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Anatomy of WiFi Access Traffic of Smartphones and Implications for Energy Saving Techniques

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Abstract

Today's smartphones are equipped with more features than an average personal computer. They have become the preferred means of communication, and consequently, smartphone traffic constitutes an increasingly large share of Internet traffic. However, development in battery technology has not kept pace with the developments in other sub-systems of smartphones, and battery energy puts the ultimate constraint on the availability and performance of smartphones. For this reason, energy saving techniques for wireless interfaces is more relevant to smartphones. In this article, we present a detailed analysis of WiFi access traffic of Android based HTC Nexus One*, Apple's* iPhone 3GS*, and* BlackBerry 9700 *smartphones for different classes of applications, namely,* web browsing*,* YouTube video playing*, and* Skype VoIP calling*. We setup a bench to capture the WiFi access traffic data of smartphone applications, and analyzed the data in terms of* packet size, packet inter-arrival time, burst duration, burst inter-arrival time*, and* burst size*. We discuss the implications of these observed parameters on existing* MAC *level energy saving techniques. The results provide network designers with useful information about how to combine multiple data packets to create relatively longer idle periods for the communication interface. Thus, this study helps reducing communication costs which play a key role in reducing energy consumption of smartphones. This work complements the efforts of the IEEE standard for WLAN, 802.11n that facilitates aggregation of packets at the MAC level.*

Keywords: Wireless network design; Energy saving; Internet traffic; Smartphone.

1: Introduction

Today's smartphones are equipped with good processing capabilities, graphical user interface (GUI), and multiple radio interfaces, because of significant development in microelectronics technology. More capabilities are being built into these phones, and they are able to support resource intensive applications. These applications include web browsing, social networking, email client, online gaming, online multimedia playing, global positioning system (GPS) based navigation, and weather/stock updates. Due to these network related applications, smartphones draw a significant amount of wireless access traffic while producing much uplink traffic. This traffic volume is growing rapidly and significantly faster than broadband traffic volume [1].

Though wireless access traffic of smartphones is routed through cellular and 802.11 based WiFi data networks, Universal Mobile Telecommunications System (UMTS) based 3G cellular data networks typically require more energy with less data rates compared to WiFi based networks [2, 3]. Moreover, WiFi hotspots have become very common at homes, institutions and public places. Accordingly, smartphones use WiFi data link by default due to its accessibility, higher bandwidth, and less cost in comparison to cellular networks. Cellular data networks are mainly used while the users walk around or stay on transports. Analysis of residential digital subscriber lines (DSL) of a large European ISP shows that there is a significant and increasing number of active smartphone connections [4]. Therefore, novel energy saving measures need to be addressed for both cellular and WiFi based data networks.

The energy saving strategies for communication interfaces can broadly be classified into two categories [5]: (*i*) inactivity threshold strategy, and (*ii*) micro power management (μPM). *Inactivity threshold strategy* is based on the principle that the longer a component has been inactive, the longer it will continue to be inactive [6]. When a user does not interact with a smartphone for a while, the device turns off the display and further saves energy by keeping all the hardware at minimum energy level. Only minimal interaction is maintained with the network to trace call and to update applications' status. A recent study [7] revealed that users interact with their smartphones in a bursty manner, and each session of interactions (*usage burst*) generally lasts for $10 - 250$ seconds. A smartphone starts a timer to observe the idle period after each usage burst, and goes into idle mode to save energy once the period exceeds a preset threshold.

In contrast to the *inactivity threshold strategy* discussed above, *micro power management (μPM)* is applicable during a usage burst, and this technique deals with keeping a component in low energy state (*pause* or *doze* mode) for a very short interval so that the functionality of the device is not compromised. The fundamental requirement for these strategies is the ability of the related hardware component to go into low power mode for a very short period of time. The short interval is in the range of microseconds to couple of milliseconds [8, 9]. This strategy enables a communication interface to enter into power-saving mode even between two medium access control (MAC) frames. The gaps between successive frame exchange can further be extended by aggregating couple of data packets into one MAC frame, which make room for hardware to be in low energy state for longer period of time [3, 10, 11]. Though the concept of packet aggregation on the device side is new, various forms of traffic aggregation have been used in data backbone networks, and new techniques are being proposed to achieve higher bandwidth and energy efficiency [12, 13].

The process of packet aggregation adds delay to data packets and creates packets of larger size than that of the original packets. However, some kinds of traffic such as VoIP and real-time multimedia are very much delay sensitive. For each type of communication interface, there is a threshold value for data packets, known as *maximum transmission unit* (MTU). For example, a 1500-byte packet is the largest packet allowed by Ethernet at the network layer [14]. If the size of a data packet to be transmitted exceeds MTU size, that packet is segmented into multiple packets. As a result, it is not advantageous to have an aggregated packet whose size is more than MTU; rather, it causes more overheads. Therefore, while applying μPM, clear understanding of the nature of traffic and distributions of the inter-arrival times and sizes of the network data packets is required to maintain a certain level of performance and quality of service (QoS).

