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Using Multiple Interfaces with Guaranteed Quality-of-Experience

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ABSTRACT

Wi-Fi and cellular networks are provided for mobile Internet access. Although most existing mobile devices are equipped with both Wi-Fi and cellular network interfaces, concurrent data transmissions over these interfaces for improved throughput are not provided. A bandwidth aggregation prototype, named Application Layer Protocol based Aggregation (ALP-A), easy use by simply installing an application in mobile devices without modifying their operating systems. It provides good quality-of-experience (QoE). An online algorithm of traffic scheduling over Wi-Fi and cellular interfaces with the objective of minimizing energy consumption. This prototype implemented on Android-based smartphones, conduct extensive experiments to show that ALP-A outperforms existing schemes significantly.

Keywords-bandwidth aggregation, energy efficiency, quality-of-experience.

I INTRODUCTION

THE increasing popularity of wireless devices and availability of radio access technologies (e.g., Wi-Fi, 3G and LTE) are stimulating various new mobile services [1]. e.g., smartphones and tablets, are usually equipped with multiple network interfaces, such as Wi-Fi and 3G, which imply the opportunities of multipath communication with improved throughput on a single device. However, existing mobile devices do not exploit such a great potential because they just simply activate a single network interface for data transmission. For example, the 3G-interface of smartphones with Android operating system will be automatically turned off when Wi-Fi connection is available.

Bandwidth aggregation [2] is a promising technique for throughput enhancement by allowing concurrent data transmission over multiple network interfaces as shown in Fig. 1, where a mobile device accesses the Internet via a Wi-Fi access point and a 3G base station simultaneously. However, existing bandwidth aggregation solutions are far from providing efficient and practical solutions for mobile users because of the following weaknesses. First, they are implemented in lower layers of network protocol stack, such as network or link layer, relying on the modification on operating systems. To enjoy the benefits of bandwidth aggregation, users need to reinstall the operating system, which would be time-consuming or even impossible for common users without expertise. Second, the variability of link quality in both 3G and Wi-Fi networks is ignored. Mobile devices need to contend for network access opportunities in such networks without any performance guarantee. The more devices exist in the network, the lower throughput can be achieved by each device. As mobile users join or leave the network, the achievable transmission rate of Wi-Fi and 3G interfaces in each device may change, and such influence has not been studied. In this paper, develop a bandwidth aggregation prototype at the application layer, named Application Layer Protocol based Aggregation (ALP-A), by taking dynamics of wireless links into consideration. Specifically, an consider mobile devices equipped with both Wi-Fi and 3G network interfaces, and each device has a batch of downloading requests that arrive in an online manner. To guarantee a certain level of quality-of-experience (QoE), ALP-A specifies a deadline for each request according to the characteristics of applications and user behaviors. To satisfy these downloading requests, An online algorithm to dynamically schedule data transmission on both network interfaces. In particular, energy efficiency is pursued in our design because mobile devices are usually powered by batteries with limited capacity. While energy saving for mobile device has been intensively studied, the energy consumption in bandwidth aggregation has not been addressed. Data transmissions are made on both Wi-Fi and 3G interfaces in an energy-efficient manner while the QoE constraints are guaranteed.

The main contributions of this paper are summarized as follows:

- Develop an application layer protocol called ALP-A for bandwidth aggregation of Wi-Fi and 3G wireless links.

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- Propose an online algorithm for data transmission over both network interfaces with the objective of minimizing energy consumption while guaranteeing user experiences.
- Implement ALP-A on real devices, and evaluate its performance by conducting extensive experiments.

