The Mobile Experience

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Understanding and evaluating mobile devices today and tomorrow

Introduction

This report is designed for mobile application developers , OEMs, and consumers, and offers a perspective and focus that expands the evaluation of a mobile device from just processor speed, data feeds, and synthetic benchmark scores, to one that is more encompassing that includes the user experience, including:

Key Smartphone components

Today's modern smartphone has evolved and embraced a large variety of features and function, as well as an amazing number of components. The major components are:

a. CPU
b. GPU
c. Modem
d. Memory
e. GPS
f. DSP
g. Camera
h. Audio
i. Video

The combination of these components makes the modern smart phone a robust and extraordinarily useful device. They also make it a difficult device to evaluate and no simple test would adequately define a smartphone's capability or usefulness.

Mobile devices components

It's safe to say the mobile device revolution began when multimedia elements first appeared in the mobile phone beginning with an FM tuner, camera, and stereophonic sound. From those early, somewhat exploratory steps—would consumers respond favorably to such features or not, to the amazing breadth and wealth of functions we have today has been a rapid and exciting trip.

Consider the capabilities found in a modern smartphone:

Component	Function
Modems	
1G - TDMS	Voice and text.
2G - GSM/GPRS/1x	Voice, text, and data exchange.
3G – UMTS/WCDMA	Voice, text, graphics, video, and data exchange.
4G - LTE	Voice, text, graphics, video, and data exchange.
Radios	
AM receiver	
Bluetooth	Peer-to-peer communications and other peripherals.
FM receiver	Entertainment and information, emergency services.
FM transmitter	Play podcast, audio books, and music in the car.
GPS	Location information, tie into maps and databases for services.
NFC	Sense and communicate with transaction exchange points and security systems.
TV	OTA reception TV channels.
WiFi	Local linking with PCs and routers, reduce network traffic.
WHDI	Wireless displays
WiDi	Wireless displays.
WiGig	File transfer, wireless display, and docking.
WiMedia	Wireless Personal Area Networks for multimedia.
Sensors	
Accelerometers	Orientation, motion control, and potential health monitoring.
Barometer	Altitude and potential weather measurement
Camera(s)	Picture taking, video conferencing, Augmented reality, ambient light sensing, and stereoscopic capture.
Gyroscope	Pedestrian navigation, image stabilization, and game playing.
Magnetic	Provides a compass function.
Proximity	Turns off screen when talking on phone to save battery power.
Processors	
CPU	Two, four or more cores.
DSP	Microphone(s) input, speakers and headphone outputs, hi fi stereo.
GPU	2D and 3D games, user interfaces, and Web browsers.
Image	Light and color balance, fast picture taking.
Video	Decoding, encoding, and output to HD screens and monitors.

Peripherals	
Display (2D/3D)	The more screen area for user interfaces, videos, games, etc. and stereoscopic display.
Memory	SSD memory.
Microphone(s)	Audio input.
Speakers	Audio output.
Touch screen	Natural user interface with multi finger touch and virtual keyboard.
Input-Output	
Audio in-out	Ear phones and external microphone.
USB	Communications with peripherals and PC, and charging connection.
HDMI	Play a full 1080p video on a HDTV from the phone.
SD	Auxiliary memory.

Table 1: Features and functions in a smart phone

AM tuners were tried experimentally in 2008 (by Sony Ericson) but because the ferrite bar antenna required by AM radio receivers is much longer than that of an FM receiver, even if you coiled up the antenna tightly, it would add unwanted bulk, so AM didn't get included. In the case of FM, the wires of the headphone or earphone act as the antenna for the FM radio.

Wireless HDMI will soon appear in mobile phones implemented with either Intel's sponsored WiDi, or the Wireless Home Digital Interface (WHDI) consortiums solution

Exploiting the powerful processors found in a mobile phone the software applications that make use of the above listed hardware features is almost too numerous to list.

The mass acceptance of the smart phone has attracted new and exciting applications and created infrastructures to exploit the phone's sensors, the massive computing resources of the cloud, and the consumer's willingness to participate in activities that build databases of experiences and behavior.

Key User Experiences

The mobile phone can be used for so many things it's challenging to list them all. A few uses are listed here.

Augmented Reality. Augmented Reality (AR) applications on mobile devices was first demonstrated at the Christian Doppler Labor for Handheld AR lab at the Graz University of Technology in Austria in 2003. Since then the technology has expanded widely and is now used in advertising, game playing, maintenance, and health care to mention a few applications. Street sign translations, and navigation aids are being deployed by most carries around the world. The most important pieces of an AR system are: the tracking of location, in 3D and in real time, displaying video images blended with computer graphics, employing visualization techniques to determining what should be displayed, and in which form, and interfacing with a database of virtual and real objects to interact with.

Camera, Pictures and Video. In addition to the now ubiquitous touch, swipe screen, voice recognition, eye tracking and gesture recognition are also emerging as natural interfaces to the phone. The camera can be used for many things including traditional tasks such as photo blogging to more specialized sensing activities such as tracking the user's eye movement across the phone's display as a means to activate applications.

