Vision: Augmenting WiFi Offloading with An Open-source Collaborative Platform

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ABSTRACT

Offloading mobile traffic to WiFi networks (WiFi Offloading) is a cost-effective technique to alleviate the pressure on mobile networks for meeting the surge of data capacity demand. However, most existing proposals from standards developing organizations (SDOs) and research communities are facing a deployment dilemma, either due to overlooking device limitations, lack user incentives, or missing operator supports.

In this position paper, we present an open-source platform for WiFi offloading to tackle the deployment challenge. Our solution leverages the programmable feature of software-defined networking (SDN) to enhance extensibility and deployability in a collaborative manner. Inspired by our field measurements covering 4G/LTE and 802.11ac/n, we exploit context awareness as a use case to demonstrate the efficacy of our solution. We also discuss the potential usage by cloud service providers given the opportunities behind the growing popularity of mobile virtual network operators (MVNO). We have released our platform under open-source licenses to encourage future collaboration and development with SDOs and research communities.

1. INTRODUCTION

Cellular networks are experiencing a data explosion posed by the increasing bandwidth demands from various mobile applications and cloud services. Although mobile network operators (MNOs) are promoting new wireless technologies such as 4G/LTE to upgrade their networks, the growth of capacity provision is still behind the notable demands [1]. Therefore, MNOs are resorting to leverage auxiliary networks (e.g., WiFi networks) and offload mobile traffic for additional capacity. In recent years, WiFi offloading is rapidly emerging as the preferred technique to meet the needs. However, WiFi offloading without a balanced control may result in poor network utilization and undesirable user experience [2, 3]. Furthermore, despite the lengthy process required for standardization [4], proposals from SDOs and research communities typically address different segments of WiFi offloading such as offloading efficiency [5, 6, 7, 8], energy efficiency [3, 9], user incentives [10] and operator supports [11, 12]. Those solutions are often isolated from each other, built from scratch for incumbent legacy hardware, or overlooking practical limitations of mobile devices and operational environments. Such issues make the solution deployment a formidable task in today's fast evolving mobile networks.

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Since the surge of mobile traffic necessitates an agile, cost-effective and deployable approach, we propose SoftOffload, an open-source WiFi offloading platform that aims to enhance deployability and collaboration among MNOs, WiFi providers and mobile users. The highlights of SoftOffload include:

Collaborative and Efficient Management – Based on a collaborative and hierarchical design, SoftOffload splits offloading functionality between its central controller and local agents, and thereby strikes a balance between global control and responsiveness at the network edge.

Openness and Extensibility – SoftOffload builds on open standard protocols (e.g., OpenFlow) and benefits from the programmability of SDN. It follows a light-weight overlay design without adding extra modifications or requirements to existing standards. The source codes of SoftOffload have been released and can be found via:

`https://github.com/TKTL-SDN/SoftOffload`

In this position paper, we make the following contributions. First, we present our measurement study exploring hidden issues in WiFi offloading, which drives the design of SoftOffload. Second, we exploit context awareness to enhance the gain of WiFi offloading as a use case for SoftOffload. Third, we release our solution on GitHub to share our experience and encourage future collaboration. Among others, we highlight the opportunities for cloud service providers to utilize SoftOffload through the mobile virtual network operators (MVNO) channel and alliance with WiFi service providers.

Note that, our goal is to augment WiFi offloading with a programmable and collaborative approach. We do not expect our solution to replace existing mechanisms from SDOs (e.g., 3GPP, IETF) or research communities. Instead, we provide an open and extensible platform to integrate existing techniques and promote development of novel network applications to meet the requirements of the fast evolving mobile networks.

2. PLATFORM DESIGN

2.1 Leverage Context Awareness

A key challenge in WiFi offloading is that valuable contextual information is often distributed across network entities and end users. This uneven distribution indicates that the contextual information possessed by each side along is insufficient to guide the offloading process.