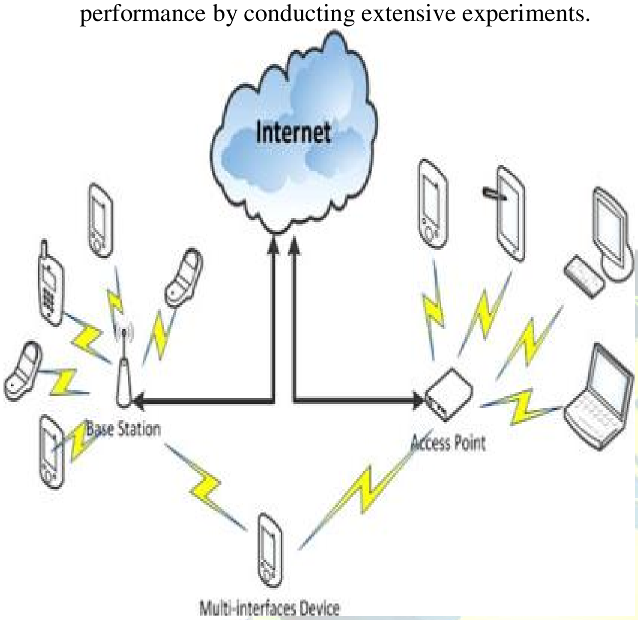

Fig. 1. Virtualization Environment

2 RELATED WORKS

2.1 Bandwidth Aggregation Solutions over Different Layers

Bandwidth aggregation can be addressed at different layers of the network protocol stack [3]. Early work on application layer bandwidth aggregation is based on multiple logical channels on the same network interface, such as XFTP [4] and Grid FTP [5]. PSockets [6] creates multiple parallel sockets to transmit data over multiple logical TCP connections. However, these approaches use only a single physical interface, and their performance is limited by the available bandwidth offered by the interface. Kaspar et al. [7] respectively, have shown the feasibility of using MPTCP for mobile devices in Wi-Fi/Cellular networks. Although they attempt to avoid the modification of existing Internet infrastructure, their implementation still needs to revise operating system kernel. Bandwidth aggregation at the network layer has been studied in , . However, above solutions are difficult to be implemented for mobile devices in wireless networks.

2.2 Energy Efficiency of Mobile Devices

The energy efficiency of mobile devices has been extensively investigated in recent years. In [8], the energy consumption of mobile devices in different environments of 3G and WLAN is considered. The authors have proposed a mathematical model, e-Aware, considering two energy consumption elements: signalling and media transfers, to estimate how application layer protocol properties affect the energy consumption of mobile devices. Activating multiple network interfaces of a mobile device simultaneously incurs more power consumption. Chowdhury et al. [9] present an efficient interface selection scheme. Mahkoum et al. [10] present a framework with power-efficient management from a global point of view. The basic idea behind is to power off the idle interface but at the same time to keep it in virtual idle mode in the network by extending IEEE 802.21 on both mobile node and network side. Chen et al. [11] consider the balance between energy consumption and throughput of devices using MPTCP.

3. BACKGROUND AND MOTIVATION

3.1 Bandwidth Aggregation Based on Application Layer Protocol

In this paper, bandwidth aggregation is exploited at the application layer to support different application protocols such as HTTP and RTP. The major benefit of such approach is no need to modify the protocol stack. Furthermore, the information of upper applications can be easily obtained and used to adjust the utilization of multiple interfaces according to user experience.

4 SYSTEM MODEL

4.1 Design Objectives

(1)Simplicity. ALP-A should be easy to use such that users can enjoy the benefits of bandwidth aggregation by simply installing an application in their mobile devices. For this purpose, the implementation of ALP-A should be independent of operating system and network protocol stack.

*(2)Quality-of-experience***.** ALP-A receives communication requests from applications with various QoE requirements. For example, even a bit longer delay in loading CSS and JavaScript for web browsing would seriously degrade user experience, while buffering in video playing can tolerate a certain level of latency. To guarantee QoE, ALP-A should schedule the requests on two interfaces to guarantee their deadlines specified by applications.

(3)Energy efficiency. Activating multiple network interfaces imposes a great challenge for energy efficiency of mobile devices powered by batteries with limited capacity. When there is no communication request, network interfaces should be in low-power states. When communication requests arrive,

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ALP-A needs to determine which interface should be activated for data communication. The different energy consumption features of Wi-Fi and 3G interfaces should be exploited in ALP-A to reduce energy consumption while guaranteeing user-experience. All above objectives are closely related. In the next section, will address all challenges by designing an applicant layer protocol for bandwidth aggregation.

4.2 ALP-A: Protocol Design

ALP-A receives communication requests from applications and dispatch them to different network interfaces. Meanwhile, ALP-A takes charge of caching responses from lower layers, which will be then delivered to applications. As illustrated in Fig. 4, ALP-A is composed of three modules: data recorder, scheduler and interface switch. The interface switch is used to control the activation of multiple interfaces. Recall that the Android OS will turn off 3G-interface automatically when Wi-Fi connection is available. To implement bandwidth aggregation without modifying OS, ALP-A specifies multiple interfaces with different IP addresses. To realize the requests partitioning and scheduling, the data recorder module is responsible to acquire the current transmission rate and to predict the rate in the next time slot. The scheduler is the core component of ALP-A. The details of its workflow and implementation are presented as follows:

1.Original request caching. ALP-A caches data transmission requests, such as GET of HTTP requests, from applications. For this purpose, ALP-A first enables a listener port, to which all packets are redirected. Then, it listens to this port for any request that will be further processed by the request partitioning component.