Remote diagnose using the camera to show a physician how an ill or injured person looks can assist in rapid and correct first-aid treatment until emergency units can arrive. Conversely medical records and x-rays can be sent to a phone to help a local doctor.

Gaming. When smartphones first started to be equipped with integrated graphics engines most people thought gaming would be the killer app. And then the iPhone was introduced at which time the UI, mobile web browsing, and all types of media became the killer app. But games didn't go away they just got better tracking the improvements in graphics engines and screen resolutions to the point that today's tablets provide a gaming experience that is near console quality from a graphics perspective.

GPS. Employing the GPS time location-trace collection and trace processing can be processed. This offers a class of adaptive, human in-the-loop sensing systems that combine the distributed processing of the web with mobile technology to engage people in exploring the previously unobservable relationships of their actions to the world around them. The GPS data can be used to recognize the mode of transportation of a user, such as using a bike or car or taking a bus or the subway.[1]

Mobile phone sensing systems will operate at multiple scales, enabling everything from personal sensing to global sensing. Obviously a rich multimedia mobile phone is a lot more than just pushing a few zillion polygons around on the screen, even if in stereovision.

Kenya's M-PESA mobile banking service, for example, allows customers of the mobile phone operator Safaricom to hold cash balances which are recorded on their SIM cards. Cash may be deposited or withdrawn from M-PESA accounts at Safaricom retail outlets located throughout the country, and may be transferred electronically from person to person as well as used to pay bills to companies.

Mobile Banking. In many countries, mobile phones are used to provide mobile banking services, which may include the ability to transfer cash payments by secure SMS text message. Mobile payments were first trialled in Finland in 1998 when two Coca-Cola vending machines in Espoo were enabled to work with SMS payments. Eventually, the idea spread and in 1999 the Philippines launched the first commercial mobile payments systems, on the mobile operators Globe and Smart.

Branchless banking has also been successful in South Africa and Philippines. A pilot project in Bali was launched in 2011 by the International Finance Corporation and an Indonesian bank Bank Mandiri. Another application of mobile banking technology is Zidisha, a US-based nonprofit microlending platform that allows residents of developing countries to raise

[1] M. Mun et al., "Peir, the Personal Environmental Impact Report, as a Platform for Participatory Sensing Systems Research," Proc. 7th ACM MobiSys, 2009, pp. 55–68.

small business loans from web users worldwide. Zidisha uses mobile banking for loan disbursements and repayments, transferring funds from lenders in the United States to the borrowers in rural Africa using the internet and mobile phones.

NFC. Near Field Communications technology is widely used in Japan to pay for anything from a train ticket to a can of soda, with consumers simply 'bumping' their NFC enabled smartphone in order to make an instant transaction. Mastercard Paypass is now making inroads with this technology in the US, and it has been suggested that NFC will become a standard smartphone feature by 2015, creating a commerce opportunity of $800 billion. Enabling NFC transactions games could open the door to impulse purchases of in-game content and associative or adjacent applications.

Stereovision. One of the most exciting developments taking place in various platforms today is stereovision. As smart as out devices are, they look at, and display a flat 2D world. That is too limiting. Very soon all our devices will offer us a stereo display. We can choose to use it or not. Stereo vision will not be just display but capture too, and you can expect to see your devices with either two optical sensors, or a plenoptic lens, and most likely it will be the later. With a plenoptic lens (facing and forward) and a powerful SIMD heterogeneous processor, backed up by the cloud AR begins to look like the next killer ap. AR for location sensing and assistance, games, health, and various commercial and safety applications. However, costs are still critical and so the market may be delayed waiting for "first mover" to get the product ramped and the costs down.

Business intelligence. Mobile business intelligence (BI) and analytics applications raise a number of important data management concerns. Organizations need to evaluate their readiness to meet data security, availability, performance scalability, real-time data, and other challenges that are likely to increase in intensity as mobile deployments grow. Organizations also face new data synchronization challenges in making sure that mobile users see the same data that's presented on premises to desktop users BI and analytics applications.

And much much more

The mobile has become so ubiquitous and so powerful it's almost impossible to catalog all of its uses and applications. Email and text are among the most common usages of a mobile phone besides phone calls and various surveys have been done to find out what users do with them.[2] [3] [4] [5] No conclusive results could be found, the surveys gave different results depending upon who did the survey, and most of all, who the surveyors could get to take the survey. For example the respected PEW Internet found 76% used their phone to take pictures and 34% to play games. Well know surveyor Nielsen found that 61% played games

[2] Internet use and data applications using mobile phones. http://www.pewinternet.org/Reports/2010/Mobile-Access-2010/Part-2.aspx
[3] Games Dominate America's Growing Appetite for Mobile Apps. http://blog.nielsen.com/nielsenwire/online_mobile/games-dominate-americas-growing-appetite-for-mobile-apps/
[4] Social Media Report: Spending Time, Money and Going Mobile. http://blog.nielsen.com/nielsenwire/online_mobile/social-media-report-spending-time-money-and-going-mobile/
[5] Young Adults Lead Mobile App Use. http://www.marketingcharts.com/direct/young-adults-lead-mobile-app-use-13509/

and picture taking wasn't even mentioned. But is interesting is looking at the surveys is the list of activities considered.