In this article, we present an in-depth insight into the characteristics of wireless access traffic, which will spur the development of *micro power management* strategies for the WiFi communication interface of smartphones. We have collected wireless access traffic data of smartphones for some representative applications [15], and studied the characteristics of individual packets as well as packet bursts for both uplink and downlink traffic.

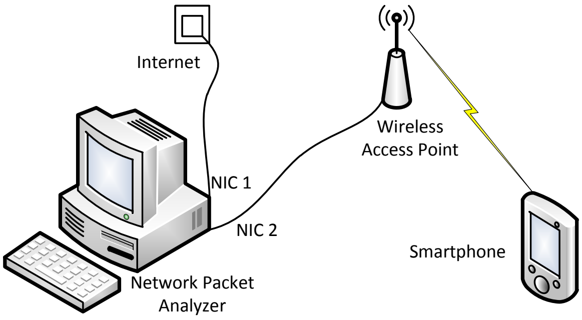

Figure 1. Connection details of network packet probing setup. (NIC = *Network Interface Card***.)**

We gathered the Internet traffic data of three state-of-art smartphones, namely, *HTC Nexus One*, *iPhone 3GS*, and *BlackBerry 9700*, connected to Internet via WiFi network. We route the traffic from and to a smartphone via a desktop computer as shown in Fig. 1. The WiFi *access point* (AP) is attached to the computer and only one smartphone is associated with the AP at a time. Therefore, all data packets traveled to and from smartphone can be sniffed by the packet analyzer running on the desktop computer. The traffic data for 3G networks could be collected at the cellular base station (BTS) or by placing a packet probing application in the smartphones. However, we did not have access to the BTS of cellular networks or have packet probing applications for the smartphones. The analysis of wireless access traffic in 3G networks is beyond the scope of this work, and we aim to investigate that in future.

We carried out *web browsing*, *YouTube video playing*, and *Skype VoIP calling* on the smartphones. A *network packet analyzer* installed on the desktop computer captured all the data packets. In the dataset, we observed some network management packets originated from the WiFi AP and we exclude them from further processing. We examine the distribution of *packet sizes* and *inter-arrival times* of the packets in uplink and downlink traffic. The packets are grouped into *bursts* based on their *inter-arrival time.* Then, we compute the distribution of *durations, inter-arrival times* of the bursts, and *number of packets* in each burst. As we discuss in Section 6, the parameters are very important in designing energy saving techniques for communication interface of a smartphone. For example, the duration of bursts is crucial in designing packet aggregation techniques at the MAC level. This article makes the following contributions.

- We present a test bench to capture and analyze the WiFi access traffic generated by the smartphone applications. Traffic of representative applications such as *Internet browsing*, *social networking*, *online video playing* and *VoIP calling* were observed on the state-of-the-art smartphones to collect data.

- The characteristics of the wireless access traffic are analyzed in terms of burst *duration, inter-arrival time, size of burst* and *number of packets per burst*, which are relevant to designing energy saving techniques for communication interfaces.
- We have collected traffic data from *HTC Nexus One*, *iPhone 3GS*, and *BlackBerry 9700*, and observed whether there is any significant difference in the distributions of the above mentioned parameters.
- Observations reveal that the size of almost 80% of the uplink data packets is less than 66 bytes, and about 60% of the downlink packets have less than 1 millisecond inter-arrival time. For uplink traffic, it is about 50%. The inter-arrival times of bursts in both directions is more than 10 millisecond for more than 90% of the bursts.
- Based on the observations, we have identified opportunities for designing a packet aggregation scheduler tuned for smartphones that takes advantage of the IEEE 802.11n MAC protocol for aggregating data packets.

The rest of this article is organized as follows. We review some substantial work that focus on energy saving measures for communication module in Section 2. In Section 3, the applications and traffic parameters used in the observations are described. The details of our test bench is described in Section 4, analysis of the results is given in Section 5. Section 6 illustrates the impact of traffic attributes on MAC level energy saving techniques. We conclude our discussion in Section 7.

2: Related Work

We discuss the relevant prior work in energy saving in wireless networks. One paper proposes a scheme for optimizing inactivity periods of a mobile device in $3G$ cellular networks, and the rest of the papers focus on 802.11 based infrastructure wireless networks.

Yang [16] investigated the discontinuous reception (DRX) mechanism for saving energy of mobile devices in the Universal Mobile Telecommunications System (UMTS) networks. The DRX mechanism is controlled by two parameters: the inactivity timer threshold t_I and the DRX cycle t_D. Based on a M/G/1 queueing model with vacations, the author studies the optimal values for t_I and t_D which maximize the energy saving in mobile devices. The author also presents an adaptive algorithm called dynamic DRX (DDRX) that dynamically adjusts the values of t_I and t_D close to the optimal values.

Liu *et al.* [9] proposed micro power management (μPM) scheme that works in the client devices. It allows a WiFi radio to sleep for short intervals, in the range of a few microseconds. The communication interface can be used to sleep even between two MAC frames to save energy. The μPM technique uses predictions to exploit short idle intervals, and it relies on 802.11 retransmissions to recover from any mis-predictions.

