Energy Awareness in Mobile Traffic Offloading

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1 Introduction

Mobile traffic offloading is a promising solution to relieve the pressure on cellular networks that are overloaded by data traffic from bandwidth-hungry mobile applications (e.g., HD mobile streaming). By offloading the data traffic away from the cellular access, cellular operators can avoid severe congestion that degrades the service quality for mobile users. The maturity of wireless technologies such as WiFi standards and hardware integration also supports this vision. However, by focusing mainly on the network perspective, i.e., traffic management, most of the existing solutions are lack of consideration for their energy impact [1–8, 10–13], especially for the resource constrained mobile devices. Since the battery life is crucial to the mobile user experience, energy awareness can play a key role to the successful adoption of offloading solutions [14–17]. This chapter illustrates the core issues in mobile traffic offloading from the energy perspective and discusses feasible approaches to improve the energy awareness in mobile traffic offloading.

2 Mobile Traffic Offloading

Cellular networks are suffering from the tremendous growth of mobile data traffic in recent years [7, 18]. The pressure has driven operators to search for solutions that can alleviate network congestion and fully utilize the existing network resources. As investigated in recent studies [1, 2, 4, 5, 12], mobile traffic offloading is regarded as a feasible approach to relieve this challenge by using complementary communication technologies such as WiFi and femtocells to deliver traffic originally targeted for cellular networks. In a typical mobile service scenario, the mobile traffic offloading consists of six main steps:

1. Offloading Initiation: The offloading procedure can be initiated by the network side (network-driven offloading), or the end user (user-driven offloading). Network-driven offloading is often triggered by dedicated signalling protocols such as router advertisement [20], enabling operators to dynamically manage and balance their traffic load. User-driven offloading is triggered by applications that need to access the Internet for content, which is based on the demand of the user.
   The network-driven offloading introduces overhead in terms of extra signalling and potential energy cost, but it can offer timely and optimized offloading guidance based on the comprehensive knowledge from the network

side, i.e., network structure and condition. On the other hand, user-driven offloading avoids the extra signalling cost but lacks of network context and less efficient for users at high moving speed, e.g., driving or cycling.

2. Context Collection: The context information is essential for mobile traffic offloading especially as input for the offloading decision. Users can obtain context information either from network operators or from the surrounding access environment. The key information includes the user location, network access condition (e.g., signal-to-noise ratio of WiFi access points, wireless fingerprint information [21]), potential offloading targets, connection detail (e.g., ESSID or MAC addresses).

   The collected context information will be feed to either remote/cloud controlling servers or local management components. For the remote option that utilizes the cloud support, a dedicated signalling channel is required, such as cellular data connection. Therefore the proposals relying on remote support are limited by the channel condition, especially when such channel is congested or the infrastructure suffers from instability due to technical issues. This also affects the scalability due to the dependence on a centralized entity. Comparing to the first option, the local solution does not depend on external entities. However, by relying solely on local resources, context information can be incomplete or less accurate comparing to the remote option.

3. Offloading Decision: The decision process involves computation according to the pre-defined algorithm or operation logic, and delivering control messages to mobile users to carry out offloading. By taking the context information as input, an offloading decision can be made either at the network side or using local resources on the mobile device.

   By offloading the computation to the network side, we can improve efficiency in terms of energy and latency for using the powerful hardware. However, this approach depends heavily on the infrastructure support. On the other hand, local decision can be more flexible and robust to network condition, but at the cost of local resources such as energy. The local operation also suffers from the limitation that there no available external knowledge to improve the accuracy of offloading decision.

4. Network Association: Based on the offloading decision, mobile devices need to perform network association to enable traffic offloading. The association process includes access/peer discovery via pre-defined configuration protocol such as DHCP and DNS to establish connectivity to the target offloading networks.

   For users at high moving speed, the connectivity period for offloading is often short. This demands an efficient association at both hardware and software level supported by optimized protocols to avoid excessively cost of association, which will decrease the time for data transmission.