2.Request partition. ALP-A partitions each original request into several sub-requests. An example of request partition, where requests are divided into sub-requests to be scheduled over Wi-Fi or 3G interface. To implement request partition, an modify the “Range” field in the header of HTTP request, which indicates a range of data to be downloaded. For example, “Range: bytes=0-100” means that the first 100 bytes of the file are requested. If the request is correctly processed by remote servers providing network services, a response with a state code 206 instead of 200 is returned. For example, a HTTP response with a header “Content-Range: byte 0-100/2350” means that this response contains the first 100 bytes of the requested file with total 2;350 bytes.

3.Sub-requests scheduling. ALP-A uses the Application Programming Interfaces (APIs) provided by the operating system to schedule sub-requests to available network interfaces with the objective of reducing energy consumption while guaranteeing user-experience. The detailed design of our scheduling algorithm will be presented in the next section.

4.Sub-responses buffering. ALP-A buffers all sub-responses returned from remote servers in a pool that is realized using binary heap. Since the sub-responses should be assembled into responses of the corresponding original requests, an use a hash table to facilitate such process. Specifically, the key of the hash table is the original response, and the associated value is a list of sub-responses sorted in a non-descending order according to their deadlines.

5.Response assembly. ALP-A combines several sub-responses into a response, and delivers it to applications. To deal with the instability of wireless networks, ALP-A provides a fault-tolerant mechanism for response delivery. Specifically, each sub request has a retransmission index that is initialized to be zero. If there is a transmission error, an increase the index, and reset the corresponding request in the transmission queue. When the retransmission index reaches the threshold (e.g., 10 in our experiments), an set the interface to be unavailable. Accordingly, all requests in the associated queue will be delivered over another interface.

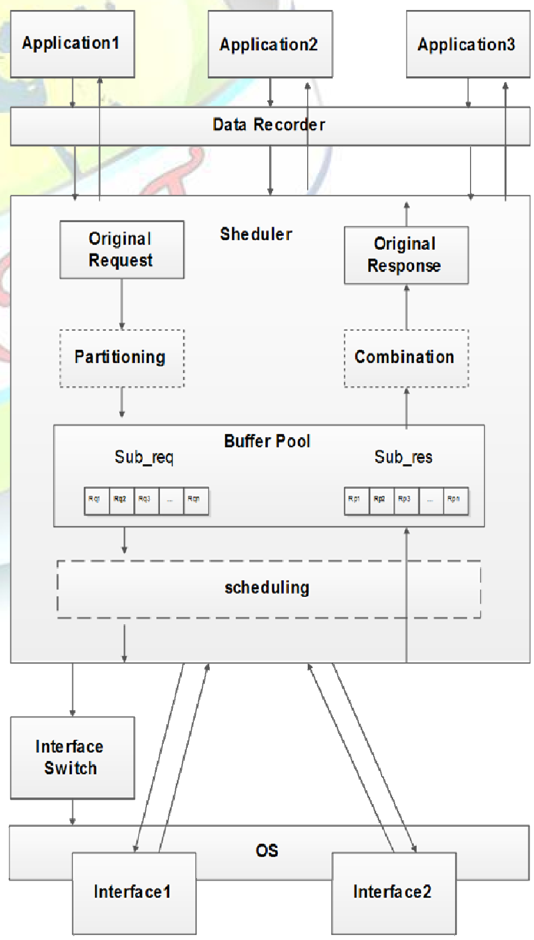

Fig.4. System Architecture

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5 PERFORMANCE EVALUATION

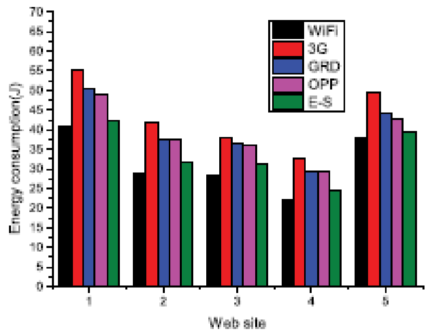

Fig.5. Energy consumption of different methods in web browsing.