Access the internet	Banking/Finance	Communication (IM, VOIP, etc.)
Dining/Restaurant	Entertainment	Food/Drink
Games	Household/Personal Care	Lifestyle/Health
Maps/Search	Music	News
Play music	Productivity	Record a video
Send or receive email	Send or receive instant messages	Send or receive text messages
Shopping/Retail	Social Networking	Sports
Take pictures	Travel	Video/Movies
Weather		

Table 2: Consumer activities with a smart phone

Let's say you're driving and become tired. Your smart device will detect that, note your blood sugar and the last time you ate, evaluate where you need to be and when, and decide if you should be directed to a local restaurant, a hotel, or just yelled at "Wake up –you're going to be late." And then if you don't respond appropriately, the car will slow down and the right turn signal will go on, with a loud beeping in the cabin.

In September 2010, and again in March 2011 YouGov Plc. surveyed people aged 16 or over in the UK and asked: For which, if any, of the following activities have you used your smartphone?

Wave 3 — 14 - 21 September 2010 - Wave 3 — 2,241

Wave 4 — 31 March - 5 April 2011- Wave 4 — 2,103

The results are shown in the flowing chart

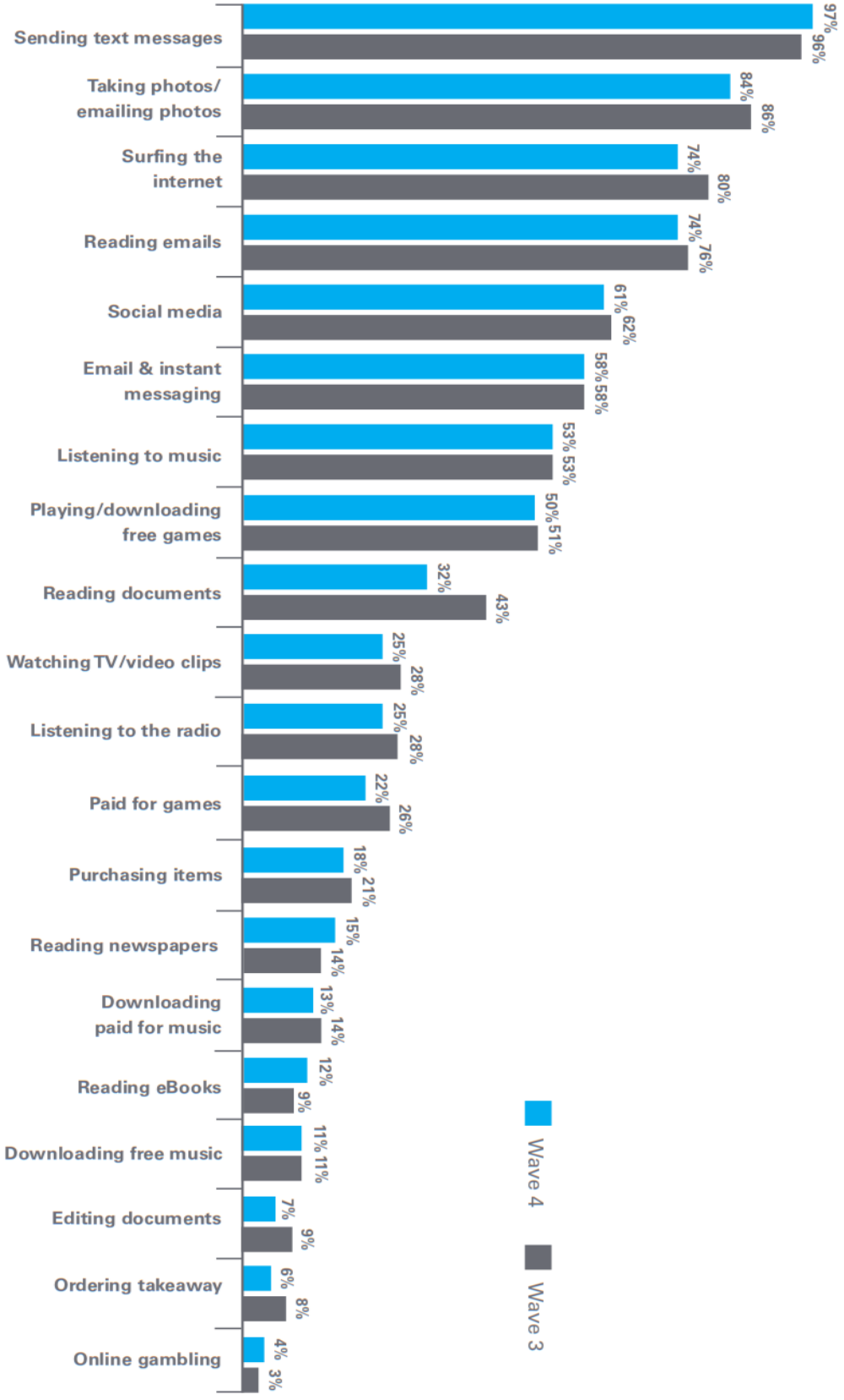

Figure 1: UK Smartphone activities