On the network side, the traffic load and condition of managed entities (e.g., router, APs) can be acquired to assist traffic offloading. For example, operators can decide to trigger traffic offloading when a cellular base station is overloaded by several active users. However, it is difficult, if not impossible, for operators to capture the instant local context perceived by those mobile users (e.g., signal strength of nearby WiFi APs).

On the other hand, mobile users can acquire local context by using WiFi scanning and embedded sensors on their devices, but they are hardly aware of the condition on the network side (e.g., congestions on the aggregated router) before connecting to the access network. A typical example is that, even if a WiFi AP is relatively close to the user, showing good signal strength, this AP can be heavily loaded by streaming flows generated by other devices. If the user chooses to offload traffic using this congested AP (with good signal strength though), the outcome can be suboptimal.

Performance and Energy Consumption

To understand the impact of contextual information in WiFi offloading, we first investigate transmission performance and energy consumption on modern smartphones. Figure 1 shows the devices used in our measurements, including Nexus S, Galaxy S2, S3, S4, S5, and Galaxy Tab 2. For using Monsoon Power Monitor[1] to conduct power measurement, we carefully select smartphone models that are battery-removable. We report results of Galaxy S5 (supporting both LTE and 802.11ac) in Table 1. Our results show that commercial LTE networks already perform well when comparing with 802.11n[2]. Meanwhile, we consider 802.11ac a promising candidate in WiFi offloading for its hefty improvement on performance.

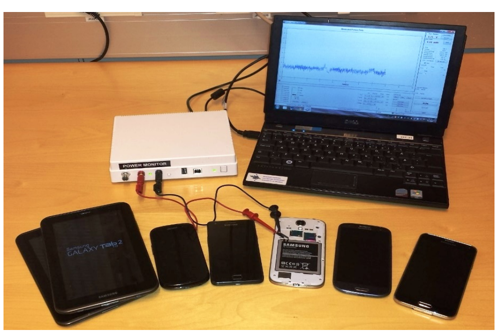


Figure 1: Mobile devices used in measurement study

Impact of Signal Strength

Through our measurements, we observe a nonlinear correlation between signal strength and energy consumption in WiFi. We report the results of S5 (average value of 5 repetitions) in Figure 2, showing the energy consumption for downloading a 30 MB file over 802.11ac.

[1]http://www.msoon.com/LabEquipment/PowerMonitor/

[2]WiFi results are obtained in a controlled environment to show the wireless link speed under -42 dBm.

Table 1: Throughput (Mbps) and consumption (Joule/MB)

	Galaxy S5	
	Throughput	Energy consump.
LTE	**42.131** ± 0.786	0.254 ± 0.013
HSPA+	12.888 ± 2.256	0.814 ± 0.106
802.11ac	**245.33** ± 16.72	0.104 ± 0.009
802.11n	39.3 ± 1.48	0.372 ± 0.007

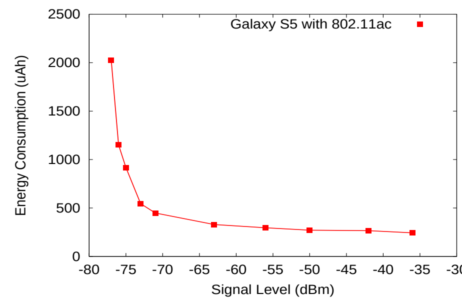


Figure 2: Impact of signal level on energy consumption.

By capturing this phenomenon on 802.11ac, we further conduct extensive measurements on multiple smartphones covering their energy consumptions and communication performance under different signal levels in 802.11n [3]. We summarize our measurement results in Figure 3a and Figure 3b.

The key observation is that when signal level is above -65 dBm, indicated by received signal strength indicator (RSSI), the impact of signal strength on throughput is relatively negligible. However, once RSSI values approach and go below -73 dBm, we experience a a steep drop of performance and a substantial increase of energy consumption.