Tan *et al.* [17] proposed an application-independent protocol, called *power save mode* (PSM) throttling. This transport level technique reshapes TCP traffic into periodic bursts with the same average throughput as the server transmission rate. Clients accurately predict the arriving time of packets, and turn on/off the wireless interfaces accordingly. PSM-throttling can minimize power consumption on TCP-based bulk traffic by effectively utilizing available Internet bandwidth without degrading the performance of application perceived by the user.

Rozner *et al.* [18] claimed that depending on the PSM implementation strategies, traffic of the other clients in the same network (competing background traffic) causes upto 300% more energy consumption in a client device. Moreover, the capacity of a wireless network reduces due to the unnecessary retransmissions and unfairness. They propose Network-Assisted Power Management (NAPman) algorithm for WiFi devices that addresses the above issues. NAPman distinguishes traffic of a PSM client from the traffic of competing constantly awake mode (CAM) clients and other PSM clients. Then it enforces a work-conserving first-come-first serve (FCFS) policy only to the packets of clients that are awake at any given time. This energy-aware fair scheduling minimizes client energy and unnecessary retransmissions.

Agrawal *et al.* [19] proposed an algorithm named Opportunistic PSM (OPSM). This scheme is effective when all the connected devices are engaged in web browsing, which is characterized by small file downloads over TCP, with a short duration of inactivity or think time in between two downloads. It performs better than static PSM when the number of associated devices with an AP increases. The reason behind the improved performance is that OPSM only permits one download at any time, due to which a device gets the maximum throughput and this results in least energy consumption. In static PSM this is not the case, since it allows simultaneous downloads, which leads to longer file download times and hence consumes more energy than OPSM.

Kim *et al.* [10] present a MAC level frame aggregation scheme, which can improve the throughput performance. By aggregating small-size frames into a large frame, it reduces MAC and PHY layer overheads. Their measurement results show that the throughput performance can be improved by 2 to 3 Mbps by applying the frame aggregation technique in the IEEE 802.11*b* standard. They have also proposed that frame aggregation can easily be performed above the MAC service access point (SAP) easily with device driver modifications. This work dealt with the impact of frame aggregation on throughput performance, and they did not consider any traffic pattern or impact of frame aggregation on QoS.

Zhu *et al.* [11] address the power saving problem by developing a model for stochastic analysis of timer-based power management in infrastructure WLANs. Based on this model, the probabilities that a device is active, idle, or dozing are derived, and the power consumption of the device, number of frames buffered, and average delay per frame are obtained. This scheme produce bursty traffic to keep the communication interface in doze mode for longer period of time. However, it does not reduce the MAC/PHY layer data overheads. Specifically, the PHY layer overhead is very much significant in WLAN.

Nath *et al.* [20] proposed to transmit multiple beacons, one for every client associated to the AP. Each client estimates the round-trip-time (RTT) of the current TCP connection and sends this information to the AP, based on this information the AP schedules the beacon frames to the clients. Ra *et al.* [21] mention a class of applications that is often naturally delay-tolerant so that it is possible to delay data transfers until a lower-energy option becomes available. They present an optimal online algorithm for energy-delay tradeoff using the Lyapunov optimization framework. Their results show that their algorithm can be tuned to achieve a broad spectrum of energy-delay trade-off, and it can save $10-40\%$ of battery energy for some workloads.

The IEEE 802.11n standard enables high data speed communication links, which is about 100 Mbps measured at MAC layer. To accommodate such data rate, it supports two MAC level frame aggregation techniques, namely, Aggregate-MAC Service Data Unit (A-MSDU) and Aggregate-MAC Protocol Data Unit (A-MPDU). These two aggregation techniques can also be combined at two levels [22, 23]. However, the standard does not specify the scheduler for these schemes, and it is left as vendor's choice. The observations obtained from this study will assist the designers of the packet aggregation scheduler to choose design parameters such as burst timer, burst size, and number of packets in a burst.

Our work explores the characteristics of wireless access traffic which must be also taken into account in designing micro power management (μPM) techniques for smartphone communication interfaces. Smartphone's communication hardware is capable of being in doze mode for short intervals (as low as 4 milliseconds), and this feature can be utilized even when the device interacts with its user. Thus, this investigation serves as the requirements of traffic patterns of network related applications, and suggest guidelines for developing novel energy saving techniques.

3: Selection of Applications and Performance Metrics

To get representative statistics of the wireless access traffic of smartphones, it is very important to consider a set of relevant applications that constitute smartphone traffic. We have considered a set of applications according to usage rating given in [15]. In this section, we also describe the metrics that we measured from the traffic data.

