Batteries for portable ICT devices

How to store large amount of energy in batteries for increasingly complex mobile and portable applications is a major technological challenge, and of particular importance in the area of information and communication technologies (ICT). At present, both manufacturers and governments are investing in research on clean and energy-efficient technologies and longer-lasting batteries to cater for portable electronic devices with power-hungry features. This Alert summarizes some of the key trends and developments.

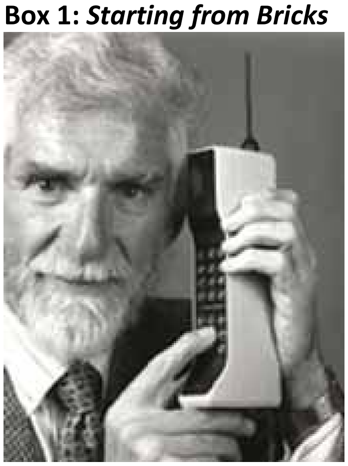
Advances in processing power and new-generation communications links have increased mobility and driven the demand for mobile phones, laptops and other gadgets, including e-books, portable media/MP3 players and digital cameras. (Hybrid) electric cars have become the dynamo of many motor shows[1], and on-board battery packs are a crucial ingredient. Market research suggests that the $71 billion-a-year world-wide battery market – rechargeables accounting for two-thirds – could grow by 4.8 percent annually through 2012[2].

Battery characteristics

The speed at which mobility and portability advance depends to a large degree on battery performance, but while mobile ICT devices have been enhanced quickly, batteries have not kept pace. In recent years, batteries have been improved in terms of energy density, but higher power requirements of devices have eaten up any benefit made in better battery performance, with the result being more powerful devices with the same runtime.

To address the demand for longer device runtimes, progress has been made in reducing power consumption at different levels of the system design, allowing devices to operate more energy efficiently. Some of these advances in energy savings are, however, again offset by the demand for faster processing of lap-

Box 1: *Starting from Bricks*



The picture shows a Motorola DynaTAC 8000X (Dynamic Adaptive Total Area Coverage), the world's first commercial cellular phone, receiving FCC approval in 1983. Also known as 'brick phone' for its dimensions (33cm x 4cm x 9cm) and weight (0.9kg), the $3,995 phone and its battery offered a half-hour talk time, up to eight hours of standby time, and took 10 hours to recharge. More than 25 years after Motorola launched the brick, the number of global mobile phone subscriptions has grown from approximately 300,000 in 1984 to more than 4.6 billion today.

Source: Retrobrick, http://www.retrobrick.com/moto8000.html

[1] See, for instance, Geneva International Motor Show 2010, and ITU/ISO/IEC's The Fully Networked Car workshop, 3-4 March 2010, http://www.itu.int/ITU-T/worksem/ict-auto/201003/

[2] The Wall Street Journal. "The Search for a Better Battery Seems Everlasting," 28 October 2008. http://online.wsj.com/article/SB122514888694374121.html

tops or energy-hungry multimedia features of mobile phones (see Box 1).

To design an all-in-one solution – a safe, lightweight, small size and environmentally friendly battery, with a high-energy density, long run- and lifetimes – appears to be a difficult task. An overview of important battery features and characteristics is given in Table 1. While no breakthrough innovations are imminent, existing solutions are being gradually improved and adapted to best meet the particular requirements of a given device or application.

Table 1: Battery characteristics (adapted from various sources, mainly BatteryUniversity.com)

