Integration and Management of Wi-Fi Offloading in Service Provider Infrastructures

Engin Zeydan, A. Serdar Tan, Yavuz Mester, Gözde Özcan

Türk Telekom Labs, Istanbul, Turkey

engin.zeydan@turktelekom.com.tr

Abstract—**Integration of offloading technologies into mobile network operator's infrastructures that provide heterogeneous access services is a challenging task for mobile operators. A connectivity management platform is a key element for heterogeneous mobile network operators in order to enable optimal offloading. In this study, development and integration of a connectivity management platform that uses a novel multiple attribute decision making algorithms for efficient Wi-Fi Offloading in heterogeneous wireless networks is presented. The proposed platform collects several terminal and network level attributes via infrastructure and client Application Programming Interfaces (APIs) and decides the best network access technology to connect for requested users. Through experimentation, we provide details on the platform integration with service provider's network and sensitivity analysis of the multiple attribute decision making algorithm.**

Keywords—*connectivity management, multiple attribute decision making, heterogeneous networks, offloading.*

I. INTRODUCTION

In modern century, communication technologies are playing an important role in peoples lives. Cellular (4G and above) and Wi-Fi technologies are the major communication technologies that provide wireless Internet access and services to users. Wide deployment of these major communication technologies has led to significant increase in global wireless data traffic with an average annual rate of 80% [1]. In order to cope with this tremendous mobile data traffic increase, several solutions are proposed in literature [2] [3]. Existing solutions that improve network capacity include solutions such as installing base stations, upgrading networks from the current to next generations, installing new base station architectures and offloading traffic through Wi-Fi networks. Wi-Fi offloading has many benefits compared to the other solutions as it has fewer capital costs or operation expenditure. Moreover, in [4] it is shown that 65% cellular base station power consumption can be saved through Wi-Fi offloading.

In the literature, many studies were conducted on Wi-Fi offloading which are aimed to get more efficient and successful offloading. In [5], an optimization problem is formulated to select users to be offloaded from the cellular to Wi-Fi networks so as to maximize energy efficiency. Simulations show that the proposed offloading algorithm performs nearly the same as the exhaustive search and greedy algorithms, but requires much lower computational complexity. In [6], the authors developed analytic models on Wi-Fi offloading efficiency both in delayed and opportunistic offloading techniques and these models are tested by simulations. For both models, the Wi-Fi offloading

performance which is characterized by offloading effectiveness is analyzed in terms of desired average service delay. In order to work and evaluate vertical handover process, Multiple Attribute Decision Making (MADM) has been shown to be a successful tool in [7]. On the other hand, the studies in [7] does not take Wi-Fi offloading into account. Although there have been various studies on offloading in the literature, there is no study on an operational connectivity management platform that takes into account various requirements of Mobile Operators (MOs). Wi-Fi networks can easily get congested under user high density environments. Thus, offloading all users to Wi-Fi whenever available may result in lower Quality-of-Service. Therefore, an intelligent mechanism is required for the optimal management of Wi-Fi Offloading. In this paper, we design and demonstrate a real-time and fully-functional connectivity management proof-of-concept platform for integrated heterogeneous mobile networks. The platform collects information from the mobile phones and operator infrastructure and uses a MADM algorithm to decide on the best network connection based on the requirements of MOs.

The rest of this paper is organized as follows. First, the chosen MADM algorithm is explained in Section II. The implementation and integration aspects of proposed MO controlled centralized connectivity management platform is discussed in Section III-A. The performance analysis of the platform is presented in Section IV and finally conclusions are given in Section V.

II. MADM ALGORITHM

MADM algorithms provide the best selection among a decision set based on a set of observed attributes. Due to its ease of implementation, Total Order Preference By Similarity to the Ideal Solution (TOPSIS) algorithm [8], [9] is selected as the target MADM algorithm for the developed offloading platform. TOPSIS algorithm consists of easy implementation steps as described in [8] [10]. The algorithm creates a decision matrix $\mathbf{A} = [a_{ij}]_{p \times m}$, where m refers to size of the multiple attribute set $\mathrm{S} = \{s_1, s_2, ..., s_m\}$ consisting of elements such as link quality, average latency of the target network for the given application, user preferences (cost, security), backhaul capacity, etc and p refers to size of the multiple decision set $\mathrm{E} = \{e_1, e_2, ..., e_p\}$ which consists of candidate networks such as Long Term Evolution (LTE), Wireless Local Area Network (WLAN) or femtocell communication opportunities for a given user. Note that that all the attributes are transformed to have positive impact if necessary in our analysis. The remaining steps are already described in [10].

