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Data Upload Capability of 3G Mobile Phones

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Abstract – **Mobile phones are becoming an important platform to measure free-living energy balance and to support weight management therapies. Sensor data, camera images and user input are needed by clinicians and researchers in close to real time. We assessed upload (reverse link) data transport rates for 2007-2008 model mobile phones on two major US wireless systems. Even the slowest phone (EVDO Rev 0) reliably uploaded 40 MB of data in less than 1 h. More than 95% of file uploads were successful in tests that simulated normal phone use over 3 d. Practical bandwidth and data currency from typical smart phones will likely keep pace with the data needs of energy balance studies and weight management therapy.**

I. Introduction

OBESITY is a serious public health problem associated with more than 112,000 excess deaths per year in the US and is burdening health care systems worldwide. Low levels of physical activity and inappropriate diet over the past four decades has resulted in more than 66% of the US adult population and 16% of children being overweight or obese (sex and age specific BMI $\geq 95^{th}$ percentile for age) [1]. Obesity and low Physical Activity (PA) are prime risks for several chronic diseases, including coronary heart disease, diabetes and cancer [2,3]. Wang, et al. estimated that by 2030, 86.3% of adults will be overweight or obese, and the prevalence of overweight in children will nearly double. Further, the cost of obesity and overweight could double to more than $860 billion by 2030; 16–18% of total US healthcare costs [4]. Unfortunately, past approaches to weight loss treatments have proven ineffective for both children and adults, despite increasing awareness and individual efforts to lose weight. One problem is the difficulty of effectively measuring energy balance (the sum of dietary energy intake, energy expended as work and heat, and weight gain) outside of a laboratory. Cell phones provide a way to measure the components of energy balance during every day activities in a person's natural environment. These measures are referred to as "free-living" energy balance. Behavioral and other researchers are now approaching successful weight management strategies by bringing frequent and accurate information on metabolic Energy Expenditure (EE) to mobile devices [5]. Support that is long term, timely and sensitive to context can improve behavior and interrupt damaging behaviors.

There are numerous PA and Heart Rate (HR) monitors that provide indices of daily EE and energy cost of various activities. However, limitations include cost, inconvenience leading to poor compliance, undetected failures, and limited performance (low data capacity). Mobile phones solve these problems by being ubiquitous voluntary accessories, having almost unlimited data capacity (both local memory and data upload capability), and many incorporate a local area network (LAN, Bluetooth), high quality accelerometer, and global positions receiver (GPS).

Hardware, software and provider services for mobile phones vary significantly and change frequently. Top priorities for mobile phone handset manufacturers and service providers emphasize the user experience (display, application and download (forward link) performance). Efficient streaming of data to smart mobile devices has been evaluated in a variety of conditions [6,7]. Uploading EE data that is collected continuously from multiple sensors has the characteristics of "reverse mobile streaming" [8]. We engaged in these tests because we could not find any studies that assessed real-world upload streaming performance relative to peak specifications.

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II. Methods

A series of tests were made on the two 3G data networks available in the US: CDMA EVDO and GSM EDGE. All tests were conducted with Motorola Q9 phones running the Windows Mobile OS (version 5.0 on a Q9c using Verizon CDMA **EVDO** and version 6.1 on Q9h for AT&T GSM **EDGE**). Two types of tests were conducted: "burst" data transport of 40 MB representing upload of data accumulated over 24 h of records and "continuous" data uploads to simulate monitoring of a free-living subject in near real-time.

The application for the mobile phones was written in C# with the Windows Mobile Version 6.1 SDK and .Net Compact Framework 3.5 edition. It comprised a timer and thread to initiate uploads of prepared data files at timed intervals or continuously. An SQLite database stored the data acquired from the GPS and accelerometer and wrote it to a comma delimited text file. For these tests, the prebuilt files were logged to the SQLite database on the phone with a timestamp, written to a StreamReader, and then passed to a dedicated web service (Fig. 1). When the upload was completed another timestamp was saved to the local database table as the stop time, along with signal strength, battery condition and current cell tower identifier. Signal strength and battery condition were retrieved from the phone's operating system.

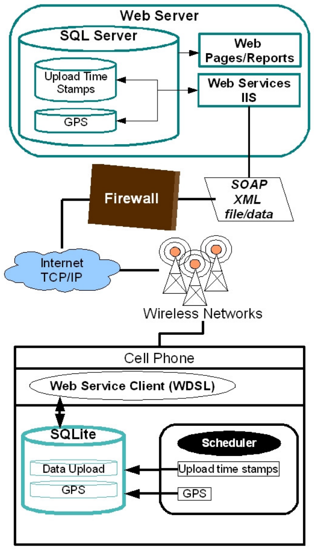

Fig. 1. Data transport from mobile phone to internet service.