Characteristics	Description	Unit	NiCd	NiMH	Li-ion	Li-ion polymer	Lead-acid
Energy Density	Amount of energy stored in a given system per unit. Gravimetric and volumetric energy density.	Wh/kg	40-60	30-80	100-160	130-200	30-40
		Wh/L	50-150	140-300	270	300	60-75
Nominal cell voltage	Potential difference the battery can supply when charged.	V	1.2	1.2	3.6	3.7	2.1
Charge / Discharge Efficiency	Amount of power used from the battery while discharging divided by the amount of power delivered to the battery while charging, multiplied by 100 to yield per cent.	%	70-90	66	80-90	99.8	70-92
Self Discharge	Internal chemical reactions reduce the stored charge of the battery without any connection between the electrodes. It decreases the shelf-life of batteries and causes them to have less charge than expected. It is highly dependent on temperature. Numbers for discharge at room temperature.	% / month	20	30	5	5	3-4
Fast Charge Time	*"Fast" Charging:* Recharge requiring complex circuitry (e.g., timers for fail-safe cutoff) for faster charging time.	hours	1	2-4	<1.5	<1.5	8-16
Lifetime	It is the elapsed time from manufacturing and until before a battery becomes unusable whether it is in active use or inactive.	years	n.a.	n.a.	2-3	2-3	5-8 (car bat.), 20 (stationary)
Cycle Durability	Number of complete charge-discharge cycles a battery can perform before its nominal capacity falls below 80% of its initial rated capacity.	#	1500	500-1000	~1200	~1000	500-800
Maintenance requirement	Maintenance period for procedures to keep the battery in good condition , e.g., to avoid sulphation	months	1-2	2-3	Not required	Not required	3-6
Memory effect	Performance degrading effect describing batteries gradually lose their maximum energy capacity when repeatedly being recharged after being only partially discharged.		YES	NO	NO	NO	NO
Safety	(1) Thermally stable (2) Thermally stable, fuse recommended (3) Protection circuit required/recommended, can rupture, ignite, or explode when exposed to high-temperature environments		(2)	(2)	(3)	(3)	(1)
Toxicity	(1) Highly toxic, harmful to environment (2) Toxic lead and acids, harmful to environment (3) Relatively low toxic, recycling recommended (4) Low toxicity, disposable in small quantities		(1)	(3)	(4)	(4)	(2)
Cost	Energy per consumer-price (approximately)	Wh/US$	n.a.	1.37	2.8-5	2.8–5	5-8

Even though manufacturers and advertisers state battery run- and lifetimes, this information should be treated with caution, as it depends on variable usage patterns, e.g., power management settings, the use of features (WiFi, DVD drive) or applications. To date, no common methodology or standardized procedure is available to provide exact and comparable information on battery runtime of ICT devices.

Current battery technologies

Today's most known and most used batteries are based on lithium-ion (Li-ion), nickel-metal-hydride (NiMH), lead-acid and nickel-cadmium (NiCd). While the sale of NiCd batteries has been legally banned in the European Union due to toxic components[3], lead-acid batteries are typically found in applications which require high peak power, e.g., to start a car, or in scenarios where battery weight is a minor concern, e.g., for uninterruptable power supply. However, due to their low energy density, lead-acid batteries are not practical for mobile use.

For this reason, Li-ion and NiMH batteries are most commonly used in portable electronic devices, with Li-ion batteries usually offering a higher energy density than NiMH. In addition, Li-ion batteries allow for a great number of charge/discharge cycles without memory effect, which ensures a long battery lifetime: it is estimated that Li-ion batteries lose up to 5 per cent of charge per month due to self-discharge processes, compared to an up to 30 per cent loss per month in NiMH batteries. Form and weight are important factors for the choice of batteries in portable devices. Li-ion batteries exist in a wide variety of shapes and sizes while being relatively light weight. Advantages of NiMH over Li-ion batteries include lower cost, high current, and no need for processor controlled protection circuits. NiMH batteries are often found in digital cameras.

New energy sources for mobile devices

The constant need to recharge batteries compromises the mobility and autonomy of the devices they power. Aware of this, many manufacturers are involved in the research for advanced or alternative energy sources that should also be safe, clean and cheap. Promising technologies exist, although a leader has not yet emerged.

Research on mobile power supplies can be generally grouped in three categories[4]:

1. Incremental advances to current solutions, mainly in the field of Li-ion batteries;
2. Application of known alternative power supplies (such as photovoltaics, fuel cells, thermoelectricity, piezoelectricity, (human) movement) to mobile devices;
3. Breakthrough developments by applying nanotechnology: cell-sized batteries, nanoscale fuel cells, nanoscale capacitors, electroactive polymers, dielectric elastomers, new semiconductor compounds and the use of organic materials.

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[3] European Union: "Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment," 2002/95/EC, February 2003. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0095:EN:HTML

[4] Robion, A. et al.: "Breakthrough in energy generation for mobile or portable devices," Telecommunications Energy Conference, 2007, pp.460-466, 30 September 2007 – 4 October 2007. http://ieeexplore.ieee.org/iel5/4448710/4448711/04448821.pdf?arnumber=4448821

Within the second category, an exploratory focus has been laid on photovoltaics and fuel cells[5]. If these technologies could be miniaturized and incorporated into portable electronic devices, they would represent a step forward in extending the autonomy between recharges.