5. Data Transmission: As the key part of mobile traffic offloading, data transmission determines how much data can be offloaded away from the congested cellular networks in order to improve the overall service quality. Depending on the types of data traffic (e.g., real-time streaming, delay-tolerant traf-

fic, web surfing), offloading design can utilize the traffic characteristic for optimization.
In the short period of offloading, which is typical for mobile users, the bandwidth and condition of networks can greatly affect the offloading efficiency, i.e., the amount of data offloaded against the data volume that would flow to the cellular network otherwise [2]. At the same time, offloading design should also take into account the hardware limitation on mobile devices such as wireless antenna.
6. Offloading Termination: A successful offloading session must end with terminating the temporary offloading connection and smoothly switching to other available networks to continue the data communications. It is important to keep the data flow uninterrupted and hence delivering satisfying service experience. The prior research work on handover mechanisms have illustrated how to seamlessly migrate from one access network to another [31–35].
To enable efficient and smooth termination, guidance can be obtained from either the network side or local heuristic prediction to spot potential connectivity [8, 9, 30]. The termination process is also one of the key factors affecting the adoption of mobile traffic offloading.

The fast development of wireless communication technologies is the key enabler for mobile traffic offloading. On the infrastructure level, mobile operators are upgrading to LTE and LTE-advaced (4G) to provide better access performance. WiFi and femtocells are gaining popularity in metropolitan areas to offer diverse and convenient wireless access, which can help alleviate congestion for the cellular infrastructure in the overlapping areas. On the device level, multiple network interfaces such as cellular, WiFi, and Bluetooth are integrated on modern devices. The evolving of standards such as Bluetooth 4.0 [53] and WiFi-direct [54] further enhances the traffic offloading in terms of connection diversity and energy efficiency. At the same time, the network performance, user mobility and traffic characteristics can largely determine the usage pattern of mobile services [15, 46–48, 50], and therefore are the essential components driving the design of mobile traffic offloading schemes.

3 Energy Concern in Mobile Traffic Offloading

The impact of mobile traffic offloading can be evaluated from two aspects, the network (operator) perspective and the user perspective [18], and the ultimate goal is to to benefit both. Many early proposals and related work [1–8, 10–13] have investigated the network perspective where the offloading efficiency is of higher priority, i.e., to offload as much traffic as possible to alleviate the pressure of cellular networks. As pointed out in recent studies [14, 15], we must also take the user perspective into serious account in order to guarantee consistent service experience for mobile users. A key factor in the user perspective is the battery life, which raises the energy concern in mobile traffic offloading.

We break down the problem domain and analyse the energy cost in each step of offloading. The major concern is highlighted as follows:

1. In the initiation phase, if offloading is trigged by the network side, there is energy cost associated with the signalling. The impact of maintaining such live controlling channel is discussed in recent work [23], that if the signalling message is delivered too frequently with large volume of data, such unintentionally recurrent interactions can trigger promotion of cellular network status and lead to excessive draining of the battery. On the other hand, the user-driven initiation can not benefit from the proactive guidance but it does not consume extra energy in this phase.
2. In the context collection phase, scanning the surroundings and GPS positioning can cause significant energy consumption. Early study shows that the WiFi scanning alone can reduce the battery life on smartphones (N900) from 300 hours down to less than 6 hours [17]. The interval of scanning and number of WiFi APs nearby also affect the energy consumption. Therefore, the existing mechanisms [1,3,4,8] that rely on constant scanning can be very harmful for the battery life on mobile devices. At the same time, GPS positioning can take around 20 seconds to obtain a usable position fix from the cold-start, with $\sim$6.30 Joules consumption [14]. If the context information is delivered to remote server, it can cause the change of cellular network status that entails extra tail energy cost [1].
3. In the decision making phase, if the computation is done locally, the complexity of algorithm will determine the energy consumption [1, 8]. By using cloud support to offload such computation, there is still an overhead in terms of data communication to exchange the context and decision messages.
4. In the association phase, the connection establishment that involves various hardware and protocol operations can consume non-negligible amount of energy. For instance, DHCP alone can consume 4.8 Joules [14]. There are also various energy cost in association at hardware level, such as WiFi beacon broadcasting. If the association occurs frequently when users move at the high speed, it can accelerate the battery drain on mobile devices.
5. In the data transmission phase, the bandwidth of offloading affects greatly the energy consumption as found in recent studies [14, 15]. By taking WiFi-based offloading as an example, as shown in Table 1, when WiFi throughput is lower than the cellular access, it can cost 2x more energy in the case of Nexus S to offload traffic through WiFi.
6. For the termination phase, the timing is critical to the energy cost in that if the offloading session terminates too late, the low bandwidth will lead to high energy consumption in data transmission. On the other hand, if offloading terminates too early, we may gain no energy saving and reduce the offloading efficiency.

