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Weighted proportional fairness and pricing based resource allocation for uplink offloading using IP flow mobility

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ABSTRACT

Mobile data offloading has been proposed as a solution for the network congestion problem that is continuously aggravating due to the increase in mobile data demand. However, the majority of the state-of-the-art is focused on the downlink offloading, while the change of mobile user habits, like mobile content creation and uploading, makes uplink offloading a rising issue. In this work we focus on the uplink offloading using IP Flow Mobility (IFOM). IFOM allows a LTE mobile User Equipment (UE) to maintain two concurrent data streams, one through LTE and the other through WiFi access technology, that presents uplink limitations due to the inherent fairness design of IEEE 802.11 DCF by employing the CSMA/CA scheme with a binary exponential backoff algorithm. In this paper, we propose a weighted proportionally fair bandwidth allocation algorithm for the data volume that is being offloaded through WiFi, in conjunction with a pricing-based rate allocation for the rest of the data volume needs of the UEs that are transmitted through the LTE uplink. We aim to improve the energy efficiency of the UEs and to increase the offloaded data volume under the concurrent use of access technologies that IFOM allows. In the weighted proportionally fair WiFi bandwidth allocation, we consider both the different upload data needs of the UEs, along with their LTE spectrum efficiency and propose an access mechanism that improves the use of WiFi access in uplink offloading. In the LTE part, we propose a two-stage pricing-based rate allocation under both linear and exponential pricing approaches, aiming to satisfy all offloading UEs regarding their LTE uplink access. We theoretically analyse the proposed algorithms and evaluate their performance through simulations. We compare their performance with the 802.11 DCF access scheme and with a state-of-the-art access algorithm under different number of offloading UEs and for both linear and exponential pricing-based rate allocation for the LTE uplink. Through the evaluation of energy efficiency, offloading capabilities and throughput performance, we provide an improved uplink access scheme for UEs that operate with IFOM for uplink offloading.

1. Introduction

The continuous increase of cellular data demand that is already witnessed, is the main driving force for cellular network operators towards the capital investments on upgrades of their cellular network infrastructures into 4G systems, as LTE. With the upgrade of their networks, cellular providers aim to be able to serve the requested traffic by their customers. Despite the upgrade of the cellular infrastructures, the pace of the increase of the data traffic demand [1] puts pressure on the cellular network providers, as traffic congestion is not avoided. These facts have led the research community to propose offloading techniques that will leverage the mitigation of the overload of the cellular network spectrum and the network's traffic congestion.

According to the work of Paul et al. [2] on the dynamics of cellular data networks, downloads dominate uploads with more than 75% of the traffic coming from download traffic. On the other hand, smartphone applications slowly change the users attitude, transforming them into content creators. Facebook, Twitter, Youtube and Instagram are some of the main applications that let users upload their content (videos, photos, audio, text and combinations of them) at the time of creation. This change of use habits is highly demanding in terms of energy consumption, as in LTE, uploading is nearly eight times more energy consuming compared to downloading according to the extensive measurements of [3]. In the same work it is experimentally measured that LTE consumes two times the energy of WiFi for uploading small files of size equal to 10 kB and 2.53 times the energy of WiFi for larger files of size equal to

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10 MB. Considering the solution of offloading the uplink traffic of users that are in the range of WiFi Access Points (APs), the battery life of mobile users will be extended and at the same time the uplink load of an eNodeB will be mitigated. According to Cisco's mobile data traffic forecast [1], mobile offload is going to increase from 45% (1.2 exabytes/month) that was in 2013 to 52% (17.3 exabytes/month) by 2018. As operators will not likely be able to keep pace with the current pace of mobile data demand, they respond by rolling out WiFi APs to public areas to offload data traffic. WiFi is an appropriate solution, as WiFi APs are easier to deploy and they cost less than upgrading existing cellular infrastructure gear.

With the release-10 of 3GPP, a UE in LTE networks is able to concurrently maintain connections with the cellular network and a WiFi AP, in order to offload part of its traffic through WiFi access and upload the rest through LTE. The scheme that allows this connectivity is named IP Flow Mobility (IFOM) [4]. The other two offloading techniques are Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO). LIPA is a method by which a UE, connected to a home eNodeB, is able to transfer data to a local network connected to the same home eNodeB, without the data traversing through the macro cellular network. SIPTO is a method by which a UE can divert its traffic through a femtocell or a small-cell, but without keeping a concurrent connection with the macro cellular network. More standardisation activities include the Access Network Discovery and Selection Functions (ANDSF) [5] and the Packet Data Convergence Protocol (PCDP) aggregation for LTE and WiFi integration [6]. The ANDSF is not limited to 3GPP technologies, as it can also be used in non-3GPP access networks. It was introduced as an optional component in the 3GPP standard to exchange discovery information and policies with the User Equipment (UE) according to the operator's requirements and to improve the handover behaviour. Qualcomm proposed PCDP aggregation aiming to further integrate WiFi APs with cellular infrastructure. With this technology, operators will manage access to their WiFi APs via LTE. It focuses on the control plane for interworking between Wi-Fi and LTE, which will allow more dynamic and reliable control of Wi-Fi offloading. ANDSF and PCDP aggregation give to the operator the control of the offloading process. At the same time, IP Flow Mobility is being standardized in 3GPP [7]. The key difference of this technology is that it allows an operator or a UE to shift an IP flow to a different radio access technology, without disrupting any ongoing communication. We focus on IFOM, as we want to take advantage of this feature given also to UEs. Consider a UE connected to a cellular base station having multiple simultaneous flows. For example, it maintains a voice call and a file upload, and it is moving into the range of a WiFi AP. The UE may shift the file upload on the WiFi network and when it moves out of the AP coverage it will make a seamless shift of the flow back to the cellular network. Another example is the division of a UE's data flow into two sub-flows and the service of each sub-flow by different radio access technologies, as proposed in [8]. In [9], the authors introduce the first peer-assisted method for offloading traffic from the uplink, and the selection of the most cost-efficient alternative access technology for data transmission.