Solar photovoltaics have been used in some applications for about three decades (e.g., in pocket calculators), and recent progress has encouraged some ICT manufacturers to experiment with thin-film solar cell powered portable devices[6]. However, as solar radiation is highly variable, photovoltaics can at best extend battery lifetimes at the current state of development. Other obstacles for mobile use of solar cells include efficiency, size and cost.

Fuel cell systems, in particular direct methanol fuel cell (DMFC) technologies, are embraced by some as the energy technology of tomorrow. Similar to conventional batteries, fuel cells produce energy through an electrochemical reaction, but from compounds like hydrogen, methanol, and ethanol. The main difference is that fuel cells are constantly being charged due to the flow of chemicals, as long as the fuel supply lasts. Current DMFCs are limited in the power they can produce, but they can still store a high energy content in a small space. This means they can produce a small amount of power over a long period of time. This would make them optimal for consumer goods such as mobile phones, laptops and cameras (see Box 2). The main hurdles to be overcome for fuel cell technology in such devices include power handling, down-sizing and cost. For now, there still exist problems related to the longevity of the fuel cell stack and the membranes, the core of the engine. Hence, fuel cells are at present often found only in special applications, such as providing power to space vehicles and submarines, in environments where no combustion is possible, and where toxic exhausts cannot be tolerated.

Nanotechnology – the branch of engineering that deals with things smaller than 100 nanometers (especially with the manipulation of individual molecules)[7] – can be applied to most current technologies with a multitude of benefits, among them miniaturization, flexibility in scaling, and increased energy density for energy storage systems. One field of nanotechnology research is addressing the storage of energy in carbon nanotubes,

Box 2: *Mobile fuel cells*

Toshiba DMFC laptop

Hitachi fuel cell PDA

Source: Fuel Cell Today, http://www.fuelcelltoday.com

[5] Jiang, L. and Korivi, N.S.: "Miniature fuel cells for portable power applications," SoutheastCon, 2007. Proceedings. IEEE , pp.343-343, 22-25 March 2007. http://ieeexplore.ieee.org/iel5/4147361/4144548/04147448.pdf?arnumber=4147448

[6] LG Display Co.: "LG Display Unveils 'Solar Cell e-Book'," October 2009. http://www.lgdisplay.com/homeContain/jsp/eng/inv/inv101_j_e.jsp?BOARD_IDX=1773&languageSec=E&kinds=IN1

[7] See Princeton WordNet http://wordnetweb.princeton.edu/perl/webwn?s=nanotechnology

for instance with the help of electric fields. Also, the properties of nanomaterials can be beneficial to the development of high-performance Li-ion batteries. But before being ready for use in consumer goods, further research is required to better understand the mechanisms of lithium storage in nanomaterials, and to achieve controlled, large-scale synthesis of nanostructures and kinetic transport on the interface between electrode and electrolyte[8].

An even more recent field of research focuses on cell-sized batteries. These are tiny microbatteries about half the size of a human cell, which might one day power a range of miniature devices by stamping them onto a variety of surfaces[9]. One of the potential benefits of nanotechnology and cell-sized battery technology is that they could open the way for new features and start a new era for mobility.

Chargers and charging of portable ICT devices

Closely connected with battery powered devices are adapters and chargers. When replacing a mobile phone, the user is usually obliged also to replace its charger, which is often not compatible even within the product line of the same manufacturer. The growing pile of unused chargers causes a great amount of unnecessary electronic waste and inconvenience to users. As part of its work on ICT and climate change, the International Telecommunication Union's telecommunication standardization sector (ITU-T) is progressing in the approval process for a technical standard describing an energy-efficient one-charger-fits-all new mobile phone solution. Developed by ITU-T Study Group 5 on environment and climate change, Recommendation L.1000 (ex. L.adapter) or "Universal power adapter and charger solution for mobile terminals and other ICT devices"[10] provides high-level requirements for a universal power adapter and charger solution that will reduce the number of power adapters and chargers to be produced and recycled by widening their application to more devices and increasing their lifetime. This solution also aims to reduce the energy consumption and to increase energy efficiency. The introduction of the new standard is estimated to lead to a 50 per cent reduction in standby energy consumption, an elimination of up to 82,000 tons of redundant chargers, and a subsequent reduction of 13.6 million tons in greenhouse gas emissions each year. Moreover, the use of the power adapter and charging solution is not limited to mobile phones and addresses a great number of ICT devices.

