node.

Fig. 2, the Network Profile Repository (NPR) consists of two units, namely Network QoE Profile (NQP) and Network QoE Predictor (NQPr). Based on the received user satisfaction indicator, the NQP entity builds/updates the QoE profile of each access network available in the wireless domain. NQPr implements a QoE predictor similar to that defined in [18], using any suitable learning technique (e.g., Neuronal Networks, Fuzzy techniques, etc.) that translates QoS indicators such as available bandwidth, and time of connection to user satisfaction. NQPr predicts the average user satisfaction from the relevant QoE statistical profile available at NQP. Indeed, according to network profile available at NQP, the learning function establishes a relation between user satisfaction (ω_{min}, ω_{max}) and the time duration as well as user throughput (θ, λ). Thus, the predicted user satisfaction $S_p(\theta_p, \lambda_p)$ depends on the predicted time duration θ_p and the predicted available throughput λ_p for a specific time window. The learning algorithm is constantly enhanced, by assessing the prediction accuracy. A value predicted for a time slot $[Tk-1;T_k]$ is compared against real values effectively measured during the specific time slot and correlation between the two values is assessed. The correlation between the predicted link bandwidth value and the actual one measured during a time period $\Delta(j)$ is denoted by $\Phi(j)$. The system assesses this prediction by comparing the predicted user satisfaction values $S_p(j; j < k)$ and the actual satisfaction values $S_a(j; j < k)$ measured during a number of previous time periods $\Delta(j; j < k)$. The correlation between the predicted user satisfaction value and the actual one measured during a time period $\Delta(j)$ is denoted by $\Psi(j)$. The learning algorithm is then constantly improved to reduce the difference between $\Phi(j)$ and $\Psi(j)$.

On the other hand, User Profile Repository (UPR), which was first introduced in [20], consists of four units Context Repository Service (CxRS), Context Gathering Service (CxGS), Context Aggregation Service (CxAS) and Context Distribution

Service (CxDS). At regular times, CxGS gathers context information from users. Contextual information may also include users personal information and preferences provided by the user when he/she first subscribes to the service and users mobility patterns predicted by a Mobility Predictor (MP) entity implemented at terminals. Indeed, in the envisioned network architecture, UEs comprise two new tools, Mobility Predictor and Context Uploader. The Mobility Predictor makes estimates of the users' mobility features, by using for instance models developed in [16] [17], and notifies them to the CxGS unit of ANDSF. After this operation, UPR at ANDSF is informed of the list of access points that the UE is most likely going to be connected to during the service time. Fig. 3 depicts the overall

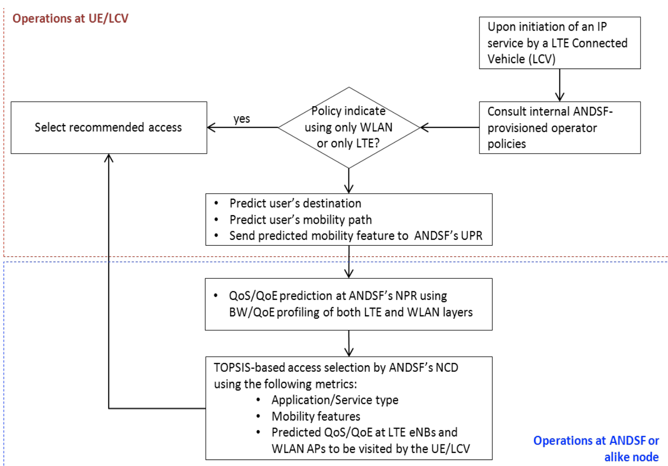

Fig. 3. Proposed wireless access steering mechanism for vehicles connected to LTE (or to other suitable mobile access technology).

process of network selection used in the proposed solution. When a user (of a UE) initiates a particular service, the UE first checks its table of operator policies provided by the mobile operator through ANDSF. If the policies indicate that the UE needs to first consult ANDSF for the access selection for this particular service/application, it accordingly contacts ANDSF, providing ANDSF with further information on its mobility features (i.e., predicted by models similar to those of [16] [17]). Based on the users mobility profile, and following the UE-AP encounter model devised in [22], ANDSF sorts out a list of access points AP^{list}, from both the WLAN and LTE layers, likely to be visited by the UE, and the relevant time and duration of encounter with each access point. For each access point AP_k from within the list AP^{list}, the predicted QoE profile is loaded from NQPr. This gives rise to a matrix as depicted in Fig. 4.