Almost three-quarters (74 percent) downloaded apps on their smartphones in the past 12 months — however, 42 percent only downloaded free apps, up from 39 percent in wave 3.Those paying for apps spent, on average, £5.65 in the month to 31 March 2011, up slightly from £5.30 in wave 3.

Other measurements and surveys of usage have been conducted by Nielsen and Comscore and are shown in the following diagrams.

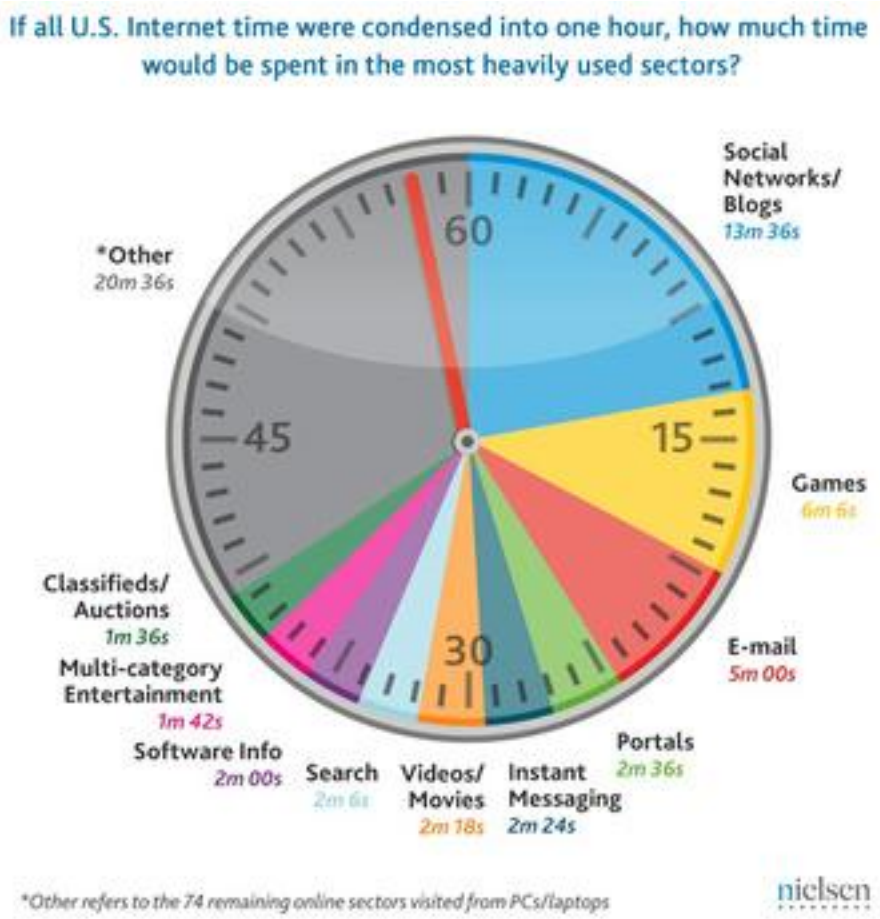

Figure 2: Nielsen measurement of Internet usage

Mobile Activities in the U.S., EU5 and Japan by % Share of Total Mobile Users
Source: comScore MobiLens, 3 mo. avg. ending Dec-2010, Japan data for Dec-2010 only

	U.S.	EU5	Japan
Played Games	23.2%	25.3%	16.3%
Accessed Search	21.4%	14.9%	31.5%
Captured Video	20.2%	26.1%	15.8%
Accessed Maps	17.8%	13.0%	17.1%
Used Instant Messaging	17.2%	14.2%	3.6%
Accessed Sports Info	15.8%	12.0%	18.2%
Listened to Music	15.7%	25.0%	12.9%
Accessed Bank Accounts	11.4%	8.0%	7.0%
Accessed Financial News or Stock Quotes	10.2%	8.0%	16.5%
Accessed Restaurant Info	10.0%	6.5%	9.7%
Accessed Traffic Reports	8.4%	7.4%	14.0%
Accessed Classifieds	7.3%	4.8%	3.6%

Figure 3: Comscore measurement of mobile activities

In China the trends are similar as shown in the following survey.