The remote web server was configured in Microsoft IIS to load and run pages written in ASP.Net and web services written in C#. SQL Server 2005 was used to parse the uploaded file and store GPS, accelerometer and other data. The SQL database ran a series of stored procedures written in TSQL that were called from the web services to load the data into tables and acknowledge receipt of the file from the handset and capture timing.

On phones with an on-board 3D accelerometer we found that each axis (x, y, z) could be read at 15 Hz. This is sufficient to capture much of the frequency content of PA, which is believed to lie between 0.2 to 8 Hz. Though many investigators are now interested in continuous data to 30 Hz or higher to examine deliberate limb motions and tremors.

A. *Internet Service Delay*

A 100 kB file was uploaded to the internet data service from a desktop PC through a high-speed internet connection every 10 s to assess variation in delays caused by processes running on the server and in internet transport.

B. *Burst Data Transport Tests*

Mobile phones will not always have a wireless data connection to a remote server. Most phones accept memory expansion (SD) cards to increase storage up to several GB. So data can still be collected from an accelerometer and other sources even when wireless service is disrupted. When remote communication is restored the data must be uploaded in an intensive, burst, fashion to catch up.

Each read of three accelerometer axes plus a time stamp is 40 B. We calculated that 24 h of tri-axial data at 15 Hz along with GPS data and overhead would be approximately 40 MB and used this file size to represent 24 h of sensor data.

We created data files of 0.5, 1, 2 and 3 MB that contained mixed data of 15 Hz accelerometer records, GPS location and time stamps every 10 s. The phones were programmed to upload each size file as quickly as possible until a total of 40 MB of data reached the web service. Signal strength and start/stop times for each attempt to upload a file were logged on the phone and downloaded later for analysis. The phones were on line power and kept in a single location that allowed line-of-sight to at least one cell tower.

C. *Continuous Data Transport Tests*

An important benefit of using mobile phones is to provide data to investigators in near to real time during free-living studies. In many countries, cities and key transportation routes have good signal coverage that supports data transmission close to the declared rates. Lower performance occurs as a phone connection is handed off from one tower to another, with distance from a tower and where older equipment is installed. The continuous data tests measured actual data upload rates over 24 h periods as phones were carried and used normally.

Two file sizes (100 and 500 kB) were uploaded at 5 min intervals for 3 d. As in the burst upload tests, the files contained accelerometer and GPS data along with time stamps. The same process was also followed to log signal strength, battery status, cellular tower ID, whether a phone call was in progress and upload start/stop times. In addition, actual GPS location was logged on the phone every 10 s.

III. Results

A. *Internet Service Delay*

The server received 100 kB file uploads directly from the desktop PC within an average of 2.4 ± 0.17 s.

B. *Burst Data Transport Tests*

Burst data transport tests that moved 40 MB from mobile phones to a web server with file sizes of 0.5, 1, and 2 MB are summarized in Table I. The tests were run 7 times with each file size. The standard deviations shown were calculated for upload times of each file. Even with the slowest phone (EVDO Rev 0) and least efficient file size (0.5 MB) 40 MB was uploaded in 60 min or less.

TABLE I.
MEAN (± SD) UPLOAD RATES FOR CDMA EVDO REV 0 AND GSM EDGE TYPE 1 MOBILE PHONES

File size (MB)	EVDO ($kb \cdot s^{-1}$)	EDGE ($kb \cdot s^{-1}$)
0.5	99 ± 22	201 ± 78
1.0	109 ± 13.9	175 ± 56
2.0	110 ± 8.5	181 ± 65

The CDMA EVDO phone measured signal strengths at discrete values of 16, 42, 66, 90 and 100% (average 42, 71, 82% for 0.5, 1 and 2 MB files, respectively). Upload times by measured signal strength for the 0.5 MB file uploads are shown in Table II. Signal strength (94%) for GSM EDGE phone never varied and were not analyzed.

TABLE II.
MEAN (± SD) BURST UPLOAD TIMES FOR 0.5 MB FILE ON A CDMA EVDO REV 0 MOBILE PHONE BY SIGNAL STRENGTH

Signal strength (%)	Upload time (s)
42	45 ± 7.7
66	42 ± 7.3
90	42 ± 5.8
100	38 ± 2.7

C. Continuous Data Transport Tests

1) Upload Test with 0.5 MB file

The EVDO phone was used to upload 0.5 MB files every 5 min for 67.4 h (809 intervals). There were 35 upload errors (4.3%). On average, 157 MB of data was uploaded per day at 64 ± 47 s per file. This test included a round trip to rural Minnesota with 600 km of highway driving.

Table III shows upload times summarized by signal strength. Even when reported signal strength was 0 uploads were completed. The signal strength was read at the beginning of each upload and not checked again during the upload process.