Optimized power efficiency features at higher data rates are also expected from the next generation of computer interfaces, such as USB 3.0. Consumer products featuring this new interface are expected to become available in 2010[11].

Wireless recharging is an area of research aimed towards address replacing chargers and cables and powering mobile devices on the fly and over distances up to several meters using non-radiative electro-

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[8] Wang, Y. and Cao, G.: "Nanostructured materials for advanced Li-Ion rechargeable batteries," IEEE Nanotechnology Magazine, vol.3, no.2, pp.14-20, June 2009. http://ieeexplore.ieee.org/xpls/abs_all.jsp?isnumber=5034972&arnumber=5036051

[9] MIT Energy Initiative Spotlight: "MIT engineers work toward cell-sized batteries," September 2008. http://web.mit.edu/mitei/research/spotlights/cell-batteries.html

[10] ITU-T: Draft Recommendation L.1000 "Universal power adapter/charging solution for mobile terminals and other ICT devices," draft text currently available for ITU members and TIES users, at http://www.itu.int/ITU-T/aap/AAPRecDetails.aspx?AAPSeqNo=1996, October 2009

[11] See http://www.usb.org/developers/ssusb

magnetic coupling. The technology has shown to be able to wirelessly power devices, such as DECT handsets or vacuum cleaners, in the range of a few milliwatts up to kilowatts.[12]

Energy and communications for all

By the end of 2009, ITU estimated there were 4.6 billion mobile subscriptions globally (3.3 billion by end of 2007), making mobile cellular the most rapidly adopted technology in history, and the most popular and widespread technology on the planet[13]. A major part of this growth is taking place in the developing world, where there is no or limited access to reliable power grids in some places, notably rural areas. In some instances, mobile phones might even outnumber lightbulbs[14]. Users often need to come up with creative alternatives to overcome the lack of ubiquitous power supplies: some kiosks in rural areas not only recharge (prepaid) units, but also batteries. To foster development of batteries or devices that do not solely depend on electric power grids for recharging, and to gradually improve and expand the energy infrastructure are therefore essential to connecting any user, anywhere, and to bridging the digital divide. Programs and projects to find ways to provide sustainable electrical energy supply at minimum cost and to enable access to ICTs for these regions are being spearheaded by different international organizations.

For instance, the Energy Sector Management Assistance Program (ESMAP[15]), managed and sponsored by the World Bank and the United Nations Development Programme (UNDP), is a global technical assistance program which helps build consensus and provides policy advice on sustainable energy development and contributes to the transfer of technology and knowledge in energy sector management and the delivery of modern energy services to governments of developing countries and economies in transition. The ITU launched a series of global initiatives – Connect a School, Connect a Community, ITU Wireless Broadband Partnership, Connecting Village, etc. – to engage a wide range of stakeholders to implement projects of significant scale and impact to help connecting the unconnected by 2015[16].

Conclusion

Batteries play a critical role in the usefulness of mobile ICT devices, and with an increasing number of users going mobile, the importance of reliable and efficient mobile energy supply will increase. Technologies such as fuel cells, cell-sized batteries, nanotechnology and improvements in current Li-ion batteries may increase performance duration and thus autonomy and portability of devices. Besides power requirements, the evolution of batteries does also need to consider aspects such as size and weight, cost and environmental impact. Nonetheless, so long as batteries continue to be based on electro-chemical processes, limitations of power density and limited lifetime will be difficult to be overcome, making the battery the 'weak link' of mobile devices. However, a number of promising new technologies may provide solution in the mid- to long-term.

[12] WiTricity Corporation: "Wireless Electricity Delivered Over Distance," http://www.witricity.com/
[13] ITU: "The World in 2009: ICT Facts and Figures," October 2009. http://www.itu.int/ITU-D/ict/material/Telecom09_flyer.pdf
[14] Appfrica blog: "Do Cellphones Outnumber Lightbulbs in Uganda?," 14 July 2009. http://appfrica.net/blog/2009/07/14/2134/
[15] See http://www.esmap.org/
[16] See http://www.itu.int/ITU-D/connect/

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