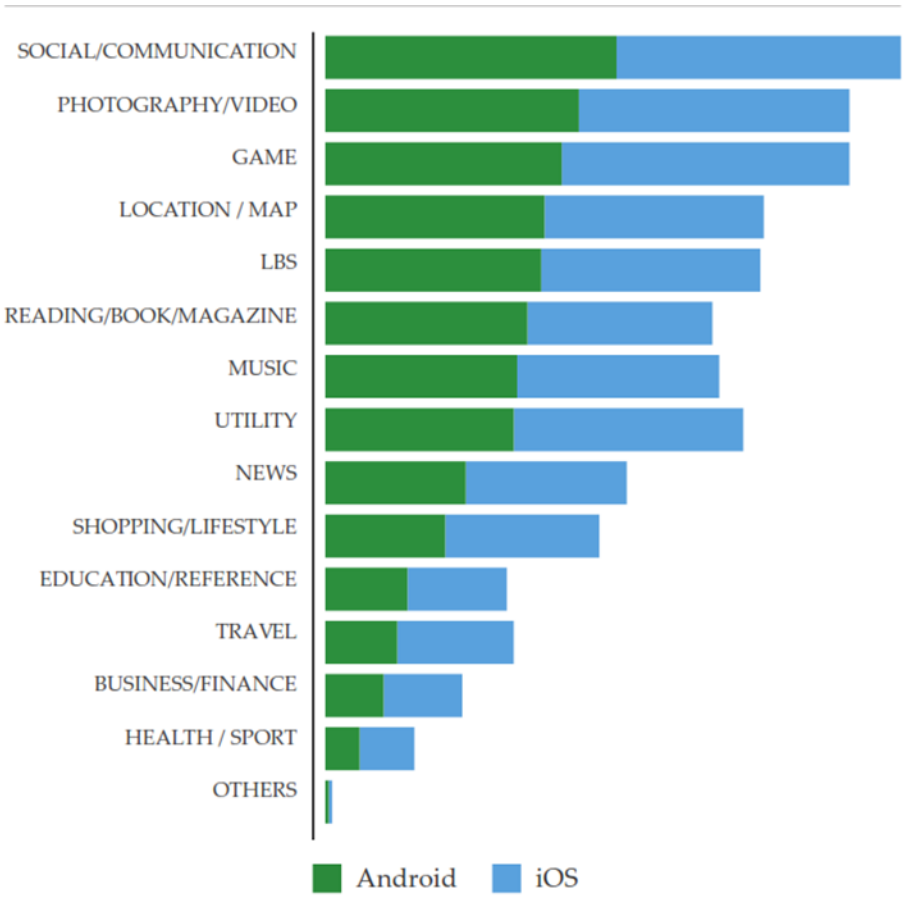

Figure 4: Smartphone users in China

Smartphone users as a whole really love games. According to Xyologic, an App Store tracking agency, over 50% of the top 150 free apps downloaded in Oct 2011 are games, around 16% are utilities and 13% are social networking apps. Similar breakdown can also be seen in the paid apps domain. Games are a very important category on mobile.

As the surveys and measurements show, a mobile device, particularly a smartphone is used for numerous activities and has truly become the ultimate "PC"—personal companion. The question then becomes, how does one evaluate a smartphone given all its capabilities?

Proposed solutions to benchmark approach

A call to action to benchmark makers

There are almost as many benchmarks for a smart phone as there are functions. It's only been recently that the smart phone has had an open and accessible operating system, so benchmark and testing programs in the public domain have been limited.

Because of the limited suite of test programs for the smart phone, too much emphasis has been placed on the few that do exist. The basic mistake that most benchmarks make is that they capture component performance and not experience performance – not the fault of the

benchmark, but of the benchmark maker – they are not measuring the user experience so people are being misled by most benchmarks if they think they can translate component results to user experience.

A few of the newer benchmarks– like Basemark OS, Electopia and Vellamo are trying hard to fix that where they by combining component scores and then weighing the results to create an estimate of user experience that can be compared across devices (and hopefully are open in their process to avoid the bias and cheating).

They of course are not perfect—could any single benchmark be, but they are a step in the right direction and will evolve. And that the next generation of user benchmarks will have to be more pertinent and useful for user experience, and not just test a component. (Component testing is of course useful to device and semiconductor builders for internal design efforts.)

In addition, the semiconductor manufacturers and IP suppliers want the tests to show off their best features. That puts the developers of benchmark programs in an awkward position: on one side they have to appeal to the SoC and IP suppliers as customers of their tests, and on the other side they have to try and be objective so their programs fairly and realistically test the SoCs.

Benchmarks are relied on by the customers of the SoCs – the handset and device manufacturers, by their customers the carries and major resellers, and by the consumers. No government agency, commercial testing labs, consumer group, or standards body is directly involved with the process of benching smart phones and its left up to individuals, publications, web sites and bloggers. That of course leaves a lot open for interpretation, nuance, unscientific evaluation, and cheating.

Add to that the limited number of tests for such an amazingly sophisticated device like a smartphone, and you end up with a mischaracterization of device and its capabilities. The consumers, carriers, and device builders are the victims, and the industry as whole is discredited as a result.

In addition many elements can be extremely difficult to test objectively, such as the cameras, battery, touch-screen responsiveness, etc.