3.1: Chosen Applications

We selected three state-of-art smartphones, namely, *HTC Nexus One*, *iPhone 3GS* and *BlackBerry 9700* which run on the most popular mobile operating systems (OS). Then, we chose a set of representative network related applications on smartphones to gather traffic data [15]. The applications are: (*i*) random web browsing, (*ii*) social networking website, *facebook.com* browsing, (*iii*) *YouTube* video playing, and (*iv*) *Skype* VoIP calling. In case of web browsing, we randomly browsed news websites such as `cnn.com` and `www.cbc.ca/news/`, searched in `google.com`, and accessed emails on `gmail.com`. During *facebook.com* browsing, we followed links, status on *friends' wall*, and viewed photos. We played two videos on *YouTube.com* for online video data, and made VoIP calls using *Skype* to gather VoIP trafiic. The duration of each of the tasks was about 10 minutes. Though we collected data from three different smartphones, in this article, we used the data obtained from HTC Nexus One handset, and only a subset of the results is shown due to lack of space.

3.2: Performance Metrics

In the traffic data, we intended to observe the distribution of packet inter-arrival times, packet sizes, and burstiness of traffic. We were mainly interested to see the attributes of the bursts. Fig. 2 shows different parameters of a burst.

We explain the performance metrics and discuss their importance below.

- *Burst Duration* is the difference of arrival times between the first and last packets in a burst. We do not consider the duration of a burst containing only one packet.
- *Burst Size* is the sum of sizes of all data packets in a burst. The packet includes application data, and headers of transport, network and MAC levels. The MAC level header size is 14 bytes in all cases as the packets are captured at wired portion of the link.

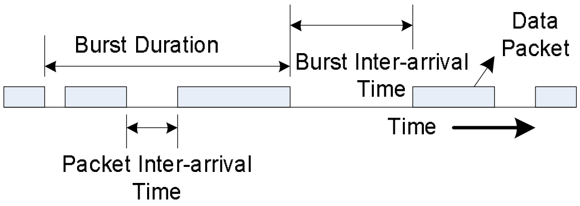

Figure 2. Schematic diagram of performance metrics.

- *Packets per Burst* is the total number of packets in a burst.
- *Burst Inter-arrival Time* is the time gap between the arrival of the last packet of a burst and arrival of first packet of the next burst is referred as the burst inter-arrival time.

A burst containing a couple of data packets, and with less duration can easily be aggregated at MAC level before transmission. Aggregation process reduces MAC and PHY level overheads. A communication interface can utilize the larger burst inter-arrival times by being into low energy mode during those intervals. Energy saving by overhead reduction, and by staying longer in low energy mode are our concerns.

4: Experiment Setup

The network connection details for collecting traffic data packet information from a smartphone is shown in Fig. 1. A 802.11*g* based access point (AP) is connected to a network interface card (NIC) of a desktop computer which is connected to the Internet through another NIC. Internet connection is shared between the two NICs of the desktop computer. If only one smartphone is connected with AP, most of the packets captured by the packet analyzer, originate from the smartphone. There is a small number of network management packets exchanged by the AP, and those packets are discarded during analysis.

As a packet analyzer, we used *Wireshark* (`http://www.wireshark.org/`), an open source and widely used network packet analyzer in the industry and educational institutions. *Wireshark* does not manipulate things on the network, it only examines packets on a network. To collect smartphone's Internet traffic data, we connect one smartphone with the AP at a time, and run an application. Then we collect the packet information from the *Wireshark*, installed on the computer. The captured data packets are exported as spreadsheet from *Wireshark* for further analysis. Then, the packets are separated into uplink and downlink packets based on the source and destination IP addresses.

One or more packets are marked as a *group* when the inter-arrival times between two consecutive packets are less than a *threshold* value. Each of the groups is referred to as a *burst*. A burst may contain only one packet if the time gaps with its previous and next packets are more than the *threshold*. The time span between the first and the last packets in a burst can be any positive time period. To the best of our knowledge, the state switching timing (active to sleep and sleep to active) of state-of-art device circuitry is around 4 milliseconds. Therefore, the threshold value is set to 5 milliseconds.

As we collect traffic information at the desktop computer, a data packet travels via AP from a smartphone before arriving at the analyzer. Thus, the AP adds some delay to each packet and that may not be uniform for all packets due to buffering effect. Presence of

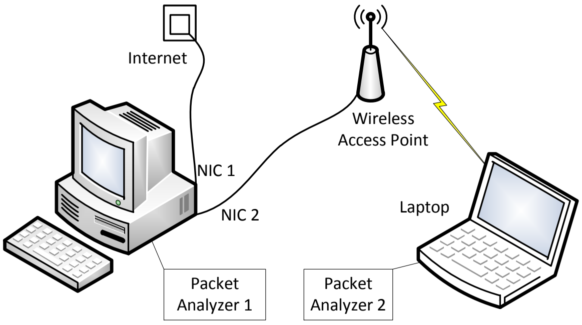

Figure 3. Connection setup for verifying the impact of access point (AP).

uneven delays corrupt the timing of packet inter-arrival times, and to investigate this effect we use a laptop computer with another packet analyzer on it (Fig. 3). We run applications on laptop computer and gather packet information at both analyzers and compare the statistics obtained from both sources. The results are discussed in the next section.

5: Results

The information regarding sizes and inter-arrival times of uplink and downlink data packets is crucial for designing an effective *micro power management* strategy for smartphones' communication interfaces. With this objective, we at first compare the total number of uplink and downlink packets for different application scenarios. Then we show the distribution of size and inter-arrival time of individual packets in uplink and downlink traffic. The same attributes of bursts are discussed later in this section. Finally, we discuss the impact of the AP and operating systems (OS).