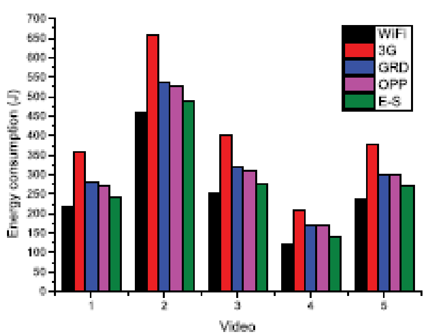

Fig. 6. Energy consumption of different methods in video playing.

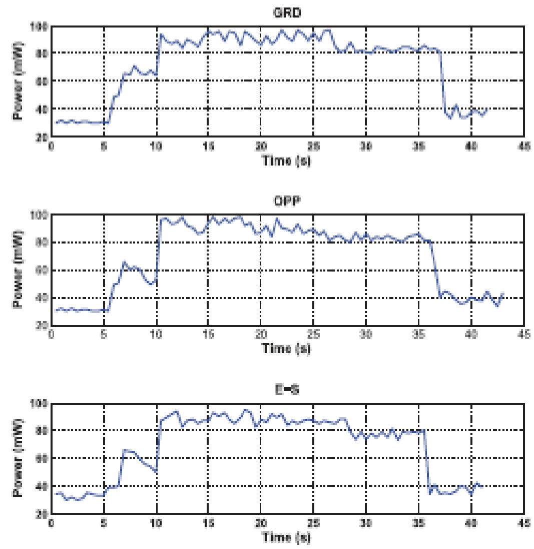

Fig. 7. Real-time power consumption in web browsing (www.sina.com.cn).

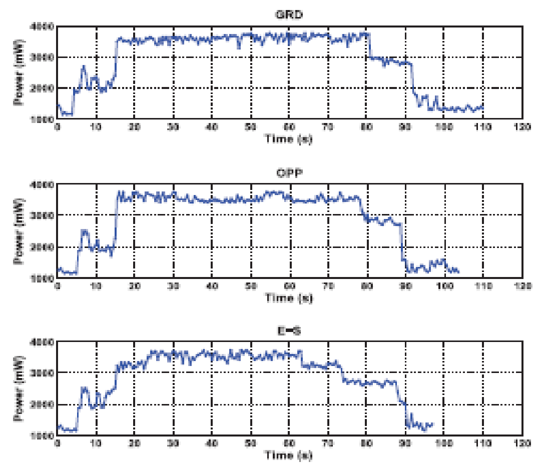

Fig. 8. Real-time power consumption in video playing.

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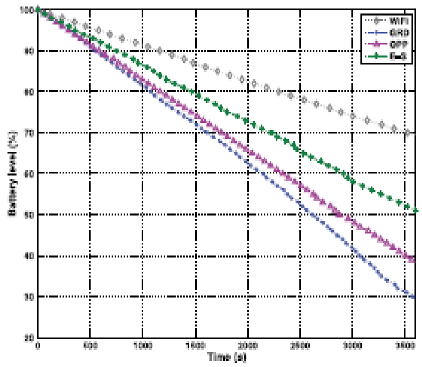


Fig. 9. Energy consumption in a one-hour test.

First investigate the energy efficiency of different algorithms. As shown in Figs. 5 and 6, Wi-Fi has the minimum energy consumption under all scenarios, while 3G always leads to the worst energy performance. Since both network interfaces are exploited by GRD, OPP and E-S, their performance is bounded by these two extreme cases. Specifically, for web browsing as shown in Fig. 5, E-S performs closely to Wi-Fi, and better than GRD and OPP by saving 16 and 15.8 percent energy consumption, respectively. A similar phenomenon can be observed under the video watching application as shown in Fig. 7. Notice that ALP-A exhibits different performance in web browsing and streaming media playing. For web browsing, there are various requests (e.g., CSS, JavaScript, Html, pictures, etc.) with different data size and QoE requirements. Since CSS and JavaScript have more influence on pages rendering, these requests impose close deadlines. On the other hand, high-throughput and continuous connection should be ensured in streaming media playing. Therefore, both interfaces are activated at the beginning to realize that playing starts faster. The real-time power consumption in web browsing and video watching is shown in Figs. 8 and 9, respectively. In Fig. 8, we observe that the period of high power state under E-S is shorter than the other two algorithms. For example, ES stays in a low power state until the 7th second while energy consumption of others increases from the 5th and 6th second. Furthermore, E-S switches back to a low power state a little earlier than others. Similarly, as shown in Fig. 10, E-S finishes all data transmissions within 100 seconds, while GRD and OPP need 110 seconds and 105 seconds, respectively. The energy consumption of different algorithms during a long-running test by issuing a series of HTTP requests with different sizes for an hour. As shown in Fig. 10, although the performance gap among these algorithms is not obvious in the beginning, E-S saves about 30 and 21 percent battery power of GRD and OPP, respectively, after an hour.