The solution

It’s easy to prescribe, difficult to implement. Test for everything. The SoC suppliers have to, and the ones who also supply the radios and modems have to test for even more situations, plus submit the reference designs to various government agencies throughout the world that regulate the spectrum.

Suites

We propose an industry-wide agreement on a set of suites of tests for five or six of the most common usage scenarios. For example, a test that shows how fast a device can take a full resolution picture, and how many times before the battery is depleted or the memory full. A

test that reports on the device's ability to download a full-length HD movie, store it, and then play it at HD on the device's screen and a HDTV. A test that reports on the performance of the device running a full resolution game with all graphics functions at maximum—and for how long the device can run that test. Other usage scenarios that would include transcoding, audio recording, and accuracy of the GPS, accelerometer, and gyro are also needed. We need a robust suite of tests that can be applied to various user modalities.

However, most of the benchmark developers are small companies, sometimes just one or two people. It's unlikely a single benchmark developer can achieve such a suite, and so what will be needed is some kind of a consortium that can fund the research and development.

Although there are several applications and use cases for a smartphone, none use more functions and components than augmented reality (AR). Almost all the sensors are used: Accelerometer, GPS, Gyroscope, Barometer, Microphone, and Camera. In addition to the sensors, all processors are used, CPU, DSP, GPU, and ISP; as well as several radios. A benchmark of AR would be as close as one could come to a total test of a smartphone.

No time like the present

Given the complexity of smartphones and the proliferation of benchmarks, we have to acknowledge we don't have an ideal world, nor do we have a complete solution, and yet we have to move on. Therefore, we have selected a few benchmarks to use in a collective manner to try and arrive at a reasonable evaluation of smartphone for a generalized use case.

To do that we have selected six primary applications to evaluate and chosen what we think is the most appropriate benchmark for the evaluation. That's not to say that these benchmarks are the only ones nor do we want to suggest that they will always be used—this is rapidly evolving industry.

CPU:

- Linpack
- CaffeineMark
- AndEBench

Memory:

- Stream

GPU:

- GLBenchmark
- BaseMark ES 2.0

Web:

- Vellamo

Gaming:

- Electopia

System:

- Basemark OS

The following a brief description of the benchmarks

AndEBench

The Embedded Microprocessor Benchmark Consortium (EEMBC) has standardized its method of evaluating Android-enabled devices with a benchmark, named AndEBench.

AndEBench gives users an opportunity to validate and compare operations on their phones or tablets, many of which vary considerably in performance.

This benchmark is available on Google Play (the rebranded name for the Android Market) and the Amazon Appstore for Android. AndEBench includes a battery of performance tests for mobile devices; however, primary focus is on the CPU and Dalvik interpreter performance. Originally authored by Dan Bornstein, Dalvik is the process virtual machine inside the core of the Android operating system.

In addition to testing a device's multicore and/or multithreading capabilities, the 1.0 iteration of the benchmark compares the Android platform's native and Java performance with the objective being to provide a quantified measure of the Java interpreters'

efficiency on a given platform and help users and developers understand what performance gains are feasible.

Basemark ES and OS

BaseMark ES 2.0 is an OpenGL ES benchmark developed by RightWare that measures performance of graphical user interfaces in embedded devices. The benchmark tests enabled by Basemark GUI generate the workloads that tax the graphics system in a realistic and visually stunning way. The Basemark GUI benchmark product gives hardware manufacturers the tool to analyze platform capability for user interface applications using 3D graphics.

Basemark GUI for OpenGL ES 1.1 and 2.0 executes tests for a user interface (3D UI) and for more specific techniques (feature tests). The 3D UI test represents a futuristic 3D user interface with main view and three sub-applications. These applications include photo browser, volume controls and music selector. The user interface elements within these screens are made completely in 3D space. The feature tests include, for example, animations, streaming of different assets, blending, different compositions.

Basemark OS for Android is a comprehensive system-wide Android OS benchmark developed by Rightware. It is designed to enable an objective comparison of Android-based devices with accurate and reliable suite of benchmark tests for mobile phones, pads, consumer electronics and other embedded devices running Android OS on ARM architectures.

The program tests standard Android applications, messaging services, Java, file operations, memory IO, databases, zip compression and decompression, as well as the classic Dhrystone ALU and Whetstone FPU tests. The graphic tests featured in Basemark OS for Android provide measurement of 2D imaging, image scaling, JPEG, PNG and GIF encoding and decoding, and a compelling 3D test set with fillrate, polycount, lighting, texturing and rendering tests. Media decoding tests include H263, H264, MP4 and 3GP video decoding tests as well as AMR, AAC, MP3 and WAV audio decoding tests. In addition, Basemark OS for Android provides program startup tests for various standard Android applications, Bluetooth and Dialer.

CaffeineMark

Developed by Pendragon Software Corporation, the CaffeineMark is a series of tests that measure the speed of Java programs running in various hardware and software configurations. CaffeineMark scores roughly correlate with the number of Java instructions executed per second, and do not

depend significantly on the the amount of memory in the system or on the speed of a computers disk drives or internet connection.

