A Survey of Available Features for Mobile Traffic Offload

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Abstract—In order to help operators control the ever-increasing mobile data volumes over their cellular networks, many offloading approaches have been proposed in the literature. In this paper, we present the two main solutions used to alleviate traffic load on the Radio Access Network (RAN), namely femtocells and wifi networks. We show that when using wifi as an offloading solution, three degrees of integration can be distinguished. In this case, one operator concern is to provide session continuity to mobile users during vertical handover. Hence, several solutions are proposed to overcome this issue.

I. INTRODUCTION

With the deployment of new cellular access technologies, such as High Speed Packet Access (HSPA) and Long Term Evolution (LTE), mobile users can now enjoy high bit rates comparable to those offered by fixed access. These levels of performance allow users to access services such as downloading/uploading contents of several megabits, streaming video, TV, Voice over IP (VOIP), etc. This encourages people to use smartphones to access the internet. Hence, the amount of traffic generated by mobile users is increasing significantly. According to Ericsson [1], mobile data traffic will grow 10 times between 2013 and 2019. The same report forecasts that by the end of 2019, a laptop will generate 13GB per month, a smartphone 2GB and a tablet about 4.5GB. Unfortunately, cellular networks were not designed to handle such a traffic load and they may quickly be saturated, which can significantly reduce the Quality of Experience (QoE) of mobile users. In a cellular network, congestion is likely to occur at two points: the Radio Access Network (RAN) and the aggregation/core network. However, this paper deals only with RAN offloading techniques.

Femtocells and wifi networks are considered to be the two main solutions to offload the RAN. According to [2], more than 50% of the global mobile traffic will be offloaded to femtocells or wifi, which corresponds to 17 exabytes each month. While femtocells are seen as regular base stations to the cellular core network, wifi uses a different technology, and its integration with cellular network can be performed at different degrees, known as loose coupling, tight coupling and very tight coupling. One major operator concern when using different access technologies is to guarantee continuous service to mobile users in the case of vertical handover. Indeed, most of the current applications use TCP which identifies a connection with the interface IP address. Hence, every change in the IP address involves a loss of the connection. Depending on the architecture used for coupling wifi and cellular, the mobile IP address is automatically preserved or solutions have to be used to provide session continuity even if the IP changes.

The reminder of this paper is organized as follows. Section II presents the possible radio access network offloading techniques. Section III deals with the different architectures of coupling wifi and cellular networks. Section IV finally concludes the paper.

II. RADIO ACCESS NETWORK OFFLOADING

To alleviate the traffic load on cellular networks, operators can use two kinds of solutions: offloading to femtocells (home base stations) or to wifi networks [3]. In both cases, macrocells are still used to provide continuous coverage. Indeed, even though femtocells/wifi networks can handle large amounts of traffic, their coverage is not large enough to ensure continuous connectivity.

Another kind of solution proposes using a Delay Tolerant Network (DTN) approach leveraging the fact that some applications are delay-tolerant. In [4], the authors proposed Wiffler, a system used to augment 3G capacity. Its main principle is to wait until Wifi becomes available to transmit the data. Madnet [5] on the other hand does not wait until Wifi is available, but rather uses opportunistic peer-to-peer mobile network by selecting $k$ mobiles that aids the propagation of the content using short-range wireless connectivity (Bluetooth, Wifi, etc). However, all these solutions require the framework to be installed in the mobile terminal.

A. Offloading through femtocells

Femtocells were first introduced to enhance indoor voice and data services in cellular networks [3]. They are typically consumer base stations working on the same spectrum as macrocells and transmitting at low power limiting their coverage to a few meters. To the mobile user, femtocells are seen as regular base stations and handover is seamlessly provided. Unlike standard base stations, femtocells are connected to the cellular core network through a public network using a broadband connection, such as a digital subscriber line (DSL) or a separate radio frequency channel.