Implementation of the algorithm assumes availability of

one registered The 3rd Generation Partnership Project (3GPP) network and at least one known Wi-Fi network (or another radio access technology) on the mobile terminal. TOPSIS algorithm is implemented in the remote server where the attributes are collected. Algorithm complexity is $O(mp)$ per mobile terminal. The attributes that can be used in this integration are: (i) Received Signal Strength Indicator (RSSI) (s_1, weight: w_1), (ii) Average Latency (s_2, weight:w_2), (iii) Battery Level (s_3, weight:w_3), (iv) Number of Connected Users (s_4, weight:w_4), (v) Backhaul Capacity (s_5, weight:w_5), (vi) Remaining Capacity (s_6, weight:w_6), (vii) Roaming Status (s_7, weight:w_7).

III. ANALYSIS, IMPLEMENTATION AND INTEGRATION OF SHARING PLATFORM

In this section, the implementation of the SHARING[1] platform infrastructure API into a Cellular (4G) and a Wi-Fi platform is presented. The SHARING platform is compatible with two different operational modes. First, with an integrated Wi-Fi and LTE operators platform, where a single operator is responsible for both Wi-Fi and LTE infrastructure. Second, it can work with independent Wi-Fi and LTE operators where the two operators are communicating with SHARING platform in order to perform smart offloading. In this implementation, we assume that SHARING platform is deployed by an operator providing Wi-Fi and LTE integrated services. The following subsections cover the implementation and integration details of SHARING platform.

A. SHARING Platform Implementation

The general architecture of the interaction between the LTE operator's and SHARING platform is shown in Figure 1. There are two main components of SHARING platform: **SHARING client** and **SHARING server**. The SHARING client is implemented as an application on mobile terminals. The SHARING server runs the MADM algorithm called TOPSIS as shown in Figure 1. In this platform, SHARING server is connected to mobile terminals and core networks of service providers via **Client API** and **Infrastructure API**, respectively. Through these APIs, SHARING server receives attribute values presented in Section II that are later going to be used for appropriate access network selection. Client API at SHARING client can be implemented inside an application on mobile terminals supporting various operating systems (OSs) (e.g. Android and IOS). The SHARING client application scans the wireless Access Points (APs) and cellular connections (4G) surrounding it and sends AP and cellular network related attributes. Additionally, SHARING client application receives instructions from SHARING server such as *network state changes* (shutdown of wireless module, connection to another AP or cellular network, etc.). The applications' scanning module may run periodically with an adjustable scanning period or via a manual button (named 'panic" button) in main fragment of the application.

On the other hand, SHARING Server can be located inside or outside of the premises of service providers. The only restriction is that it has to be reachable from both service

providers (i.e. from WLAN and Cellular providers network) when a handoff between cellular and AP occurs. The SHARING server can also be located inside a cloud service provider such as an Amazon web instance [12] to enable easy access to/from all entities of heterogeneous network depending on the agreements between cellular and WLAN service provider. SHARING server runs an application which runs a MADM algorithm called TOPSIS algorithm [8] for smart offloading decisions.

B. SHARING Client and Server Interfaces and Integration

The server has two fundamental communication interfaces: One of the interfaces, called Client API, receives client related parameters such as RSSI, battery level, roaming/non-roaming status, through Hypertext Transfer Protocol (HTTP) communication from SHARING client. Client API is also used to send the network connection decision from SHARING server to SHARING client. Second interface is a REST-based web service interface called Infrastructure API. The Infrastructure API can obtain offline (statistical and long term measurements) or real-time data from operators. Based on operator agreements, the Infrastructure API can provide channel utilization ratio, latency, number of active connections, network congestion ratio and backhaul Internet connectivity status of both WLAN and cellular networks to the SHARING server. The information collected from both APIs (such as Service set identification (SSID), Basic service set identification (BSSID), capabilities, frequency and password as well as cellular network parameters of users) are stored in the database of SHARING platform.

In order to enable Wi-Fi offload functionality within the LTE and WLAN networks, new elements into the existing infrastructure need to be added. Moreover, these new elements need to interact with the rest of the core services that LTE and WLAN networks can provide such as services provided by Authentication, Authorization and Accounting (AAA), Home Subscriber Server (HSS), network monitoring and management functions are usually included in both LTE and Wi-Fi Core. Additionally, the communication between the SHARING platform and LTE-WLAN core network need to be managed by these new elements. As a use case, the general architecture of the interaction between the LTE operator's and SHARING platform is shown in Figure 1 for topology information request of Infrastructure API. Please note that similar interaction between WLAN operators and SHARING platform can be implemented easily. The information regarding network status updates and the unique identity (i.e. Mobile Station International Subscriber Directory Number (MSISDN) or International Mobile Subscriber Identity (IMSI) numbers) of each user connected to each cell is provided to the SHARING server by the LTE mobile operator. For this, three new modules need to be included on the LTE operator's backend: a **LTE RESTful API**, **SSH Client Application** and a **SHARING database** (note that the database is also used exchangeable throughout the paper). The existing backend of a LTE network is represented by the purple box called LTE Core Network. The new modules that need to be implemented for SHARING infrastructure APIs are: SSH Client Application, LTE Infrastructure API, SHARING database and LTE Infrastructure API Client Application. As shown in Figure 1, LTE API is composed of different entities, where all the entities are located on the LTE operator's side. Note also that depending on the