The CaffeineMark uses 9 tests to measure various aspects of Java virtual machine (VM) performance. Each test runs for approximately the same length of time. The score for each test is proportional to the number of times the test was executed divided by the time taken to execute the test.

CaffeineMark 3.0 scores cannot be compared on an equal footing with scores from earlier versions of the CaffeineMark.

Electopia

Electopia was developed by Tactel US on behalf of Qualcomm. Unlike most mobile benchmarking applications available for Android users, the Electopia OpenGL ES 2.0 benchmark was written by game developers in a manner that is representative of advanced, real world mobile games. Electopia provides graphics performance measurements along with features like the ability to isolate GPU performance from other system factors like LCD resolution.

Electopia Benchmark is an OpenGL ES 2.0 3D game benchmark for mobile platforms with built in benchmarking functionality. Featured rendering techniques include post processing effects such as depth of field, as well as projected shadows and water surface rendering using normal maps.

GLBenchmark

The GLBenchmark benchmark was developed by Kishonti Informatics. The company's OpenGL ES benchmarks tests the quality and performance of the underlying OpenGL ES 1.x/2.0 implementation used in most smartphones. The company believes the test covers current trends: gaming, navigating and user interface.

As a unique feature these native tests are also implemented as Java ME applications using JSR-184 or JSR-239 that makes it possible to compare native vs. Java ME results side by side.

Linpack

The Linpack for Android application is a version created from the original Java version of Linpack created by Jack Dongarra.

The LINPACK Benchmarks are a measure of a system's floating point computing power. The tests measure how fast a computer solves a dense N by N system of linear equations Ax = b, which is a common task in engineering. The solution is obtained by Gaussian elimination with partial pivoting, with 2/3*N3 + 2*N2 floating point operations. The result is reported in Millions of FLoating-point Operations Per Second (MFLOP/s, sometimes simply called FLOPS).

This test is more a reflection of the state of the Android Dalvik Virtual Machine than of the floating point performance of the underlying processor. Software written for an Android device is written using Java code that the Dalvik VM interprets at run time.

Vellamo.

Qualcomm introduced Vellamo, a suite of 11 tests designed to gauge browser performance on Android phones and tablets. It works with any device running Android 2.0 or above, independent of processor type. The tests spans four broad categories -- rendering, JavaScript, user experience, and networking -- with only two requiring an internet connection.

Vellamo provides a holistic view into browser performance and stability, including networking, JavaScript, rendering, and user experience. Incorporating industry standard and custom tests,

Benchmark results

Several of the above benchmarks were used to evaluate the generational improvements in Application Processors (Aps) from Qualcomm. The results are shown in the following charts.