In Fig. 4, we denote by *R* and *S* the total number of the different eNBs and WLANs the vehicle is predicted to encounter, respectively, during a time window of interest (e.g., expected duration of service, predetermined period of time, etc.). During this time window of interest, the vehicle encounters k different combinations of eNBs and WLANs, each for a time period Δ_i $1 \leq i \leq k$, defining the duration of the encounter between the vehicle and the i^{th} set of eNB and WLAN (e.g., in Figure 4, Δ_2 denotes the duration of

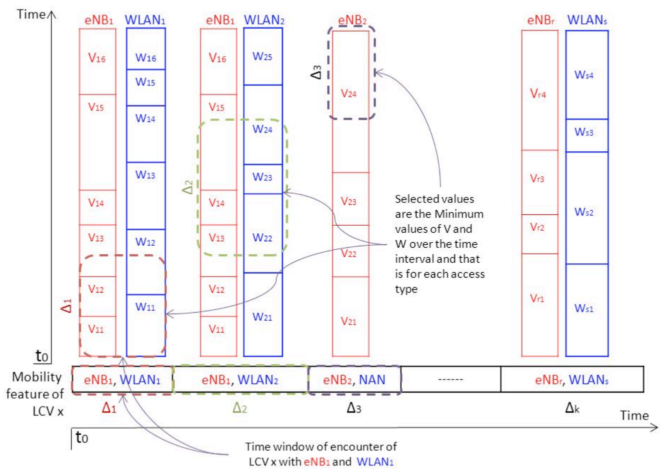

Fig. 4. Envisioned matrix for comparing QoE to be perceived at different access points of different access types a vehicle would encounter during a time window of interest.

the encounter between the vehicle and the set of eNB_1 and $WLAN_2$). From the QoE statistical profile, available and constantly updated at ANDSF's NPR, and using a suitable time-series model [22], a model of QoE distributed over time is formed for each access point of each access type, as shown in Fig. 4. In the figure, V_{pq} and W_{xy} denote the QoE perceived, and averaged over a number of days and during the q^{th} and x^{th} time intervals, at eNB_p and $WLAN_x$, respectively. For each period of time Δ_i $1 \leq i \leq k$, ANDSF compares the minimum values of QoE predicted to be perceived by users during the time interval $[t_0 + \sum_{j=1}^{i} \Delta_j;\ t_0 + \sum_{j=1}^{i+1} \Delta_j]$ and that is for each access type. It is important to note that user satisfaction or QoE is not the only criteria considered by the NSD entity, but other criteria defined by user and network operator (such as maximizing user QoE, reducing network cost, maximizing security, supporting high mobility, etc) are considered. Indeed, NSD is based on one of the multi-criteria decision making (MCDM) techniques called Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) [15].

Once the list of recommended APs is decided for each encounter time Δ_i $1 \leq i \leq k$, ANDSF communicates it to the UE/vehicle which enforces it during the service time. The IEEE 802.21 standard is then used at the UE to launch the vertical handover between two different technologies (for instance between WLAN and 3G).

IV. Performance Evaluation

A. Simulation model

3G1	3G1 (20%) WLAN1 (80%)	3G1 (20%)	3G1 (20%) WLAN2 (30%)	3G1 (20%) WLAN3 (50%)	3G2 (30%) WLAN4 (30%)	3G2 (30%)	3G2 (30%) WLAN5 (110%)	3G2 (30%)	3G2 (30%) WLAN6 (50%)	3G2 (30%)
0– 20 s	20– 120 s	120- 170s	170- 270s	260 – 360s	350 – 450s	450 – 520s	520 – 620s	620 – 670s	670 – 770s	770 – 900s

TABLE I
Envisioned simulation scenario.

