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Taking Benefit of Diversity in RAN to Offload Delay-tolerant Traffic and Improve End-Users QoE

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Abstract—Since the introduction of smartphones and tablets into the market, mobile data traffic has shown an exponential growth. To cope with such mobile data explosion, offloading techniques were proposed. The main aim of offloading is to avoid transporting unnecessary traffic in costly networks without creating any additional incremental revenue. Offloading is addressed in this paper where we focus on the the interworking between 3GPP access and WiFi. Thus, we propose an economical model for offloading, capturing simultaneously the subscribers' conditions and the operators' preferences. Such model enables the operators to specify an offload strategy to increase their economical benefits without impacting their subscribers QoE.

Index Terms—Offload Strategy, Mobile Networks, Cellular Networks, 3GPP, Wifi, Delay-Tolerant, QoE, Service Level Agreement (SLA).

I. INTRODUCTION

Since the introduction of smartphones and tablets into the market, mobile data traffic has shown an exponential growth [1]. To cope with such mobile data explosion, upgrading to 4G (e.g., Long Term Evolution (LTE) is so far the main stream solution. However, while this technology will provide additional resources, mobile data will continue to growth steadily with an expected annual rate higher than 92% [2]. This will eventually lead to rapidly exceed the capacity of 4G in few time. In this context, operators are considering other solutions such as data offloading that consists on utilizing other wireless access technologies to alleviate network congestion in cellular networks [3]. The main aim of offloading is to avoid transporting unnecessary traffic in costly networks in order to maintain a high Quality of Service for subscribers with time-constraint applications. Traffics that cause network congestion without creating any additional incremental revenue are rerouted through other low costly wireless access networks [3], [4]. Data offloading is therefore all the architectures, protocols and

mechanisms that allows to establish alternative paths for delivering data originally targeted for cellular networks [5]. At the RAN level two main technologies are currently considered, femtocells and WiFi, both are proposed to increase the indoor coverage and to free the limited 3GPP access spectrum from routing unnecessary traffic [6]. The advantage of WiFi over femtocells is that, not only it increases the indoor coverage but it also increases the data rate. Hence, WiFi does not introduce interferences created by femtocells and Worsening the congestion problem. These WiFi characteristics have attracted the 3GPP community attention which proposes the RAN offload by the co-usage of WiFi and 3GPP access.

However, the main limitation of WiFi is that it is not capable to ensure QoS and to manage services continuity. To overcome this later limitation, the Media Independent Handover (MIH) presented as part of a joint work between IEEE 802.21 and Internet Engineering Task Force (IETF) [7], was proposed as a toolkit for network discovery and handover preparation in order to reduce the delays when handing over from an access technology to another and to enable the interoperability between WiFi and 3GPP access [8]. Similar functionality were also proposed by the 3GPP community namely the Access Network Discover and Selection Function (ANDSF) [9]. This function empowers the offload mechanism enabling operators to partially control the offload process by recommending particular connection to UEs e.g. connect via WiFi or through 3GPP access.

From an operator point of view, the main offloading complexity is indeed when to trigger the offload process ? What are the services to identify ? Who are the subscribers to impact ? How to trigger the offload. For this later point, it is indeed possible to think that either the operator could control the process or the mobile subscriber maybe by some financial incentive to accept it. The remainder of the paper is therefore organized as follows. In Section II, we introduce the main issues that

are addressed in this paper. In Section III, we present the network and economical models of our solution. In particular, we explain how the proposed aggregation function to catch the users conditions could be integrated in the operator economical model. In the following section, we evaluate the proposed solution by simulation where we highlight the benefits to the operator. Finally, conclusion and future works are presented in Section V.

II. PROBLEM STATEMENT

While offloading between 3G cellular and WiFi networks has a high potential, it is not obvious that users and providers adopt it in practice. The first reason is that users may be reluctant to offload their traffic without economic incentives. For instance, if a flat pricing strategy (a popular charging model in numerous countries) with unlimited consumption is adopted, users may not have any interest to reroute their traffic to WiFi and not use the cellular access [1]. In addition, operators themselves may not always welcome their cellular traffic offloading, since the global volume to charge may decrease, possibly leading to revenue loss for the operator. Thus, it is of significant importance to formally address the offloading questions from the economic point of view in addition to the technical one.