2.2 Context-aware Decision Algorithm

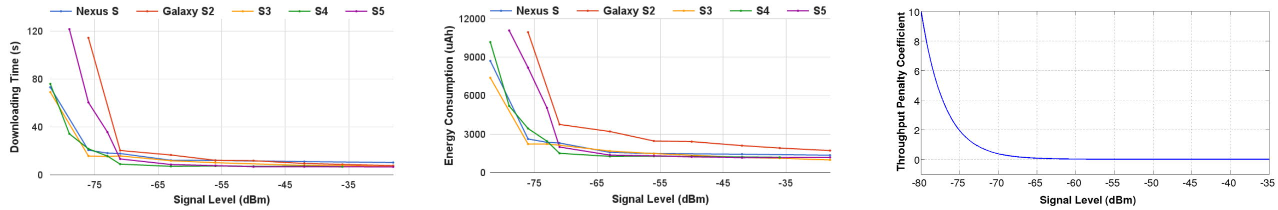
Inspired by our measurements, we propose a context-aware decision algorithm for achieving a balanced offloading decision. The core of our offloading algorithm, which produces an offloading metric value to guide SoftOffload for selecting optimal offloading targets, is shown below:

$$\mu \cdot (1 - P) \cdot \frac{estimatedBw}{\arg\max estimatedBw} \cdot \frac{restBw}{totalBw} - c \cdot \mathbb{1}A \quad (1)$$

The throughput penalty $P = e^{-k_0(S-k_1)}$ is an exponential coefficient to reflect the impact of signal strength. The $\frac{estimatedBw}{\arg\max estimatedBw} \cdot \frac{restBw}{totalBw}$ measures bandwidth capacity and utilization. We use μ to evaluate mobility effects on potential throughput, and $\mathbb{1}A$ as an indicator function for offloading overhead. c is a weight factor that provides flexibility to adjust offloading metric by taking into account network policy, user preference and device limitation.

According to our measurements shown in Figure 3a and 3b, we observe a steep drop of performance together with high energy consumption when the signal level is decreasing down to -73 dBm. Because the energy consumption is proportional to the transmission performance, we utilize this feature to reflect the impact of signal strength and integrate context awareness into our solution. We derive a

[3]We use ASUS RT-AC68U router in 802.11ac testing and NETGEAR WNA1100 USB adapter for 802.11n.



(a) Downloading Time (b) Energy Consumption (c) Offloading Penalty

Figure 3: Impact of signal level and penalty coefficient $P = e^{-\frac{1}{3}(S-(-73))}$

penalty factor $e^{-k_0(S-k_1)}$ based on the observation and assign $k_0 = \frac{1}{3}$, and $k_1 = -73$. As shown in Figure 3c, this penalty coefficient P on signal level S matches coherently to the performance and energy consumption in Figure 3a and Figure 3b, respectively. An empirical value 0.2 is used for c.

2.3 Architecture and Key Components

We propose SoftOffload to enable collaboration in wireless networks where one or several WiFi APs are deployed within the coverage of mobile network cells. Through a unified and collaborative management, our platform can guide mobile devices to offload traffic from cellular access to WiFi access, and also across neighboring WiFi APs. Inspired by the work of Odin [14], we develop our solution following the software-defined networking (SDN) paradigm. Figure 4 illustrates the overall architecture of our platform, which consists of three major components: a central controller, local agents deployed on access points, and an extension module for mobile devices. We use OpenFlow-enabled switches for monitoring and managing traffic flows.