In order to evaluate the performance of the proposed solution, we use the network simulator, NS2, with the NIST add-on [21]. This specific module includes several wireless access technologies and implements vertical handover by using the IEEE 802.21 standards. We consider a scenario whereby a UE moves randomly in the range of different available access networks composed by 3G and WiFi cells, as depicted in Table 1. The simulations are run for 900s; a duration long enough to ensure that the system has reached its stability. The UE is receiving throughout the simulation a video stream encoded with a constant bit rate (CBR) at 320 kbps. The UE moves at an average speed of 10 km/s visiting different areas covered by 3G only or by both 3G and WiFi. The residual times of the UE at each area along with load of each cell are shown in Table 1. For instance, between t= 170s and t= 270s, the UE is visiting an area covered by a 3G cell with 20% of load, and a WiFi cell with 30% of load. Here, the load represents the ratio of the bandwidth used by active connections to the maximum cell bandwidth.

Technology	QoE	Cost	Mobility
WLAN	to be measured $(x/5)$	low (3/5)	low (3/5)
3G	to be measured $(y/5)$	high (5/5)	high (5/5)

TABLE II
EXAMPLE OF CRITERIA SCORING.

As a comparison term, we use a default handover decision mechanism, selecting always WiFi, as the preference point of attachment to the network, whenever it becomes available. Unless otherwise stated, the prediction of the mobility features of the UE is initially assumed to be accurate. This assumption is made so as to avoid any possible confusion between degradation in performance due to inaccuracy in mobility path prediction. Table 2 shows an example of the criterion scoring used by ANDSF. It is worth mentioning that only QoE needs to be assessed by NQPr, whereas users or ANDSFs policies define the other parameters.

B. Results

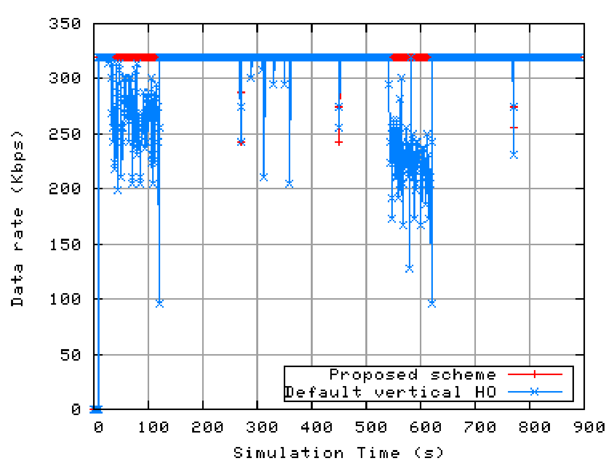

Fig. 5. Instantaneous data download rate during the simulation time.

Fig. 5 plots the instantaneous UEs data download rate during the simulation. The proposed solution exhibits better performance, in comparison to the default handover decision mechanism, and that is due to the fact that it favors access points with lowest load along the predicted mobility path of a UE. In contrast, the default scheme adopts always the same order of preference, penalizing sometimes the user satisfaction as there are periods (e.g., t= 20s to t= 20s, t= 520s to t= 620s) when 3G data rates are higher than those offered by WLAN, i.e., due to high contention in the WLAN cell. In case of the proposed scheme, we also remark degradations in the UEs data rate. These degradations occur mainly during the actual handover operation from WiFi to 3G.

Figs. 6 and 7 plot the end-to-end delays and packet loss

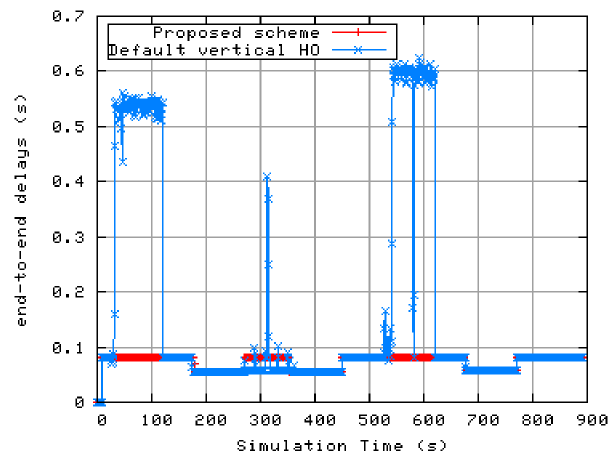

Fig. 6. Instantaneous end-to-end delays during the simulation time.