This is the focus of this paper which aims to address the following research questions:

- 1) Is it possible to design an economical model for the offloading that is capable to capture simultaneously the subscribers conditions and the operators preferences?
- 2) From this model, is it possible to derive an aggregate function that allows operators to design an efficient decision-making mechanism for offloading traffic through WiFi?
- 3) In a representative scenario including WiFi and 3G networks, and numerous mobile subscribers with different subscriptions contracts (i.e. Service Level Agreements (SLA)), does the proposed solution performs as expected? i.e., does the operator have an economical benefit deploying offload mechanisms.

III. PROPOSED APPROACH

To answer the research questions, we introduce a preliminary analytical study that considers the network and the business models. In this study, the operator is controlling the price and the subscribers are price-takers. We assume that end-users can subscribe to one of the three proposed SLAs namely: Best Effort (B), Silver (S) and Gold (G).

The considered network architecture including 3GPP cellular 3G access and WiFi is presented in Fig.1.

A. Offloading strategy

Operators' objective is to reduce as much as possible the traffics that should be routed via their mobile networks. But due to WiFi limitations e.g. can not maintain services continuity; the solution can not be based on moving all the traffic to WiFi. In contrast, a tradeoff must be ensured between the economical objective in a hand and the need to maintain users' satisfactions on the other hand. This could be ensured by the specification of an efficient offload strategy identifying the appropriate traffic flows that could be offloaded. In regard to this, three basic strategies were widely considered in the congestion management area [10]: the first one is based on subscribers profiles e.g. traffic from best effort customer will be offloaded, the second is based on applications type e.g. Facebook traffic is offloaded, the third is based on traffic or service types e.g. streaming services traffic is offloaded. The offload based on application is similar to the service traffic, yet this latter strategy is finer grained than the application type, since for example while connected to Facebook, a user could also watch a streaming video posted by a friend, then by offloading Facebook application, the streaming video will be also redirected. Therefore, an efficient offload strategy would be a mix of the subscribers' profiles and the services types.

Consequently, based on the 3GPP QoS Class Identifier (QCI), and on the packet delay budget, specified in [11]. The services to be offloaded are: Live streaming, Buffered streaming, and TCP-based services. These services are considered as delay tolerant since their transmission budget delay is relatively higher than other services. Their characteristics and how they could be identified are present in Table I.

Therefore, the idea is to offload delay tolerant traffics from cellular to WiFi networks in order to free resources in the costly cellular RAN access [12]. This will eventually improve the subscribers overall Quality of Experience (QoE) using delay sensitive applications e.g. VOIP while not degrading the QoE of subscribers using elastic or delay tolerant services.

B. Considered Scenario

The working use case is the following: several WiFi (IEEE802.11) Access Points (APs) and cellular 3G Base stations (BSs) are deployed in a defined area. N_{\max} users equipped with a Mobile Terminal (MT) have subscribed to the operator and are distributed in this area. We also

Table I
SERVICES CHARACTERISTICS [11]

Services	QCI	Packet delay budget	Identification
Live streaming	2	150 ms	APN, URL, or IP address
Buffered streaming	4, 6	300 ms	APN, URL or IP address
TCP-based services	6, 8	300 ms	APN, URL or IP address

suppose that this area is fully covered by a 3G Cell overlapping with WiFi hotspots as illustrated in Fig. 1(a). Within this area, we assume that each subscriber may randomly move following a random path with a random velocity. Some users may be almost static (pedestrians moving at low velocity) or mobile (users moving at high speed to model transportation).

An example of such scenario, is a subscriber recording a video with his smartphone and willing to immediately share with his friend on the Internet using any video storage service. Since the user is not watching the video, the uploading is tolerant to possible delay and therefore the traffic could be offloaded from the cellular RAN to the WiFi access.

C. Assumptions

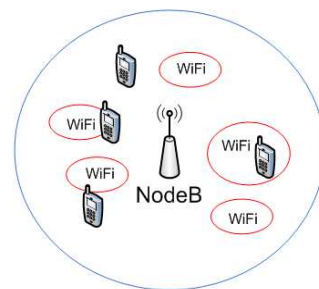
We assume that WiFi cells are homogeneous and MTs are uniformly distributed in the considered area. We assume also that the operator bandwidth is shared between subscribers belonging to three SLAs classes (Best Effort, Silver, Gold). We suppose also that the daily traffic demand of each user in the same class can not exceed the allocated bandwidth per class by the operator.

We consider a flat pricing scheme where the provider offers unlimited service for users.