In social networking website (*facebook.com*) browsing, the amount of uplink packets is about 80% of the downlink packets, and in case of random web browsing, it is in the range of 70% to 95%. The numbers of packets in uplink and downlink traffic are almost equal in VoIP traffic. Only for *YouTube* video traffic, the amount of uplink packets is only 18% of the downlink traffic. Thus, the amount of uplink packets is significant as compare to the downlink packets except for *YouTube* video traffic.

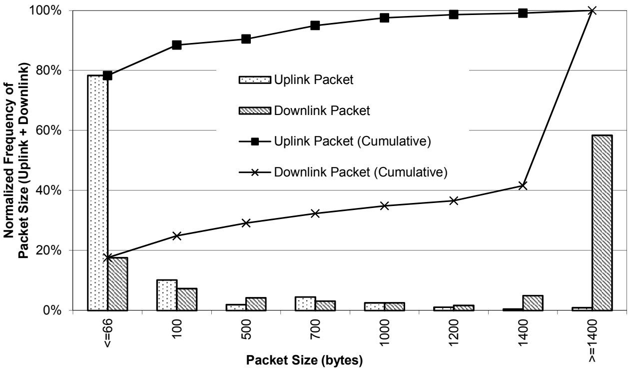

Figure 4. Distribution of uplink and downlink packet size for random web browsing.

The size of the packets in the uplink traffic is usually smaller, which are mostly ACKs (80% for random web browsing). For downlink traffic, about 60% of packets are of above 1400 bytes in random web browsing, and almost all packets are of MTU size in case of *YouTube* video playing. The distribution of the packet size is given in Fig. 4. The uplink and downlink packet size in *Skype* VoIP traffic is around 71 bytes. A significant portion of the packets in both uplink and downlink traffic have very little inter-arrival times. As shown in Fig. 5, more than 45% of the uplink packets have inter-arrival time of less 1 millisecond, and above 60% of the downlink packets have inter-arrival time of less than 1 millisecond. In the following paragraphs, we present the characteristics of *bursts* formed by the uplink and downlink traffic.

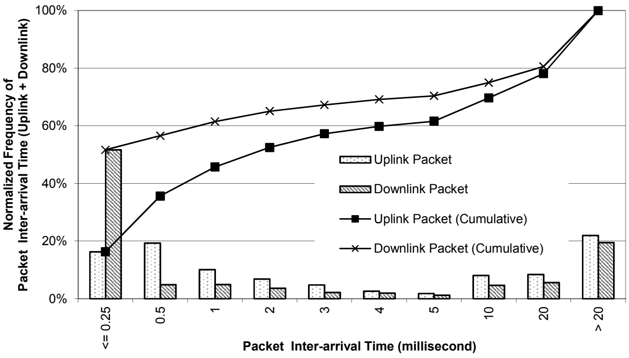

Figure 5. Distribution of uplink and downlink packets' inter-arrival time for random web browsing.

Burst Duration Fig. 6 shows the distribution of *burst durations* of uplink traffic. More than 95% of the bursts last less than 10 milliseconds. Almost 40% of the bursts live at best 1 millisecond. This phenomenon is very much interesting. This kind of shorter burst duration also indicates that packets within a burst are independent of each other. No response is required from the destination node before sending all the packets in a burst. We observe exactly the same trend with the downlink traffic.

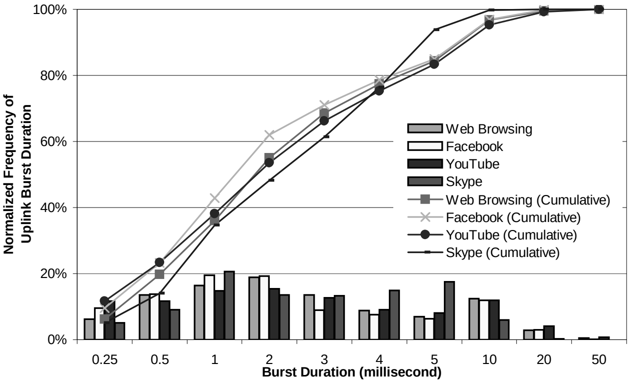

Figure 6. Distribution of uplink burst durations.

Burst Size The distribution of uplink *burst size* is given in Fig. 7. Most of the burst sizes fall below 1500 bytes. Almost 70% of the bursts formed in *YouTube* uplink traffic are single-packet bursts of 66 bytes in length. Those are basically transport level ACKs. Again, for *Skype* uplink traffic all bursts contain one packet of size around 70 bytes. In more than 50% of the cases, the *burst sizes* in uplink traffic for web browsing fall in between 200 to 1000 bytes. The *burst sizes* in the downlink traffic are larger compared to sizes of uplink traffic (shown in Fig. 7 and Fig. 8). For web browsing and online video playing, the burst size generally remains above 2000 bytes. The burst size becomes as large as 50 kilobytes for YouTube video traffic. This differences in burst sizes of uplink and downlink traffic require different strategies for energy saving in both directions.