To gain an insight of energy consumption in offloading, Table 2 illustrates the typical energy cost in WiFi-based offloading, measured by the Monsoon Power Monitor with 5 KHz sampling rate with 10 times repetition.

Due to the hardware limitation on existing mobile devices such as wireless antenna, early proposals that focus on maximizing the offloading efficiency can result in unexpected energy cost. In particular, recent studies [14, 15] show that

Table 1: Measured energy consumption of 20 MB data transfer.

	Nexus S		N900	
	Throughput	Energy	Throughput	Energy
Cellular	1.99 Mbps	**65.40** Joule	1.89 Mbps	**109.4** Joule
WiFi	0.302 Mbps	**191.7** Joule	0.422 Mbps	**116.0** Joule

Table 2: Average measured power (Watt) for cellular P_{Cell} and WiFi P_{WiFi}, and energy consumption (Joule) related to mobile traffic offloading: E_{W_on} and E_{W_off} for turning WiFi on and off, E_{asso} for network association, E_{scan} for WiFi scanning, E_{GPS} for GPS positioning.

Device	P_{Cell}	P_{WiFi}	E_{W_on}	E_{asso}	E_{W_off}	E_{scan}	E_{GPS}
Nexus S	0.891±0.022	0.658±0.16	0.27±0.019	0.25±0.049	0.29±0.016	0.27±0.017	10±1.3
N900	1.10±0.017	0.645±0.023	0.18±0.025	0.28±0.13	0.13±0.021	0.53±0.077	4.0±1.3

Table 3: Summary of the machines and antennas used in previous studies.

Citation	Machine	Antenna
[1]	Hacom OpenBrick computer	3 dBi gain omni-directional
[22]	Dell Latitude laptop	12 dBi gain omni-directional
[26]	Soekris net4511 computer	15 dBi gain directional

many existing mechanisms are based on experimenting with laptops that are connected to vehicle power supply. As shown in Figure 1, there is a clear gap between the netbooks and smartphone-alike devices in terms of network performance.

For wireless communications, it is well-known that the antenna plays an important role. For example, measurement study in US [22] reported that a 12 dBi antenna provides better connectivity than 5 and 7 dBi antennas. Eriksson et al. [24] also found that mounting an external antenna on the roof of a car can significantly increase the signal strength of received WiFi frames to gain better performance. However, due to the limited size of smartphones, it is very challenging to use external antennas. As shown in Table 3, recent studies have utilized laptops with external antennas. Figure 2 demonstrates such effect that the antenna deployed on smartphones provides shorter connectivity range to offload traffic comparing to that of netbooks [25]. Thus, mobile traffic offloading for smartphone-alike devices is much more challenging especially when moving at high speed.