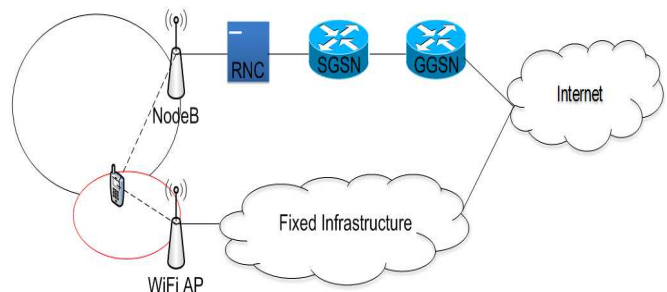
D. Network & Traffic Model

We consider a network composed of several WiFi APs and one NodeB serving N_{\max} users at a given time. MTs are always guaranteed to be under the coverage of the NodeB, but not necessarily under the WiFi APs. We consider also that one-day analysis is divided into T time slots, (e.g. a day could be divided into 4 times slots) since the users traffic and their mobility may change from a time slot to another. Thus, each user has a probability $p(\text{covwifi})$ to be under the coverage of a WiFi AP at any time slot $t \in T$.

Each user i has a traffic demand $\Phi_i(t)$ to be transported by the operator. The total traffic volume of the user i generated through 3G and WiFi is represented by the



(a)



(b)

Figure 1. (a) The Network Coverage. (b) The Offloading traffic.

vector $X_i(t)$ for each time slot $t \in T$. The traffic volume of the user i generated via 3G interface is represented by the vector $Y_i(t)$ at time t . Whereas, the traffic volume that could be offloaded through WiFi interface is represented by $Z_i(t)$ and is given by the following equations:

$$X_i(t) = Y_i(t) + Z_i(t) \quad (1)$$

and

$$X_i(t) \leq \Phi_i(t) \quad (2)$$

Let C be the capacity provided by the operator (which corresponds to the capacity of the NodeB). For the system to be in equilibrium, at any time t , the traffic

demand $X_i(t)$ of the users should not exceed the overall provider capacity.

$$\sum_{i=1}^{N_{\max}} X_i(t) \leq C \quad (3)$$

E. Mobility Management

When WiFi offloading occurs, the operator and users have to handle different mechanisms to hand off the traffic from 3G to WiFi and to ensure a seamless continuity of service. This handover mechanism may face many problems due to the mobility of the users and the congestion of WiFi cells. In term of mobility management, the handover mechanism should be able to handle any possible movement of the user e.g. 3G to WiFi or WiFi to 3G. MIH framework is widely used to facilitate handover and to enable the interoperability between IEEE802 and non IEEE802 technologies (e.g., UMTS, LTE) in order to provide transparent service continuity across heterogeneous networks. The MIH consists of a signaling framework and triggers that make information available from lower layers (MAC and PHY) to higher layers of the protocol stack (network to application layers).

In literature, the offloading mechanisms can be classified into three different categories depending on the entity that controls the handover explicitly: Terminal Controlled Handover (TCH), Network Controlled Handover (NCH) and hybrid Controlled Handover (HCH). In this paper we adopted the NCH scheme where the handover decision is taken by the network operator while considering the user context.

F. Economical Model

In this section, we explain the economic metrics that will be considered by the operator for the offload decision making. Thus, we assume that the 3G and WiFi outcomes to be paid by the customers are respectively p_{3G} and p_{WiFi} , where p_{WiFi} is significantly lower than p_{3G} since the deployment and the WiFi network are much less than 3G. We consider three classes of users: Best Effort, Silver and Gold with N_B is the number of Best Effort subscribers SLAs with price p_b , N_s silver with price p_s and N_g gold with a price p_g , where $N_g + N_s + N_b = N_{\max}$. The gold SLA ensures that the subscribers of this contract will be better served than any subscribers of other classes while eventually the pricing for this contract on the other hand is higher.

The objective of the operator is therefore to maximize its Expected Revenue (ER) while trying to satisfy as much as possible all its customers' Quality of Experience

(QoE) in their respective classes. To attend this objective, first the network operator estimates the acceptance probability of each user to offload its traffic based on:

- the number of SLA subscribers that can be offloaded
- the type of traffic whether or not it supports the offload
- the probability that a UE is covered by WiFi $p(\text{covwifi})$
- the total available network bandwidth