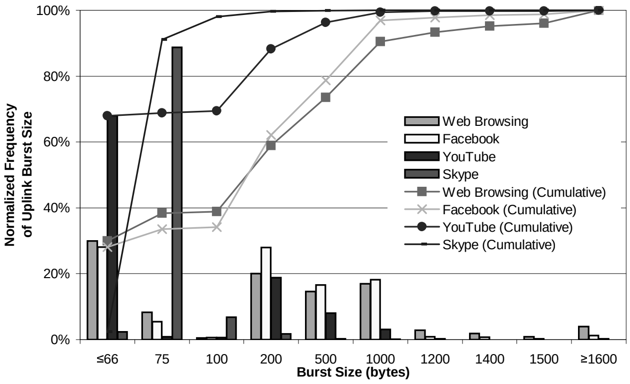

Figure 7. Distribution of uplink burst sizes.

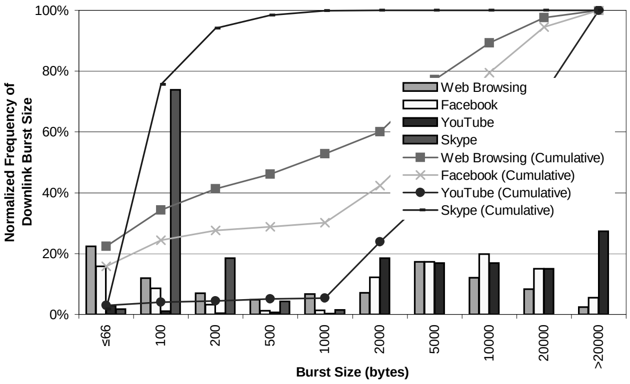

Figure 8. Distribution of downlink burst sizes.

Packets per Burst The distribution of *packets per burst* in uplink traffic is given in Fig. 9. More than 50% of the bursts contain 2 or more packets during web browsing. In *YouTube* uplink traffic, about 70% of the bursts contain single packet, and almost all bursts are single packet burst for *Skype* uplink traffic. In case of downlink traffic, similar trend is observed for web browsing and *Skype* calling. However, *YouTube* traffic contains 25% single packet burst, and 25% bursts with more than 25 packets. This bursty traffic is an indication of energy saving measure at transport level, which provides more idle time to the communication interface.

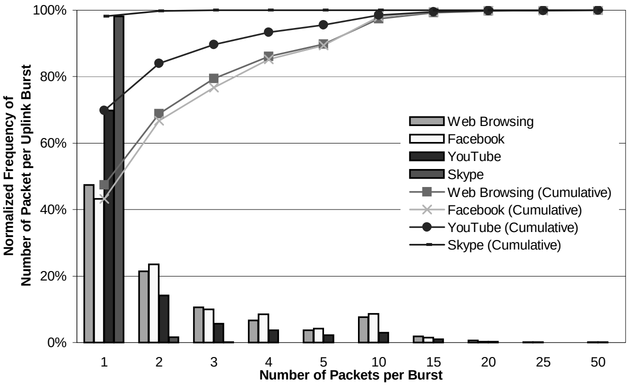

Figure 9. Number of data packets in uplink bursts.

Burst Inter-arrival Time Fig. 10 shows the distribution of *burst inter-arrival times* for downlink traffic. Only 15% of the bursts has less than 10 milliseconds of inter-arrival time, and 60% of the bursts have inter-arrival times of more than 20 milliseconds. Same trend is also observed in uplink traffic.

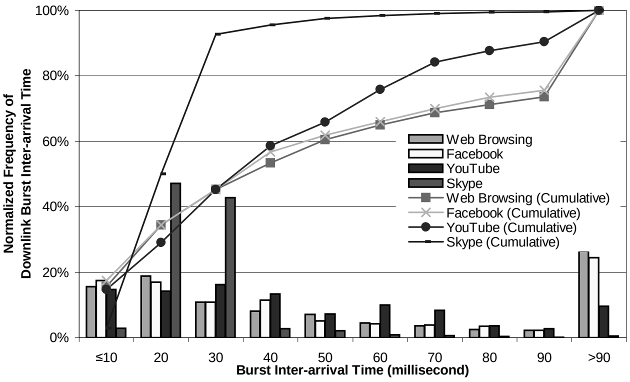

Figure 10. Distribution of downlink burst inter-arrival times.

The results discussed so far are based on separate uplink and downlink traffic data, and separate analysis is required for packet aggregation techniques. However, the communication module of a smartphone needs to be active for sending and receiving of data packets, and therefore, we examine a dataset which contains both the uplink and downlink data. Fig. 11 shows the distribution of *burst inter-arrival times* in both directions of traffic for *webpage* and *Facebook* browsing. Around 30% of the bursts have inter-arrival times of less than 10 milliseconds. In case of web browsing, half of the bursts come more than 20 milliseconds apart.