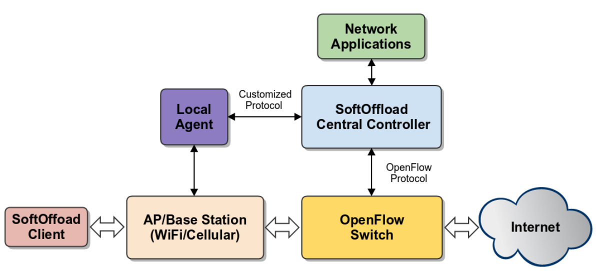


Figure 4: System Architecture

In SoftOffload, the central controller manages the entire network. It is responsible for tracking all the clients and agents in the managed network, collecting traffic information from network devices, and further making offloading decisions based on inputs from various sources. In addition to obtain flow information from switches, our local agents monitor the association status of mobile devices and serve as an information channel between mobile devices and central controller. The SoftOffload extension deployed on mobile devices collects context information from the devices and access environment, including user movement and signal strength of neighboring WiFi APs. Central controller collects such information to perform optimal offloading management.

As a use case of SoftOffload, Figure 5 presents the operation procedure of context-aware offloading. The key steps include load detection, client choosing, and offloading target evaluation. We integrate the context-aware decision algorithm in the evaluation step, during which SoftOffload will use the contextual information (i.e., available bandwidth and signal strength of nearby APs) collected from both network side and end user to select the best candidate AP to offload traffic.

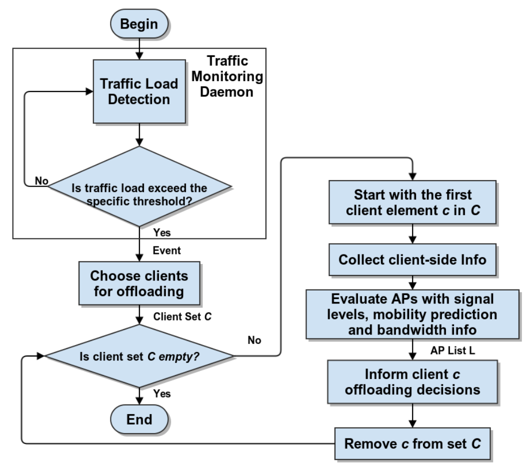


Figure 5: Conext-aware offloading overview.

3. IMPLEMENTATION AND EXPERIMENT

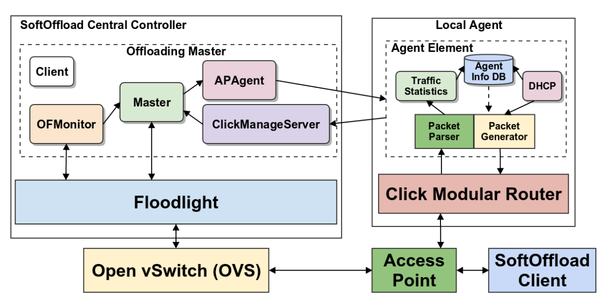


Figure 6: System Implementation

We have developed a prototype system based on the SoftOffload design. Figure 6 illustrates the key components and schematics in our platform. The central controller is implemented on the Floodlight OpenFlow controller [13]. The local agent is developed based on Click modular router [15] and deployed on each AP. It monitors the corresponding AP interface and reports association events to the central con-

Table 2: Offloading Metric Values For Different Test Cases

Signal Strength and Available Bandwidth	-34 dBm 16 Mbps	-66 dBm 16 Mbps	-31 dBm 8 Mbps	-65 dBm 8 Mbps	-75 dBm 16 Mbps	-78 dBm 16 Mbps
Throughput (Mbps)	15.12	15.04	7.84	7.52	3.68	**3.04**
Offloading Metric	1	0.903	0.5	0.465	-0.947	**-4.294**