The ER for the operator assuming a flat pricing scheme is given by the following equation:

$$ER_i = p_{3G} \times Y_i(t) + p_{WiFi} \times Z_i(t) \quad (4)$$

The objective for the operator is therefore:

$$\sum_{i=1}^{N_{\max}} p_{3G} \times Y_i(t) + p_{WiFi} \times Z_i(t) \leq R \quad (5)$$

where R is the operator revenue without offloading such that $R = \sum_{i=1}^{N_{\max}} p_{3G} \times X_i(t)$. However, this equation is always true if the p_{WiFi} is lower than the p_{3G} . In order to ensure a tradeoff between the need to maximize the revenue without impacting the QoE, the operator will evaluate the Minimum Expected Revenue (MER) based on the users acceptance probability. Hence, the MER is defined in the following equation:

$$\begin{aligned} MER(V, p_{covwifi}, p_b, p_s, p_g) = & \\ & \sum_{k=1}^{N_b} p_b A_k(V_k, p_k(\text{covwifi}), p_b) + \\ & \sum_{k=N_b+1}^{N_b+N_s} p_s A_k(V_k, p_k(\text{covwifi}), p_s) + \\ & \sum_{k=N_b+N_s+1}^{N_{\max}} p_g A_k(V_k, p_k(\text{covwifi}), p_g) \end{aligned} \quad (6)$$

where p_b , p_s and p_g are the prices paid by users under the same SLA class. V is the users traffic volume to be offloaded and $p_{covwifi}$ is the probability that a user is covered by WiFi. Indeed, the acceptance is modeled by a multiplicative utility function $U(x)$ ¹, which is a sigmoidal function, where x is an upward criterion in the range of $x_\alpha \leq x \leq x_\beta$ and a middle point of the utility x_m . Details on this utility function can be found in [13]. Therefore, the acceptance probability is described as follows:

¹This multiplicative form reflects the interdependence between the criteria considered in the utility function and can eliminate the close-to-zero effect

Table II
SIMULATION PARAMETERS: OPERATOR CASE

Class	Price	$\mathbf{w}=(w_v, w_c, w_p)$	$p(\text{covwifi})$
Best Effort	$p_b = 15$	$w_g = (0.3, 0.3, 0.3)$	60
Silver	$p_s = 25$	$w_s = (0.3, 0.3, 0.3)$	60
Gold	$p_g = 45$	$w_g = (0.4, 0.4, 0.4)$	30

$$A_k(V_k, p_k(\text{covwifi}), p_k) = [u_k(V_k)]^{w_v} \times [u_k(\text{covwifi})]^{w_{\text{covwifi}}} \times [u_k(p_k)]^{w_p} \quad (7)$$

, where $u_k(x)$ and w_k are respectively the utility function of the criteria and its sensitive for the k th user.

Thus, the objective function is given by:

$$\begin{aligned} & \text{maximize} \quad (R - \sum_{i=1}^{N_{\max}} ER_i) \wedge \\ & \text{minimize} \quad (\sum_{i=1}^{N_{\max}} ER_i - MER) \end{aligned} \quad (8)$$

, and the optimization problem is to find the best traffic distribution (Z_i, Y_i) among the N_{\max} users that satisfy the equation 8.

IV. SIMULATIONS & RESULTS

To validate our proposal, we carried out two simulation campaigns. The first one, using Matlab, aims at validating the proposed solution and at highlighting its superiority against no-offloading techniques addressed from the operator side. The second simulation campaign uses the built simulation platform MIH-NIST-NS2.29 [14].

A. Parameters of the scenario

In this subsection, we describe the setup for our network simulations, such as the real traces and the parameters values taken from the French operator. Table III highlights the main characteristics of each technology.

The duration of a time slot is set to be an hour i.e $(T = 24)$. The number of 3G BS cells is 1, the number of WiFi cells is set at 20 cells and the total number of users is 250 users². The cellular capacity is 8 Mbps which is divided through the active 3G users according to their subscribing contracts and price sensitivity. The economical model parameters are given in Table II.

²These parameters have been selected from measurements on mobile data and were adjusted in order to support the simulator constraints and to handle the scalability of our system

B. Results

We start from Fig.2(a) which depicts the offloaded traffic of the operator per day. The first observation is that, when the number of user increases until a certain threshold ($N = 100$), the offloaded traffic increases because it is possible to find available WiFi APs that could handle the data traffic. However starting from a certain number of user, the capacity of the operator (cond. Equation3) is reached and the traffic that is offloaded can not exceed the maximum offloaded traffic. The second observation is that when the number of user is low and the traffic demands of all the users (Φ_i) does not exceed the capacity C , the operator does not have to offload the traffic and all the user are satisfied by the current connection. In Fig.2(b) we plot the gain of the operator for different values of the UE. We note from this figure, that when our mixed offload strategy based on the subscribers profiles and the services types is used, the operator can find the best traffic distribution among 3G and WiFi and therefore decreases the ER satisfying the equation 8. Last but not least, Fig.2(c) depicts the proportion of the users profiles when the offloading strategy is used. It is clear that not all the traffic of user is offloaded through WiFi and we note that the Gold SLA profile is the one that is less offloaded by the operator. The reason of this behavior, is that the Gold SLA profile has a higher sensitivity of the price and the operator would satisfy the QoE of these users as much as possible by offering a 3G during their connectivity.