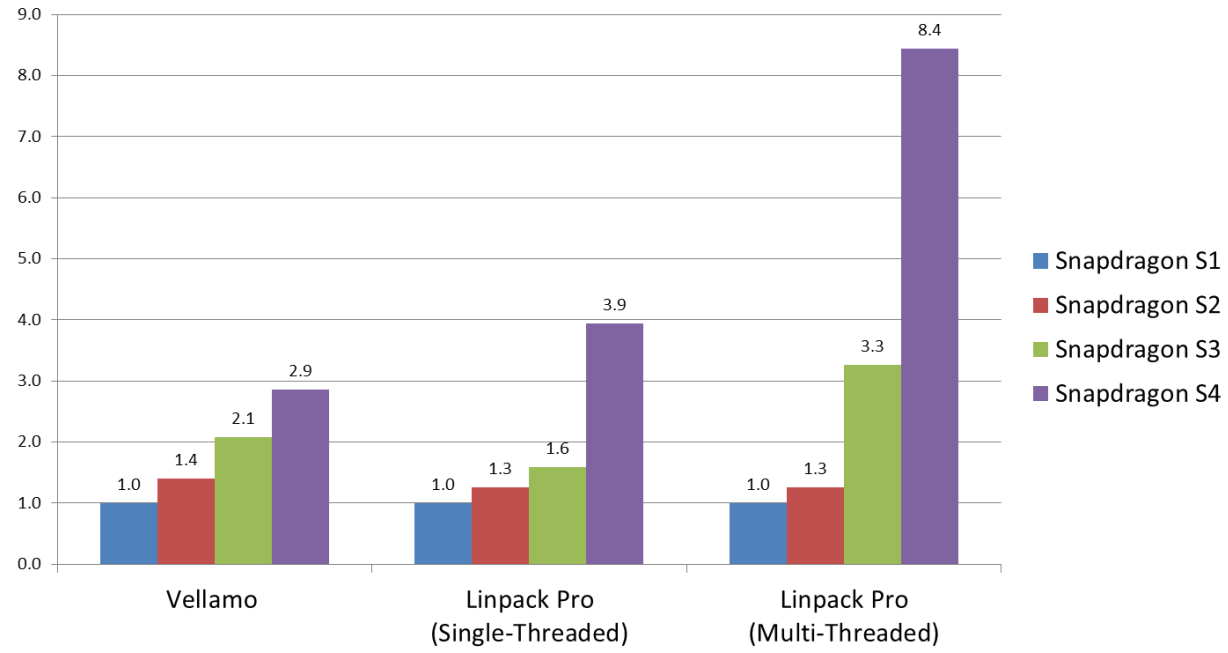

Figure 5: CPU and browser benchmark results

The same Aps were tested for their graphics performance

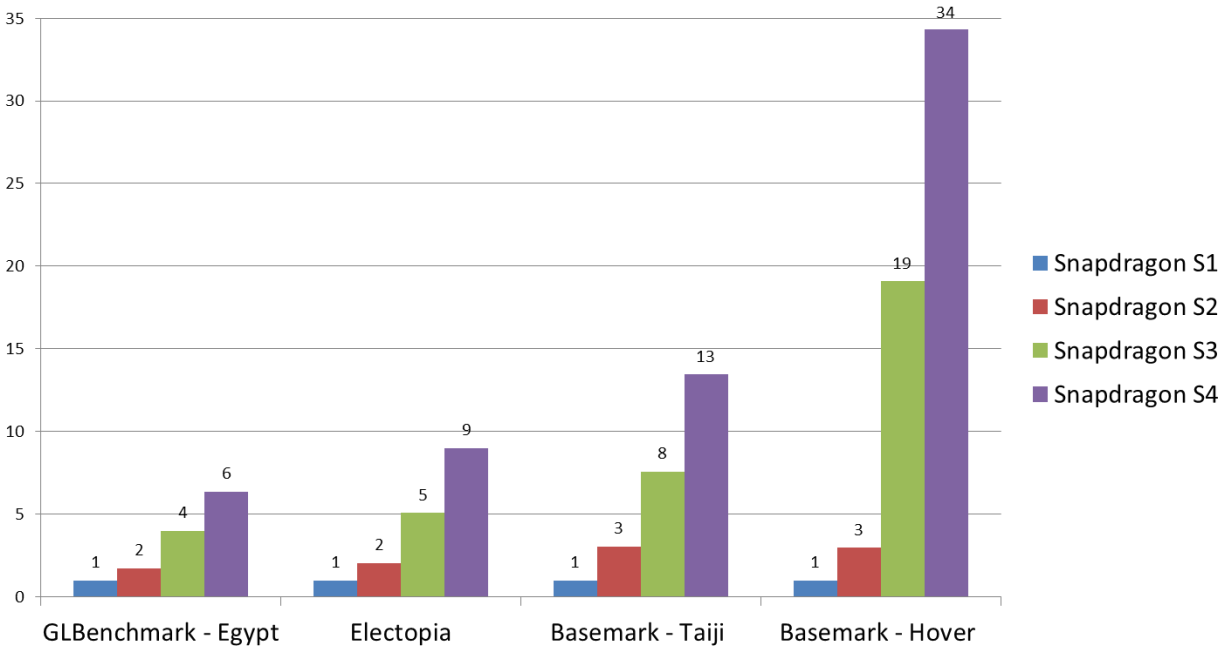

Figure 6: Graphics benchmark results

Data is based on FPS performance normalized to WVGA

Test Platforms

- Snapdragon S1 – MSM7x27AA (FFA, 1 GHz) Android ICS data measured @ WVGA
- Snapdragon S2 – MSM8x55 (FFA, 1 GHz) Android ICS data measured @ WVGA
- Snapdragon S3 – MSM8660 (FFA, 1.5GHz) Android ICS data measured @ 1024x600
- Gfx performance (FPS) linearly scaled to WVGA
- Snapdragon S4 – MSM8960 (HTC One X (Pre Commercial), 1.5GHz) Android ICS data measured @ 1280x720
- Gfx performance (FPS) linearly scaled to WVGA

Graphics Benchmark versions

- GL Benchmark – mix of v2.1.1 and v2.1.2 data
-
- Basemark ES2.0 V1 (for Taiji & Hover)

A useful benchmark would be one that measure the actual power consumption of the AP while it was going through various benchmarks. A FPS/watt measurement is needed.

Summary

Today's Smartphones have an amazing array of sensors, radios, and processors. Those pocket wonders are our lifeline, entertainment center, communications device in every form, and effectively our personal companions.

How each of us use one varies, but certain patterns of usage have been measured. We all make phone calls, take pictures, text, read email, surf the web, listen to music, pay games, use navigation aids, and watch videos. And the newest and most challenging application is augmented reality, which promises to completely change our lives—for the better.

But there is no simple way to test a Smartphone that encompasses all the myriad of uses and applications. Therefore, we need a suite of tests to be able to evaluate one device from another over a range of functions. Maybe someday a single comprehensive test will be developed. However, in the meantime a suite of available tests is proposed to be used. If we can get the industry to agree and be consistent, we'll be able to make intelligent comparisons and decisions on which Smartphone is best for our budget and needs.