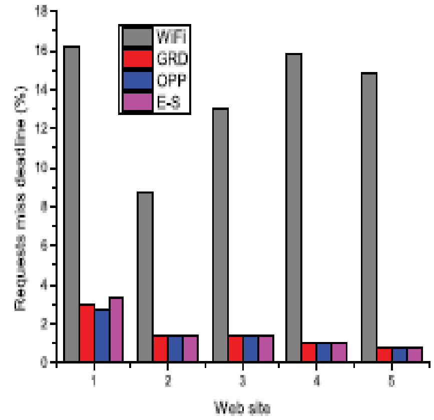


Fig. 10. Number of requests completed upon deadline over different methods.

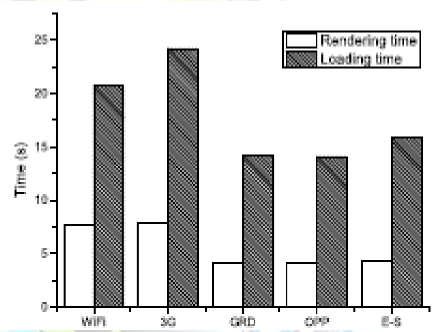
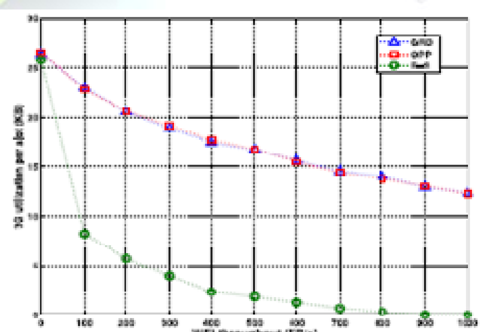


Fig. 11. Completion time and rendering time over different methods in web browsing (www.sina.com.cn).



. Fig. 12. 3G utilization over different Wi-Fi throughput.

Due to bandwidth dynamic of both network interfaces, some requests may not be satisfied within their deadlines. An

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show the percentage of requests missing their deadlines under different algorithms in Fig. 11 Although Wi-Fi always has the minimum energy consumption as an observe in Fig. 7, there are over 10 percent requests that cannot be finished within their deadlines. On the other hand, the corresponding percentages of other algorithms are all under 5 percent. An compare the loading time and rendering time.. As shown in Fig. 12, the GRD, OPP and E-S algorithms exploiting both network interfaces have shorter loading time and rendering time. Furthermore, although E-S has longer loading timer than GRD and OPP, it has similar rendering time with them, demonstrating that mobile users can hardly be aware of QoE differences under these algorithms. The 3G utilization of GRD, OPP and E-S under different Wi-Fi transmission rate in Fig. 12. As Wi-Fi rate decreases, 3G utilization grows under all algorithms because more data need to be delivered over 3G-interface to guarantee QoE. However, 3G utilization of E-S is always lower than GRD and OPP due to its awareness of energy efficiency. After request partition in ALP-A, the generated sub requests will be sent to lower layers (e.g., network layer and data link layer), where additional headers will be added. To evaluate the overhead of this process, the ratio of additional header size and original data size and conduct five sets of experiments using randomly generated requests with different sizes. Specifically, large request size in the first two sets of experiments, and small size in the rest. The ratio is less than 0.14 percent in all experiments.

6 CONCLUSION

A bandwidth aggregation prototype, named ALP-A, at the application layer for mobile devices. An energy-aware scheduling algorithm called E-Schedule is proposed to reduce energy consumption. An implement ALP-A in real mobile devices and conduct extensive experiments to evaluate its performance. This algorithm can save about 16 percent energy under web browsing and video streaming applications while guaranteeing QoE.

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