[1] SHARING is the acronym for the Eureka Celtic-Plus labeled project titled "Self-organized Heterogeneous Advanced RadIo Networks Generation" [11].
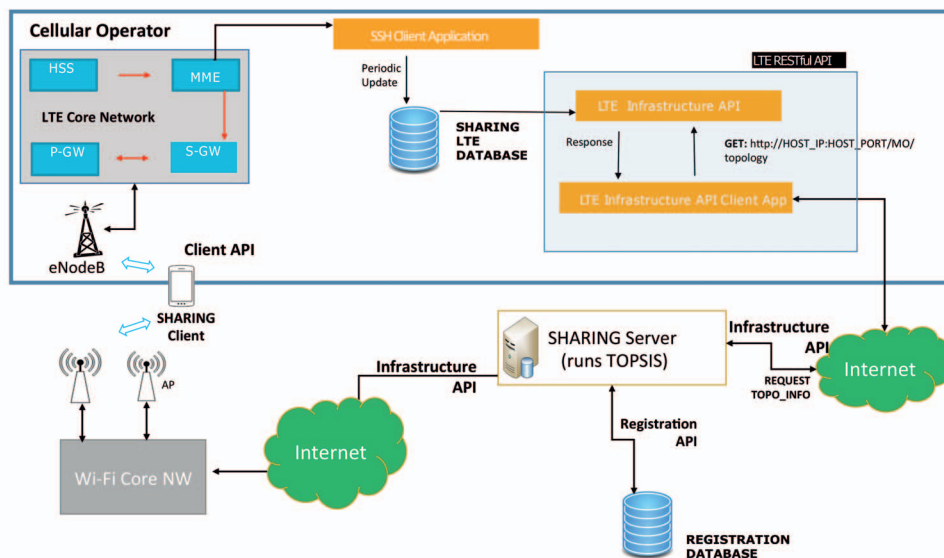
Fig. 1: Infrastructure API between LTE operator and SHARING platform for Topology Information

design choice, the entities except SSH Client Application, can also be located outside the mobile operator's premises.

In order to decide the appropriate AP or base station for a user inside a cell location, the SHARING server needs to obtain the up-to-date information from LTE and Wi-Fi core networks. For this reason, **RESTful LTE API module** is introduced as a new module inside the operator's premises. The aim of this module is to obtain network status and topology information from the **SHARING database** and post it into the SHARING server through its RESTFul API within a configurable period. The LTE RESTful API, which consists of two parts namely LTE Infrastructure API and LTE Infrastructure API client Application, ensures communication link can be established between the SHARING server and the LTE Core elements. The LTE Infrastructure API Client Application gets the related information from MO's network database (i.e. SHARING database) and sends it to the SHARING server periodically. This information is stored in SHARING database as a unique table for each information type, one table for topology information (TOPO) and another table for network statistics (NETSTATS) information.

SSH Client Application posts the LTE infrastructure parameters into the database periodically. The unique identity of users connected to each cell at each instant can be retrieved by the SSH Client Application directly from the LTE Core network element, Mobility Management Entity (MME). This information is later pushed into the database for further retrieval by SHARING platform. On the other hand, the SHARING database stores all the necessary information regarding cell identification IDs (CELL-IDs) such as backhaul metrics, remaining capacity, connected users to each cell, network status information, etc. For implementation of the LTE RESTful API, the available methods through the RESTful API are as follows:

Informing on the topological information: The topological information of the LTE network site where the SHARING

platform based Wi-Fi offloading is going to be enabled is provided by LTE network to the SHARING platform periodically. There can be mainly two ways of providing this topological information to SHARING server: first is by providing it to the SHARING core platform from LTE operator and the second one is by polling the LTE Core network status periodically by SHARING server in order to get the list of each connected users at each requested cell. Through $REQUEST\_TOPO\_INFO$ method, the list of users with their unique identities such as MSISDN, IMSI connected in real time to the requested CELL-ID is provided. This information can be obtained from MO's LTE core network element, MME. The API request has the following format (GET); $http : //HOST\_IP : HOST\_PORT/MO\_NAME/topology/CELLID$. The response to this kind of request includes the unique identities of users connected to each CELL-ID.