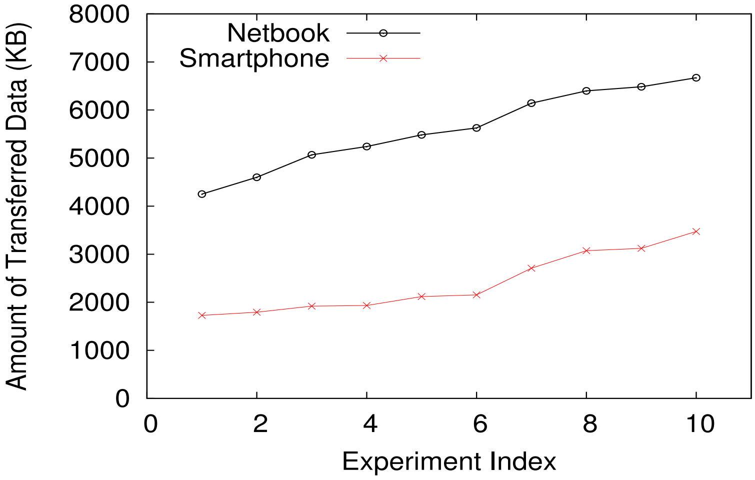

Fig. 1: Offloading performance at driving speed

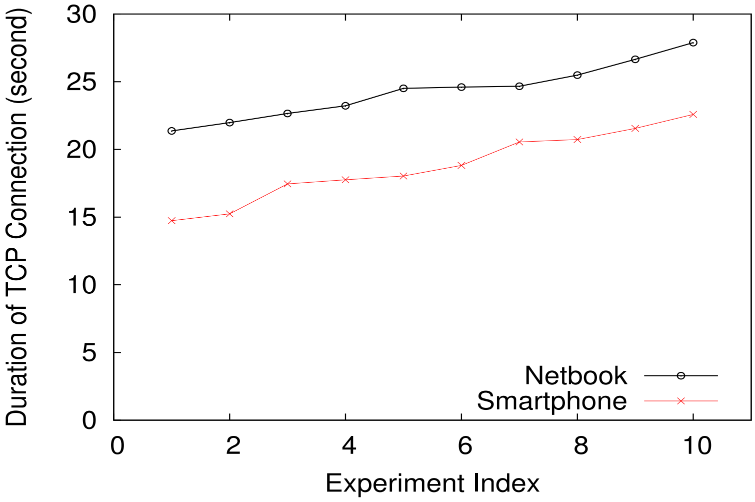

Fig. 2: Offloading duration at driving speed

Table 4: Approaches to enable energy awareness.

Phase	Recommended Approaches
Offloading Initiation	1) Avoid frequent signalling from network side that triggers cellular status change [23]; 2) Combine the user-driven and network-driven in a adaptive manner to improve efficiency [14, 17].
Context Collection	1) Avoid unnecessary scanning and frequent GPS operation; 2) Utilize energy efficient positioning mechanism such as WiFi fingerprinting [21]; 3) Adapt the context management for both local and remote processing to strike a balance [42].
Offloading Decision	1) Utilize energy-aware algorithm [14] to guide the decision; 2) Adopt dynamic mechanism (e.g., machine learning) to update the logic according to the network condition; 3) Utilize the cloud support to offload the energy cost from intensive computation.
Network Association	1) Avoid time-consuming association operation or protocol; 2) Utilize guidance from the network side if possible to assist authentication and access connectivity
Data Transmission	1) Adopt optimization schemes [1, 3–5, 14, 16, 19, 27] for different types of traffic (e.g., delay-tolerant, streaming); 2) Avoid transmission over unstable or low throughput wireless links by predicting the user mobility and network condition [3, 8, 14, 30, 37, 38, 41–45].
Offloading Termination	1) Utilize the hints if possible from either the networks or local controller for switching between connections; 2) Avoid frequent termination that can shorten the data transmission time.

4 Enabling Energy Awareness on Mobile Devices

Energy awareness can benefit mobile traffic offloading by extending the battery life and providing consistent service experience for mobile users. Because offloading process involves multiple entities, including the cellular operators, alternative wireless access providers, and mobile users, it is necessary to establish collaboration among all the entities [7, 14]. We highlight in Table 4 the viable approaches to enable energy awareness for mobile traffic offloading based on recent studies.

For offloading initiation, it is crucial to avoid frequent network signalling with large payload that can lead to extra energy consumption due to the change of cellular radio status [23]. In order to benefit from the network support and support dynamic traffic management, the adaptive scheme that combines the user-driven and network-driven initiation is recommended, which helps strike a balance between the efficiency and energy consumption [14, 17].

In the context collection phase, constant scanning must be avoided if possible for its high energy consumption [17] on mobile devices. Due to the relatively high energy consumption and the long latency to obtain a fix from the cold-start, the GPS usage in traffic offloading needs to be assisted by energy efficient design [39, 40]. To support energy efficient positioning, WiFi positioning can also be used as an alternative [21]. For context processing and management, it is recommended to share the load between local devices and remote servers, which fully utilizes the knowledge of access network and infrastructure and as well as the computing resources of both sides.

For offloading decision, energy saving must be a key factor in the decision process, e.g., by using dedicated energy-aware algorithm to guide the decision [14], together with other factors such as offloading capacity and network performance. Due to the fast change of network condition, the energy-aware offloading decision needs to be adaptive and adjust its operation logic supported by technique such as PowerTutor [52]. To save energy of computation, it is recommended to offload intensive computation load such as mobility predication [3, 8, 37] to the network side.