TABLE III.
MEAN (± SD) CONTINUOUS UPLOAD TIMES FOR 0.5 MB FILE ON A CDMA EVDO REV 0 MOBILE PHONE BY REPORTED SIGNAL STRENGTH

Signal (%)	Upload time (s)
0	94 ± 37
16	100 ± 72
42	65 ± 43
66	46 ± 21
90	41 ± 5.8

2) Upload Tests with 100 kB file

The EDGE phone was used to upload 100 kB files every 5 min across multiple days: 70.4 h (845 intervals) and 76.4 h (917 intervals). Errors occurred at a rate of 1.7% for both tests. Average upload times were 13.9 ± 3.7 s and 15.3 ± 20 s for the first (845 interval) and second (917) tests, respectively. The second test included the same road trip as in upload test 1), above. A 58.6 h (709 interval) test with the EVDO phone in a metropolitan location had 10 errors (1.4%). Average (±SD) upload time was 10.6 ± 2.2 s.

IV. DISCUSSION

Different file sizes (0.5, 1, and 2 MB) were used for the Burst test upload to determine what data transport overhead existed and to identify a most efficient file size for uploading data as quickly as possible. The Microsoft .NET compact framework has an inherent buffer limitation that explicitly prevented 4 MB and larger files from being uploaded reliably. And these phones running Windows Mobile were not able to reliably handle 3 MB files. These size limitations might be removed by using an SFTP (SSH FTP) communications library.

We did not subtract the measured 2.4 s time for PC to server uploads from the times recorded for file transfers from the mobile phones. It was not possible to accurately apportion delays between the server response and transport over the internet. And communication between the cell phone wireless provider, and potentially within the provider's system, also used commercial internet transports. Nevertheless, the 2.4 s may contribute to a lower limit for practical file transfer times.

EVDO wireless communication on Verizon CDMA networks in the US has peak forward (download) speeds of 2.4 Mb/s in Rev. 0 and up to 3.1 Mb/s with Rev. A [9]. The reverse (upload) rates are 153 kbit/s for Rev. 0, and 1.8 Mbit/s for Rev. A. The Rev 0 EVDO phone we tested on the Verizon network achieved an average upload rate of 107 kbit/s, or about 70% of peak across all file sizes. The upload times and variance (SD) was consistent across file sizes.

Although AT&T Mobility (US) now uses the GSM HSUPA 3G wireless technology on most of its network, the phones we tested employed EDGE type 1 MS that provides peak up and download rates of 236.8 kbit/s. Across all file sizes data was transported at an average of 197 kbit/s; approximately 83% of the published peak rate. Interestingly, the 1 MB files uploaded more slowly than both larger and smaller files.

Even though we kept the phones in the same location and line powered it was possible that data upload rates were influenced by other factors such as variation in available bandwidth from cellular towers. Prolonged tests and in different locations may be necessary to determine a pattern.

Systems based on mobile phones to measure energy balance are a valuable application of free-living body area networks incorporating multiple physical sensors. An accelerometer and GPS receiver on board a smart phone can identify different activities such as cycling, running and riding in vehicle that have been difficulty to discern in the past. These data improve measures of PA and allow EE to be estimated automatically. Soon we will also see the use of several 3D accelerometers on the limbs, chest and other body parts; images collected to monitor food intake, motion and the environment; GPS; HR; and supporting information on the status of phone and software applications. So the need for bandwidth will continue to increase.

We found that even an early 3G data service (EVDO Rev 0) on a 2-y-old model smart phone could readily upload the 40 MB of data estimated to be produced over 24 h from one accelerometer sensor and GPS and simultaneously make or receive phone calls and check e-mail. Thus, we can 'catch up' with a full day of data in a few hours, such as during sleep, in cases where a user does not have wireless data service during the day.

During burst uploads the phone battery was drained more quickly and responsiveness of other phone applications slowed. Thus, it will be worth looking at techniques to reduce the burden of data transmission. There is a lot of self-similarity in the data so compression techniques could substantially reduce the time needed for uploads. And a number of other techniques can be employed to use available bandwidth effectively [10,11]. In addition, the coming roll-out of faster 4G (e.g., LTE, 50 Mbit/s peak uplink) networks promises much higher data rates 3G. Though, as noted above, we expect that the amount of data to be exchanged will also increase significantly for both uploads and downloads.

It takes a long time to create and reinforce a change in behavior. It also takes months or even years to achieve and maintain a significant weight loss. We used the continuous data upload tests to gauge the reliability of 5-min uploads of representative (100 and 500 kB) data files throughout several days. Uploads succeeded on more than 95% of attempts, even during highway travel and in relatively remote locations. It seems clear that as network density and speed increase mobile phone systems can easily a means for free-living measurement of energy balance and support weight management programs.

V. Conclusion

Even an early 3G data service (EVDO Rev 0) on a 2-y-old model smart phone could readily upload the 40 MB of data estimated to be produced over 24-h from one accelerometer sensor and GPS and simultaneously make or receive phone calls and check e-mail. Thus, we can 'catch up' with a full day of data in a few hours, such as during sleep, in cases where a user does not have wireless data service during the day.

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