IV. PERFORMANCE ANALYSIS

The experimental set-up is provided in Figure 2. In the experimental set-up, there are two Wi-Fi APs (AP-A and AP-B) and one mobile phone running a SHARING client application. The network selection results under a simpler scenario were presented in [10]. In the experiments, we test the sensitivity of the attribute weight w_4, i.e. the weight of the number of connected users. During the experiments, the SHARING client stands static close to AP-A and the distance between SHARING client and AP-B is four times larger than the distance between SHARING client and AP-A. The data collection for experiment ran for 15 hours and the plots in Figure 3 are obtained by averaging the RSSI and number of connected users at AP-A over the whole period. In Figure 3, the average RSSI values of AP-A and AP-B are represented with dotted blue (RSSI(A)) and red lines (RSSI(B)), respectively. In our set-up, since initially SHARING client is attached to AP-A, we want to know the sensitivity of increasing connected users to AP-A before it
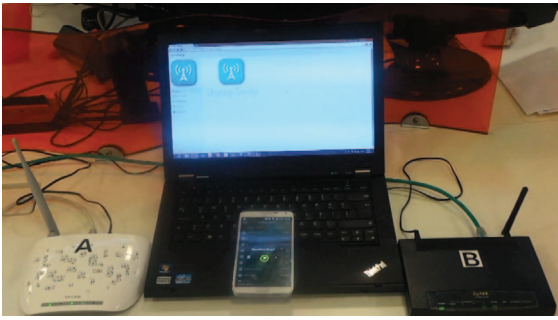
Fig. 2: Experimental demo set-up

Fig. 3: Number of users at AP-A vs. weight values, w_4

switches to AP-B for different values of weight values w_4. In our experiments, number of connected users to AP-B is 5 and number of connected users to AP-A is varied from 1 to 100. Note that in our analysis, we ignored the cases when the number of users connected to AP-A becomes larger than 100.

Figure 3 shows average number of users at AP-A before SHARING client switches to AP-B as the attribute weights of number of users increase (the solid black line, N_A^B). For our experiments the weights w_4 values are varied from 0.1 to 1.0 while other attributes are assigned equal values after subtracting w_4 from 1. As observed from Figure 3, the increase in w_4 results in lower N_A^B. For example, when $w_4 = 0.1$, N_A^B becomes 79 and when $w_4 = 0.9$, $N_A^B = 6$. The results in Figure 3 also illustrate that when w_4 value is greater than 0.4, as the number users at AP-A becomes marginally higher than AP-B (which is fixed to 5), SHARING client hand off from AP-A to AP-B. This means that for $w_4 < 0.4$, number of users connected to AP-A has to be significantly larger than the number of users connected to AP-B for SHARING client to perform hand-off. In addition, when $w_4 < 0.4$, in some cases of the experiment, SHARING client did not switch to AP-B even if the number of connected users in AP-A became very large value since the experiment results present only the cases when there is a hand-off. Note also that, this is the main reason behind the fall in the value of the average RSSI of AP-A for $w_4 < 0.4$ since the number of handovers only occurs in cases when RSSI level is low. Finally, note that the reference value obtained via such experiments can be used by operators to adapt the offloading platform to their specific requirements.

V. Conclusions

In this paper, we presented the integration and sensitivity analysis aspects of a connectivity management platform that uses a multiple attribute decision making algorithm. Experimental evaluation for the sensitivity analysis results on the weights of the chosen multiple attribute decision making algorithm, TOPSIS, is provided to guide operators on adapting the Wi-Fi offloading platform (SHARING) into their networks. The SHARING platform integration steps can be applied to all 3GPP network operators that provide converged Wi-Fi services as well.

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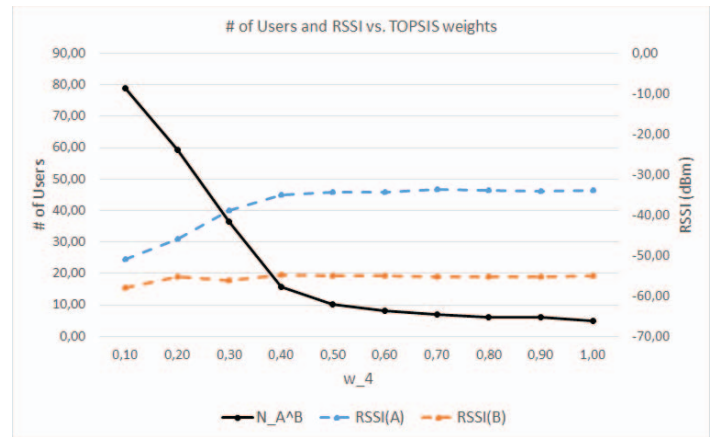
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