The main operator benefit in deploying femtocells is the very low cost compared to macrocells. Indeed, considering deployment and additional electricity costs, OPEX is reduced from $60,000 per year per macrocell to only $200 per year per femtocell [6].

However, the fact that femtocells transmit on the same frequency bands as macrocells can cause interference. Studies have been conducted to solve this issue (see for example [7]).

B. Offloading through Wifi networks

The main difference between cellular networks and Wifi is that the latter operates on an unlicensed frequency band.
Another point is that Wi-Fi uses a large bandwidth up to 40MHz, allowing high throughputs. This is why cellular operators see an opportunity to offload a part of their traffic through it. Unlike femtocell-based solutions, the operator does not have to deploy all the Wi-Fi access points and can take advantage of public Wi-Fi networks already deployed by customers.

Regarding the architecture, there are three different degrees of integration of Wi-Fi and cellular networks, defined in the literature as loose coupling, tight coupling [8] and a last one proposed recently called very tight coupling [9].

In this section, we present the three coupling possibilities between Wi-Fi and cellular networks and show that in the case of loose coupling, session continuity issues can occur during vertical handover. Several solutions have been proposed to overcome this issue, as presented in the following.

A. Loose Coupling

In the case of a loosely coupled architecture, the two wireless technologies are completely separated and the Wi-Fi traffic is never transmitted in the cellular core network. The fact that the two networks are independent means that there are two IP networks with different prefixes. Thus the mobile user obtains one IP address for each interface, engendering mobility issues such as IP preservation and session continuity when experimenting different access networks. Several solutions aiming to solve these issues have been proposed. In the following we present each one of them and highlight their advantages and drawbacks.

**MIP-based solutions:** Mobile IPv6 (MIPv6) [10] is an IPv6 extension for mobility support allowing a host to keep its IP address even if its link-layer point of attachment to the internet changes. To do so, MIP introduces a new architecture entity called Home Agent (HA). The home agent is a router on the mobile node’s home network that can be co-located within its residential gateway. Its role is to redirect the traffic to the mobile node when it is away from home and to keep up-to-date its current location. The mobile gets from the HA a permanent IP address called Home Address (HoA), and a temporary address called Care-of-address (CoA) from the visited network. An IP bidirectional tunnel is then used to transfer the traffic from and to the mobile node [11]. Another extension called Dual Stack MIPv6 (DSMIPv6) [12] was proposed to support both IPv4 and IPv6. Fig. 2-(d) shows the location of MIP in the IP stack.

IP flow mobility (IFOM) is an offload solution standardized by the 3GPP in release 10 [13]. It is based on DSMIPv6 and used to selectively offload data flows for a given PDN connection [14].

The main drawback of MIP-based solutions is the introduction of a new entity (HoA), making its deployment expensive to the operator. Also, some studies have proven that better performance can be obtained when mobility is performed at transport layer instead of network layer [15].

**SHIM6 based solutions:** SHIM6 was proposed as a shim layer in the IPv6 stack between layers 2 and 3 (see Fig. 2-(c)). To allow multihoming, SHIM6 separates the identification function and the location function of an IP address. It provides upper-layer protocols with fixed IPv6 addresses (ULID: Upper-Layer ID) to identify the different TCP connections, while the real addresses are locators [16]. If these change in the case of an outage or a handover, the ULIDs remain the same and SHIM6 ensures the association between them.

Due to its backward compatibility with current applications and with the network, SHIM6 can be seen as a good choice for vertical handover in HetNet. However, to our knowledge it has not been implemented.

**mSCTP-based solutions:** Stream Control Transmission Protocol (SCTP) [17] was introduced as a new transport protocol (Fig. 2-(b)) to allow multistreaming and multihoming without adding any new special agents[18]. It gives the possibility to an endpoint that is connected through multiple interfaces to announce multiple addresses when connecting to a distant host [19]. However, SCTP does not allow adding or deleting addresses when an association is active. This makes vertical handovers impossible. Mobile SCTP (mSCTP) [20] solves this problem by using the DAR (Dynamic Address Resolution) extension allowing mobility support.