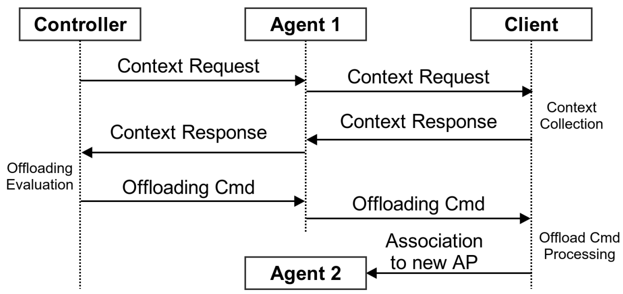


Figure 7: Operation Sequence

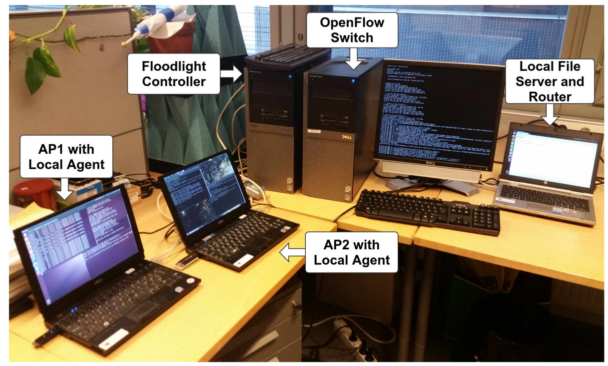


Figure 9: Experiment Testbed

troller. The client extension is implemented as an Android application, which listens on a specific port for controlling messages from the central controller and local agents, and responds to their requests. In addition, we run Open vSwitch which provides the OpenFlow supports for our experiment.

Figure 7 illustrates the operation sequence to conduct WiFi offloading in a typical scenario across two access points. To initialize traffic offloading, a central controller monitors its managed network by collecting network statistics from OpenFlow switches. If it detects unbalanced or congested traffic patterns in a specific access network (e.g., WiFi AP), the controller triggers the offloading and follows the steps shown in the figure.

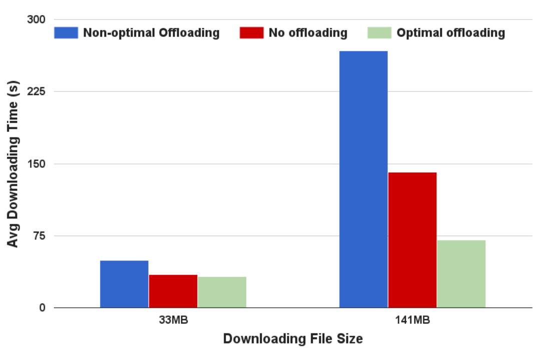


Figure 8: Static Offloading Experiment

Regarding the effectiveness of our solution, Figure 8 shows the experiment results for a series of static offloading cases in our testbed with a setup depicted in Figure 9. The "Non-optimal Offloading" bars represent the results when a mobile device is connected to a congested AP for offloading, which has only half of the bandwidth compared to the previously associated AP. The "Optimal Offloading" bars show the results by using our offloading solution, which can guide the devices to select an AP with better bandwidth (3x in our case). As revealed in Figure 8, when the download file size is large, there is a clear advantage to adopt our offloading guidance. Meanwhile, when the file size is relatively small, the improvement is less visible due to the overhead introduced by switching between APs.

To show how the context-aware offloading algorithm performs, Table 2 presents the "Offloading Metric" values matching against measurement results obtained in our testbed. The metric values are essential for central controller to make the offloading decision (i.e., selecting the optimal AP for WiFi offloading). The trend is clear in the table: when the signal strength and bandwidth decreases, our offloading algorithm yields metric values matching to the expected performance. For example, if an AP is of weak signal strength -78 dBm (e.g., far away from the end user), even if its available bandwidth is good (16 Mbps in this case), the overall performance is still poor. SoftOffload can capture this incident and reflect through our offloading metric value (-4.294 in this case). This indicates that the central controller will not select this AP as the offloading target, thereby avoiding potential poor performance and energy cost.

4. DISCUSSION

In this section, we discuss potential deployment of SoftOffload and latest SDN-based solutions for WiFi offloading.