In the network association phase, it is recommended to use light-weight configuration protocols and avoid the ones that require complex message exchange, in order to shorten the time spent in association phase. To assist authentication, network support can be utilized to deliver configuration information [30, 32].

For data transmission, the first recommendation is to adopt optimization technique tailored for characteristics of different types of traffic and thus maximizing the transmission throughput during the offloading period. For instance, data batching and energy efficient scheduling can help avoid the tail energy consumption for various delay tolerant traffic [1, 51]. The prefetching, caching, and content replication technique have been applied to improve the performance for streaming and web applications [3–5, 14, 16, 19, 27, 42, 49]. The second recommendation is to avoid using unstable or low throughput wireless links by estimating the network condition and user mobility [3, 8, 14, 30, 37, 38, 41–45].

Since the offloading termination affects the data transmission and service quality, we can achieve energy saving by utilizing proactive approaches to plan the termination and apply efficient handover schemes to ensure the service continuity [1, 30–35]. To avoid the frequent unnecessary terminations that degrade the transmission performance, it is recommended to utilize the knowledge from the network side (e.g., network setup and position of APs) combining with the mobility prediction technique [3,37,41,43,44]. We can further improve the energy aspect by managing the network interfaces to avoid the unnecessary simultaneous operation [36].

One critical component to highlight for energy awareness in mobile traffic offloading is the decision process that provides guidance to mobile users to offload to the most energy efficient access. This is essential for the mobile devices with less powerful antennas since it may consume more energy on a low throughput wireless link (e.g., WiFi network) than transferring over a high speed cellular access, as illustrated in Table 1. The recent work [14] proposed an energy-aware algorithm to assist the offloading decision through a collaborative design. Through experiment in real networks, one key observation is that when the cellular throughput increases, the gain of energy consumption by offloading mobile traffic to other networks decreases due to the shorter cellular transmission duration at higher throughput, as shown in Table 5 and 6. The test showed that the potential energy saving of offloading depends not only on the throughput of cellular and WiFi networks, but also on the amount of data that can be offloaded.

Table 5: Measured offloading capacity, average throughput of cellular $T_{\text{-}Cell}$ and WiFi $T_{\text{-}WiFi}$, energy cost E_{oo} from other elements (e.g., scanning), transmission cost of cellular E_{Cell} and WiFi E_W, and estimated energy saving [14].

	Capacity	$T_{\text{-}Cell}$	$T_{\text{-}WiFi}$	E_{oo}	E_{Cell}	E_W	Saving
	MB	Mbps	Mbps	Joule	Joule	Joule	%
Test Suit A	27.2	0.8	3.5	3.4	304.6	39.3	85.98
Test Suit B	22.9	0.8	3.2	3.5	257.3	38.9	83.52

Table 6: Estimated energy saving for different cellular throughput [14].

	0.5 Mbps	1.0 Mbps	1.5 Mbps	2.0 Mbps	3.0 Mbps	5.0 Mbps
Test Suit A	90.7 %	81.7 %	72.9 %	64.2 %	47.5 %	16.3 %
Test Suit B	89.1 %	78.5 %	68.2 %	58.2 %	38.9 %	3.4 %

5 Discussions and Outlook

Mobile traffic offloading provides a promising way to alleviate the pressure on existing cellular networks overloaded by data traffic and is gaining support in the future due to the pace at which mobile data traffic is rising. By enabling the energy-awareness in offloading process, we are able to improve user experience for both battery life and quality of mobile services.

Till present, there are open questions in this domain that deserve our attention for further improvement. First, how to utilize available resources on mobile devices (e.g., sensors) and particularly to benefit from the network side support? Second, how to enable effective collaboration between peer mobile users and mobile networks, including cellular and for instance WiFi providers? Third, how to combine existing technologies such as opportunistic communications and social networking to improve efficiency of both energy and network performance? Fourth, how to extend the offloading initiative to benefit other scenarios as shown in recent work on the potential of cellular OnLoading [28, 29]? Recent measurement study also shows that WiFi has been used in metropolitan areas as a convenient and popular technology to offload cellular data traffic [46, 47]. We believe the advance of battery technology and wireless communications can eventually benefit the mobile traffic offloading from the energy perspective.

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