SCTP has been widely studied for vertical handovers between 3GPP networks and Wi-Fi [19][21]. However, the fact that it comes as a substitute to TCP forces current applications to be changed to use SCTP socket. Also, most of the current middleboxes like firewalls or Network Address Translation (NAT) don’t understand SCTP traffic and block it.

**MPTCP-based solution:** Unlike SCTP, Multi-path Transport Control Protocol (MPTCP) [22] comes as an extension to TCP (Fig. 2-(a)) ensuring backward compatibility with current applications. In practice, an MPTCP connection consists of one or more TCP connections called subflows. Each subflow appears to the network as a regular TCP flow, while the application layer sees only one TCP connection, called the master subflow, which can be accessed by conventional TCP sockets. MPTCP aggregates the data coming from each path and transfers it to the application layer, using different mechanisms of sequencing and congestion control. MPTCP also provides different options to add or remove TCP subflows dynamically, allowing mobility from an interface to another.

One drawback of MPTCP is the use of new TCP options for signalisation. Thus, some middleboxes (firewalls, NATs, etc) that don’t understand MPTCP can block the MPTCP traffic. If this happens, the MPTCP connection...
will turn to a regular TCP connection. Using MPTCP as an offloading solution has already been studied in [23] [24].

![Diagram of IP stack with MPTCP and SCTP](image)

**Fig. 2.** Location of each solution in the IP stack

Table I summarizes the differences between each loose coupling solution.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Backward compatible with upper layer</th>
<th>Backward compatible with the network</th>
<th>Need for new entity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SHIMs</td>
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<td>SCTP</td>
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<tr>
<td>MPTCP</td>
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</tbody>
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**Table I. Summary of loose coupling solutions**

### B. Tight Coupling

The objective of a tightly coupled architecture is to make the wifi network appear as a regular access network to the cellular core network. The wifi access point is directly connected to the core network and the integration is done at layer 2 of the IP stack. Hence, even if the mobile user is connected through its two interfaces (wifi and mobile), there is only one IP connection and the mobile has only one IP address. Thus, session continuity is automatically provided when the mobile switches from one access network to another.

The 3GPP introduced the notion of trusted and untrusted non-3GPP access. A trusted non-3GPP access can be directly connected to the core network while interconnecting an untrusted non-3GPP access needs an intermediate equipment called evolved packet data gateway (ePDG) to provide security features. However, it is up to the operator to define a specific non-3GPP access as trusted or untrusted.

### C. Very Tight Coupling

Very tight coupling between 3GPP (LTE: Long Term Evolution) and wifi is a new concept proposed in [9]. Its basic idea is to connect wifi access points to the eNodeB that covers them. The difference with a tightly coupled architecture is that in very tight coupling the integration is done at a lower layer, namely at the Packet Data Convergence Protocol (PDCP). Thus, the IP layer remains the same in case of vertical handover between wifi and LTE. Hence, the mobile terminal obtains only one IP address for its two interfaces and session continuity is provided in case of vertical handover.

The objective of using PDCP as a common layer between wifi and LTE, is to reuse LTE security procedures for wifi transmissions. Thus it is possible for a mobile that is covered by a wifi access point for a short period to transmit its data through its wifi interface.

### IV. CONCLUSION

Mobile traffic offload is nowadays one of the most important objectives of mobile operators, especially since forecasts have shown excellent results for future mobile networks using offloading. In this paper, we presented the different possible offloading solutions used for Radio Access Networks (RAN), namely offloading the traffic to femtocells or to wifi networks. We then showed that there are three different degrees of coupling between wifi and cellular networks, known as loose coupling, tight coupling and very tight coupling. We explained the three architectures and highlighted the fact that session continuity in the case of a vertical handover between cellular/wifi is a major concern. We detailed the solutions given in the literature to solve this issue, and enumerated the advantages and drawbacks of each one of them.

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