Deployment Scenarios

To augment WiFi offloading, one visible trend is for MNOs to utilize third party WiFi services such as FON [4] to extend their carrier-class WiFi accesses. Regarding another fast growing trend favored by cloud service providers (e.g., Google and Amazon) who are interested in becoming mobile virtual network operators, a potential deployment scenario of SoftOffload is to support cloud service providers to expanded their business by offering collaborative cellular-WiFi connectivity services.

Figure 10 shows a visioned view of unified cellular-WiFi access empowered by SoftOffload for cloud service providers. Through the collaborative design, non-intrusive QoE measurements and contextual information from each user's device can be combined with the network-derived QoS in-

[4] https://corp.fon.com/en

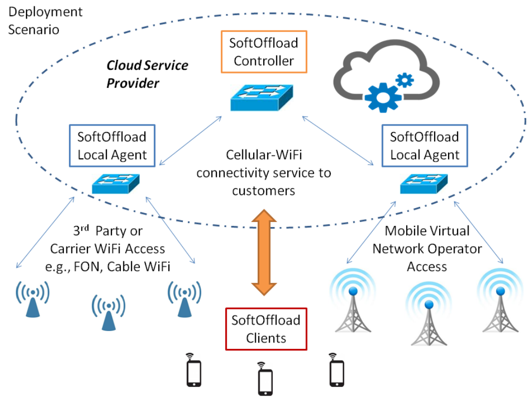


Figure 10: Deployment case for cloud service providers.

sights to guide the end user always connecting to the best-performing access network.

Through SoftOffload client extension (e.g., a dedicated application), end users can have the freedom to adjust the parameters and select the performance / cost profiles that best suit their individual needs. The local agents can function as a proxy at each access networks (e.g., WiFi or MVNO cellular access) to monitor and collect essential contextual information to support WiFi offloading. The central controller can be hosted by the cloud service provider to manage local agents deployed on the edge of cellular and WiFi accesses.

By using a flexible and extensible controlling framework to enable interworking of two types of access networks, cloud operators can adopt this approach to stand out in competition by offering a seamless cellular-WiFi interworking package for their customers. Note that, the collaborative principle of SoftOffload makes it feasible to be adopted by cloud service providers and also used in the carrier-class WiFi scenario.

SDN for WiFi Offloading

Since SDN delivers a granular control of network through its abstraction of the underlying hardware, it meets the urgent need from the mobile networks to simultaneously operate over multiple wireless technologies. A recent SDN-base proposal ATOM [16] provides an end-to-end traffic management solution that enables operators to manage traffic flows across heterogeneous LTE and WiFi networks. To enable cooperation of home WiFi APs, the COAP framework [17] offers an open APIs to pro-actively configure home APs for interference mitigation and perform traffic aware adaptations at APs.

Compared with existing proposal, SoftOffload is an open-source solution extending the collaboration principle to cover end user, WiFi providers and cellular operators, which opens up deployment opportunities for new players in this domain (i.e., cloud service providers). Because it is hard to predict what new requirements will impose on mobile networks given the fast advance of communication and application, an open and extensible approach has more prospects than a rigid design to meet the unforeseen needs.

5. SUMMARY AND FUTURE PLAN

In this position paper we present SoftOffload, an open-source collaborative platform to augment WiFi offloading. We advocate that openness and extensibility are indispensable features for smooth deployment by allowing new services to be added over time for requirements of the fast evolving mobile networks. In this regard, SoftOffload offers an open and extensible framework to encourage collaboration and potential deployment by mobile carriers and cloud service providers. We showcase how to harness context awareness through SoftOffload to improve performance and energy saving in WiFi offloading. As an attempt to enhance deployability, we have developed a system prototype and released our solution under open-source licenses on GitHub. Currently we are evaluating SoftOffload in field trials covering different offloading scenarios. We plan to enhance its north-bound APIs for developers to utilize SoftOffload and further extend its functionality.

Acknowledgement

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