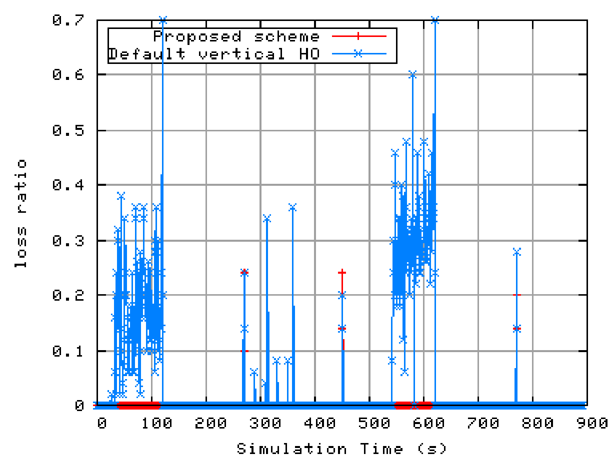

Fig. 7. Instantaneous loss rate during the simulation time.

rates experienced by the UE during the simulation time. These figures support the general observation made from Fig. 5. The degradation of the data download rate, seen in Fig. 5, is mainly due to the high loss rate resulting from the high contention in the WLAN cell. In fact, most of the packets are dropped at the Access Point queue, since the probability to access the channel is low. Furthermore, the proposed solution maintains lower end-to-end delays throughout the simulation time, while these delays are higher when the default mechanism is used. For instance, it reaches 0.7 second in case of the default mechanism; mainly when the WLAN cells are working under high loads.

In order to evaluate further the impact of packet loss on user QoE, we draw in Fig. 8 the instantaneous user QoE in terms of the Mean Opinion Score (MOS). The MOS is a value between 0 and 10, representing the quality as perceived and given by users to a service. 10 and 0 represent the highest video quality and the worst video quality, respectively. These scores were obtained by the Pseudo Subjective Quality Assessment (PSQA) tool [18], which is an automatic QoE evaluation tool for multimedia services based on Random Neuronal Network. It learns the non-linear relationship between parameters impacting the service quality and the user perceived QoE. It shall be noted that the PSQA version, used in the simulations, is dedicated to video quality evaluation. Fig. 8 shows clearly that

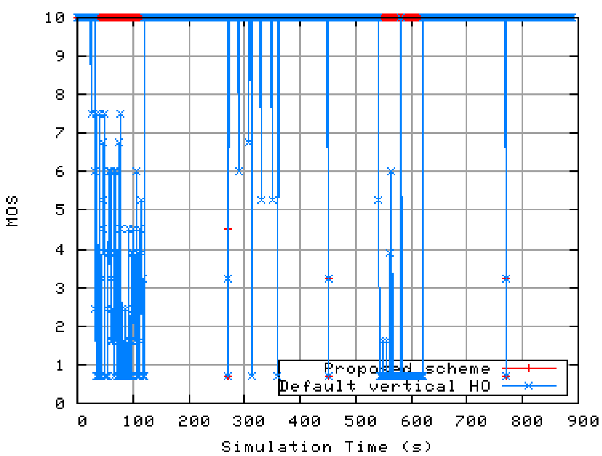

Fig. 8. Instantaneous user QoE (MOS) during the simulation time.

the users QoE degrades heavily and frequently in case of the default handover mechanism. These degradations correspond to the time periods when the packet loss and end-to-end delays are high. In contrast, the figure shows that our proposed solution maintains high values of MOS throughout the entire simulation.

V. Concluding Remarks

In this paper, we introduced a complete framework that proactively defines policies for LTE-connected cars to select the most adequate radio access out of WiFi and LTE. Within this framework we proposed different modules to be deployed at the network control plane as well as at UE in order to: (i) predict the UE mobility features; (ii) predict the available throughput backhaul network and translate this information into a user satisfaction factor (QoE); (iii) implement a network selection mechanism. Based on the prediction procedures this framework, through the ANDSF, is able to establish the list of APs likely to be visited by a UE and the mean user satisfaction during the period where the UE is supposed to be connected to these APs. Accordingly, the ANDSF can predict which AP is more suitable for increasing user QoE, and can enforce this decision to the UE. The performance of the proposed framework was evaluated through simulations and the obtained results were encouraging. They demonstrate the efficiency of the proposed network selection procedure, and how the mobility prediction precision can enhance this procedure in terms of user QoE.

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