Placement of Packet Analyzer To observe the effect of AP on the route of traffic data, we used a laptop with packet analyzer on it instead of a smartphone. We browsed random web pages, and captured packets on the laptop as well as on the desktop computer as usual (Fig. 3). On the packet analyzer of the laptop, 40% of the packets in the uplink traffic have inter-arrival time of 0.25 millisecond or less, and for downlink traffic it is 42% of the packets. On the other hand, the packet analyzer on the desktop PC, we found 33% of the uplink packets have inter-arrival time of 0.25 millisecond or less and for downlink packets

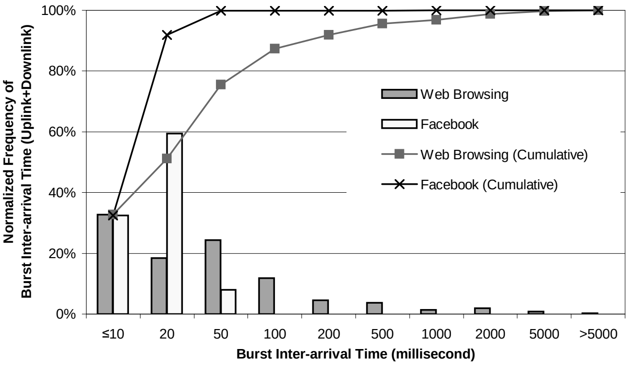

Figure 11. Distribution of burst inter-arrival times in both directions.

it is 68%. These numbers suggest that the AP is reducing the *burstiness* of the traffic in both directions by introducing uneven delays, and therefore, the presented results give a conservative estimate about the traffic bursts.

Impact of OS To observe any possible impact of operating system (OS) or device on the wireless access traffic, we conducted the same set of experiments on three different smartphones namely, *HTC Nexus One*, *iPhone 3GS* and *BlackBerry 9700* by keeping all other parameters unchanged. However, we did not observe any significant differences in the distribution of the parameters discussed above.

6: Impacts on Energy Saving Methods

We summarize the characteristics of uplink and downlink traffic, and discuss the potential application of those attributes in designing energy saving techniques. The characteristics of uplink traffic are as follows:

- Durations of more than 95% of the bursts are below 10 milliseconds (Fig. 6);
- Inter-arrival times of more than 80% of the bursts are grater than 10 milliseconds (Fig. 10);
- Sizes of almost all uplink bursts are less then 1500 bytes (Fig. 7);
- Number of packets per burst is less than 16 (Fig. 9);

We observe the same statistics for downlink traffic except for the burst size. The downlink burst size is usually larger, and in case of *YouTube* video traffic, burst size becomes up to 50 kilobytes (Fig. 8). When we consider the bursts in both directions, only 30% of the bursts come less than 10 milliseconds apart (Fig. 11). Based on the analysis given above, we discuss its implication on different MAC level energy saving techniques in Table. 1. We explain the effects of different burst parameters in the following.

6.1: Impact of Burst Duration and Size

Different applications on a smartphone communicate with different servers. Sometimes one application communicates with even more than one server. However, all communications are routed through the AP in infrastructure wireless networks. Small burst durations (couple of milliseconds) create opportunities for holding data packets in a burst without affecting the applications' performance. As most of the burst size is less than MTU in uplink traffic, all the packets in a burst can be aggregated into a MAC frame. On the other hand, for larger burst size as in downlink traffic, several MAC frames containing individual packets can be accumulated before transmitting them at a time. There are several derivatives of *frame aggregation* techniques [9, 11], and they basically create longer idle periods for a communication interface. In addition to that *frame aggregation* technique reduces MAC and PHY layer overheads significantly. However, large burst sizes introduce longer packet delays, and re-transmission rate also increases in presence of moderate bit error rate (BER).

6.2: Impact of Burst Inter-arrival Time

The inter-arrival time of bursts gives us insight into how long the communication interface should go into doze mode for saving energy. Results show that about 35% of the bursts have inter-arrival time of less than 10 milliseconds. Therefore, a millisecond-level dozing is essential for uninterrupted flow of the data traffic. However, the beacon interval is 100 milliseconds in existing WiFi networks, and therefore, the current beacon interval is unable to accommodate energy saving management scheme in presence of online multimedia or VoIP traffic. Moreover, sending PS-POLL for receiving data after each tiny doze interval is impractical, because energy saved from short doze mode would be spent in sending PS-POLL messages. Therefore, coordinating the state information of the devices with the AP is a crucial design issue.

6.3: Coordination between Device and AP

The values of device's doze interval and AP's PSM (*Power Save Mode*) message interval must be chosen in such a way that an AP is able to track the state of an attached device without getting an explicit PS-POLL message. On the device side, a device needs to wait for a PSM message after waking up from doze state. It either expects data packets from the AP or goes into doze mode again according to the status value in the PSM message. The challenge in the device side is to reduce the wait time before going into doze mode further. To achieve these objectives, one or more of the following measures worth investigation.