A question that arises from the IFOM uplink offloading scheme is how the UEs will offload part of their data through WiFi with fairness, where their different upload data needs and their LTE connection with the eNodeB will be considered, and how the rest of the data will be uploaded through LTE. Although the access method in 802.11 DCF (Distributed Coordinated Function) uses the CSMA/CA protocol to share radio resources in a fair way, it treats all users equally. This access scheme creates unfairness considering the different data needs of each UE and the different channel conditions of their connection with the eNodeB. In cases where different queue lengths are considered [10] or in multi-rate conditions [11], fair resource allocation is achieved by weighted proportional fairness. While the downlink of a WiFi AP can be adaptive, based on priority queuing of data, e.g. by applying the 802.11e standard [12], the uplink does not present the same flexibility. In uplink, all transmitting users are treated equally, following the binary exponential backoff algorithm of 802.11 DCF. Based on this fact we focus on providing an effective access scheme for uplink offloading through WiFi that will treat all UEs on a weighted proportionally fair way, which includes the UEs uplink data needs in conjunction with their LTE channel conditions. The main objective of this approach is to achieve energy efficiency and throughput improvement in the uplink offloading with IFOM.

The main challenge of our work is to provide an efficient uplink offloading algorithm that takes into consideration the different uplink data volume needs of UEs that are associated with the same WiFi AP and eNodeB, and present different channel conditions regarding their LTE uplink. The main questions that are tackled throughout this paper are the following: (i) How the different data needs of UEs under the coverage of the same eNodeB and WiFi AP should be divided into two sub-flows per UE that will be concurrently routed through the available access technologies? (ii) How can we improve the WiFi uplink access to maximize the uplink offloading of the data volume needs of the UEs? and (iii) How can we provide an efficient resource allocation for the LTE uplink of the data volume needs of the UEs that are not offloaded through WiFi? In this paper we discuss on the limitations of IEEE 802.11 DCF uplink access and we propose an offloading algorithm for IFOM that combines weighted proportional fairness in the WiFi access and price-based resource allocation in the LTE upload. UEs that have larger upload data needs or experience worse LTE connection are favoured in the WiFi offloading part. This is achieved by choosing appropriate weights for the proportional fairness. The LTE uplink rate allocation we propose is a two-stage pricing algorithm. In the first stage, the LTE operator decides the price p per unit of a UE's LTE uplink rate. In the second stage, the UEs decide the rate for which they intend to pay, based on the price and the spectrum efficiency that they experience. Data pricing has been recently adopted as a promising economics tool that provides effective solutions for resource allocation aiming to mitigate network congestion [13]. We follow two different pricing schemes. A linear pricing scheme, that was used in [14] and [15] and an exponential pricing scheme, that was used in [16]. The main contributions of this work are the following:

- To the best of our knowledge this is the first work that considers uplink offloading methods for WiFi and LTE networks that operate under the IFOM offloading technique.
- We propose a weighted Proportionally Fair Bandwidth (PFB) allocation algorithm for the WiFi, aiming to improve the uplink offloading. We include in the fairness criteria the different data needs of the UEs and their LTE uplink spectrum efficiency.
- For the rest of each UE's data we propose a price-based rate allocation for the LTE uplink, and we follow a linear and an exponential pricing scheme. Our major focus is to investigate the effect of different pricing schemes on the energy efficiency and throughput performance of UEs under IFOM uplink offloading.

We compare the PFB algorithm with 802.11 DCF and with a state of the art uplink access scheme in terms of UEs' energy efficiency for both linear and exponential pricing of the LTE rate allocation. We investigate the conditions under which exponential pricing performs better than linear pricing and we reveal the effect of the UEs' data needs and spectrum efficiency on their energy efficiency and throughput performance. In addition, we evaluate the offloading capabilities of PFB and we show that a greater data volume is offloaded using our proposed algorithm.