V. CONCLUSION & FUTURE WORKS

In this paper an economical model enabling operators to conceive an offload strategy that considers the delay tolerant services in addition to the subscribers SLAs is proposed. The main aim of this model is to define the best traffic distribution between WiFi and 3G among the total network subscribers in order to increase the operator revenue and at the same time satisfy an aggregation function summarizing the subscribers conditions and indicating as well whether or not the offload should be performed. Results highlights the effectiveness of our model and show that it is possible to find the best traffic distribution ensuring the tradeoff between the operators

Table III
NETWORKS CHARACTERISTICS

Characteristic	WiFi	UMTS
Coverage area/Cellule Size	50 m - 100 m (indoors)	1000 m (macro)
PHY Spec. Propagation model	Two-Ray Ground Model	Ray Tracing Model
Antenna Type	OmniAntenna	OmniAntenna
Frequency Range	2.4 Ghz	1.8 Ghz
RX Threshold	5.2×10^{-10} W	1.0×10^{-16} W
Peak Data Rate (DL)	11 Mbps	384 Kbps
QoS	Best Effort	Support
Cost Mbps/euro	≤ 0.01	0.07
License cost	Free	Expensive

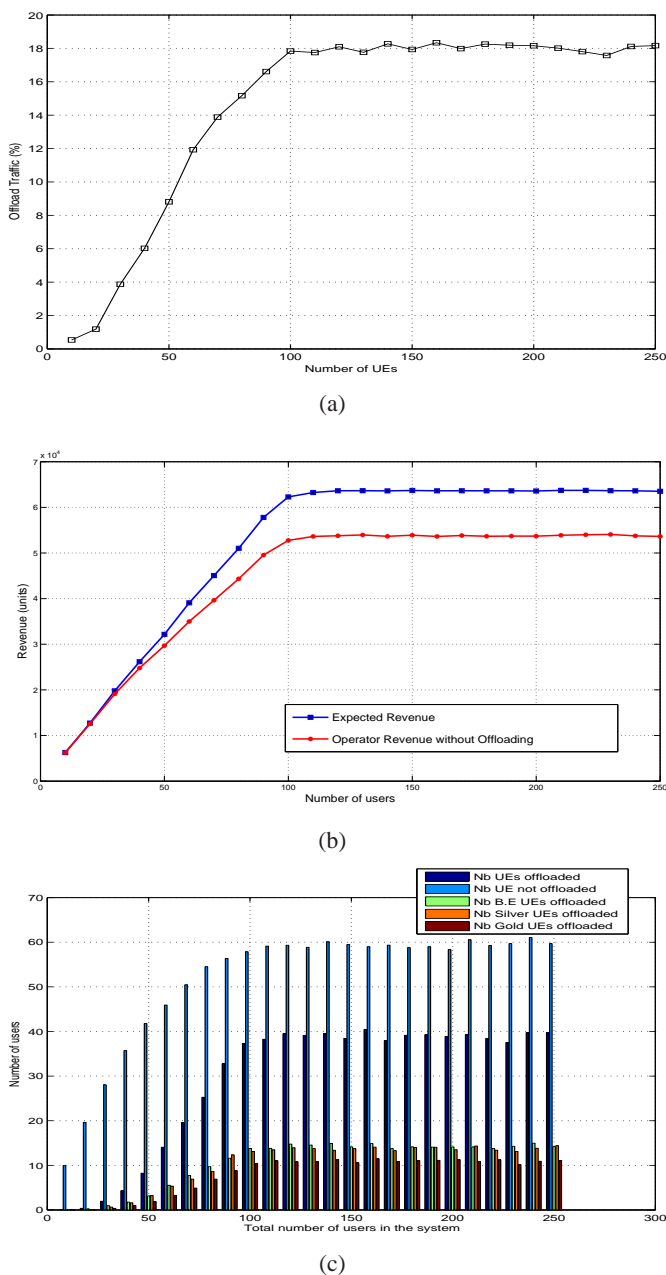


Figure 2. (a) The offload traffic per day. (b) The operator Gain by unit cost. (c) The distribution of user profiles in the system

need to increase their revenues while maintaining the subscribers satisfaction.

Future directions may find other ways to extend this work by proposing several offloading strategies and compare their behaviors when different type of traffic could be used.

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