Natural Coordination As we mentioned in the beginning of this section, the number of uplink packets is comparable to downlink data packets, and the distribution of burst inter-arrival times in uplink traffic is similar to the downlink traffic. A device can take advantage of this natural phenomenon by synchronizing the doze interval with the uplink frame rate. An AP informs a device of any buffered data using the Acknowledgment's (ACK) *more data* field, and the device receives subsequent frames from the AP. No extra PSM message is needed here. However, this scheme may not work when the uplink frame rate is low as compare to downlink rate (as in *YouTube* traffic).

PSM Message with ACK In infrastructure wireless networks, in any data exchange, access point becomes either a sender or a receiver, and it often needs to send ACKs. Since the beacon message is large, and beacon interval is long, an AP can tag the buffer status of connected devices with MAC level ACKs. For example, if an AP supports 256 devices, it needs only a 8 bytes vector to indicate the status for each device. This technique does not require extra PHY or MAC level overheads, and the status message can be sent more frequently. The client devices can update themselves accordingly.

Extra PSM Message When the network is under-loaded, AP does not need to send ACKs very often. In such situations, AP itself can send PSM messages time to time containing buffer status. AP does not run on battery and in low traffic scenario, this frequent PSM messaging will not reduce network throughput.

7: Conclusion

Battery life is an important aspect of smartphones to the users. Increasing number of network related applications have made it more difficult for the smartphones to last longer on a single re-charge. As a result, design of energy efficient communication interfaces for smartphones is essential, and for that, study of the characteristics of traffic is necessary. In this paper, we observed WiFi access traffic of smartphones for popular applications, and analyzed some key parameters such as distribution of packet length, inter-arrival times, *burst size*. Based on the observations, we have explained the challenges associated with designing energy saving strategies for communication interfaces. We have identified some values and bounds from practical usage data. It will help the system designers to come up with better design and implementations of packet aggregation scheduler for IEEE 802.11n. We aim to investigating any variation of patterns in the networks of 3G and above.

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Table 1. Impact of the given analysis on Different MAC-Level Energy Saving Techniques

Traffic Parameters	**Observations**	**Standard PSM** (***e.g.***, [24])	**Flexible Beacon Period Technique** (***e.g.***, **[20]**)	**Micro-Power Saving Techniques** (***e.g.***, **[8, 9]**)	**Frame Aggregation Techniques** (***e.g.***, **[19, 10, 11]**)
Packet Size (Fig. 4)	About 85% of the uplink packets are smaller than 100 bytes and 60% of the downlink packets are greater than 1400 bytes.	x	x	x	Smaller packets in uplink are suitable for aggregation as a number of them fit into a MAC frame. Larger packets in downlink are suitable for accumulation into a physical layer frame, so that physical layer overhead is reduced.
Burst or Packet Inter-arrival Time (Fig. 10 & Fig. 11)	The inter-arrival times of 80% of the uplink packets is less than 20 milliseconds, and it is less than 1 millisecond for 60% of the downlink packets. The inter-arrival times of 70% of the bursts in both uplink and downlink traffic is more than 10 milliseconds.	Small inter-arrival times of packets are not suitable. The lowest beacon interval in standard PSM is 100 milliseconds, whereas, only 20% of the packets (see Fig. 5) have inter-arrival time of more than 20 milliseconds. Therefore, standard PSM is not feasible to save energy when applications (used in the analysis) run on a device. However, when a device is in idle state, standard PSM can be used to save energy utilizing the *doze* mode.	Longer burst inter-arrival times cause less number of beacon messages. For the kind of traffic we observed, this technique requires transmission of frequent beacon messages as the inter-arrival times of 60% of the packets (see Fig. 5 and Fig. 11) are less than 20 milliseconds. Significant portion of bandwidth would be spent on sending beacon messages with increased number of clients attached to an AP.	Inter-frame space dozing is always beneficial (if achievable). However, longer inter-arrival times can be utilized in dozing if coordination with the AP can be maintained. These techniques suggest to utilize very small inactive periods even in between MAC inter frame spaces. Though dozing for a couple of micro-seconds is quite challenging given the present state of the wireless interfaces, it does not require co-ordination with the AP.	Small inter-arrival times are also good as they result in small burst durations. 80% of the uplink bursts have less than 5 millisecond of inter-arrival times and these bursts consist of packets of smaller sizes. These features are attractive for frame aggregation techniques. Inter-arrival times of packets can also be controlled by transport level technique such as PSM-throttling [17] to facilitate frame aggregation.
Burst Duration (Fig. 6)	About 80% of the bursts has duration of less than 10 milliseconds.	x	x	x	Data packets incur less delay for small burst durations. The observed burst durations are smaller than the packet inter-arrival times of *VoIP* traffic.
Burst Size (Fig. 7 & Fig. 8)	The size of the 90% of the uplink bursts is less than 1000 bytes. In downlink traffic, the burst sizes vary with the type of the applications, and for *YouTube* video, the burst sizes go beyond 20 kilobytes.	x	x	x	Smaller burst durations sometimes lead to larger burst sizes, and based on traffic, longer burst durations can also result into smaller burst sizes. Thus, both timer and size based thresholds need to be used in aggregation techniques.

x denotes that a technique does not deal with that parameter.

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