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Battery Management in Wireless Sensor Networks

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Introduction

Among the wireless networks, a relative new class of computer networks arose; there are sensor networks. This new type of wireless network has some particularities consisting in the huge numbers of nodes that have to self organize in order to achieve various tasks. Each node of the network, called sensor, embeds a radio transceiver, a microcontroller, electromechanical components, transducers and a power source, commonly a battery (Fig. 1.). Due to the small dimensions of sensors, the batteries have also small size. Thus the available energy is not only limited but is also very small. In most settings, the network must operate for long periods of time, so the available energy resources – whether batteries, energy harvesting, or both – limit their overall operation [1]. To ensure a long time operation for sensor, the energy of battery have to be rationally used. There are only few ways for this: using high-energy batteries, using rechargeable batteries with additional harvest system and mitigate the power consumption.

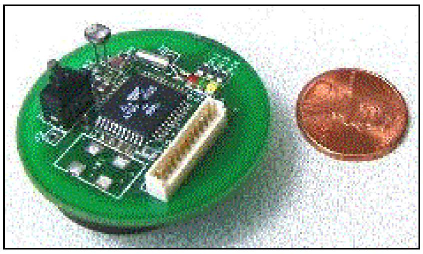


Fig. 1. A wireless network sensor

Choosing the right batteries

There are a lot of battery types among we can chose the proper ones. A common classification groups them by the type of electrolyte used in their construction: acid, mildly acid and alkaline. Some batteries are rechargeable and others are not. A different classification splits the battery into wet and dry. Most often acid batteries are wet, so inappropriate for usage in sensor devices. Two notable drawbacks of this type of battery are their sensitivity to the orientation and the necessity of maintenance. Thus, the remaining alternative is dry battery. There are many types of dry battery and we will try to summarize the properties of the most known, as a function of electrolyte type.

Zinc-Carbon (Z-C). Zinc-carbon cells, also known as "Leclanché cells" are widely used because of their relatively low cost. They produce 1.5V and are not rechargeable. Zinc-carbon cells are composed of a manganese-dioxide-and-carbon cathode, a zinc anode, and zinc chloride (or ammonium chloride) as the electrolyte. The main drawback of these kinds of batteries is that the outer, protective casing of the battery is made of zinc. The casing serves as the anode for the cell and, in some cases, if the anode does not oxidize evenly, the casing can develop holes that allow leakage of the mildly acidic electrolyte, which can damage the device being powered. Their usage is limited to non-critical application.

Alkaline Batteries. In alkaline batteries the mildly acid electrolyte is replaced by an alkaline electrolyte, as Zinc-Manganese-Dioxide. Their usage life is 5 to 6 time longer than the Zinc-Carbon ones and don't leak. They produce 1.5 volts and, generally, are not rechargeable.

Nickel-Cadmium (Ni-Cd). A Ni-Cd cell contains a cadmium anode, a nickel-hydroxide cathode, and an alkaline electrolyte. Nickel-cadmium cells are the most commonly used rechargeable household batteries. Batteries made from Ni-Cd cells offer high currents at relatively constant voltage and they are tolerant of physical abuse. Even if nickel-cadmium batteries exhibit the "memory effect" they are tolerant of inefficient usage cycling. If a Ni-Cd battery experiences memory loss, a few cycles of discharge and recharge can often restore the battery to nearly "full" memory [2]. The Ni-Cd cells produce 1.2V, are expensive, because Cd is expensive; moreover it is toxic and not environment friendly.

Nikel-metal-hybride (NI-MH). The anode of a Ni-MH cell is made of a hydrogen storage metal alloy, the cathode is made of nickel oxide, and the electrolyte is a potassium hydroxide solution. They provide up to 40% more energy than Ni-Cd batteries but the self-discharge rate is higher. Also they are more expensive than Ni-Cd batteries.

Lithium and Lithium Ion. Lithium is a chemical element with a high electropositivity. As a result, the specific energy of some lithium-based cells can be five times greater than an equivalent-sized lead-acid cell and three times greater than alkaline batteries. Lithium cells produce a starting voltage of 3.0 V and exhibit a higher and more stable voltage profile. They are also lighter in weight, have lower per-use costs but, at the same time, are more dangerous because they can explode if lithium enter in contact with the water. For this reason the Lithium and Lithium Ion cells are made in small size. Currently some Lithium based cells are rechargeable, the voltage provided being of 3.7 V.

Nickel-Hydrogen (Ni-H). Nickel-hydrogen cells were developed for the U.S. space program. Under certain pressures and temperatures, hydrogen can be used as an active electrode opposite nickel. Because of special conditions required to be functional, this kind of batteries have a limited terrestrial usage.

Moreover than the characteristics mentioned above, for the battery right choosing we have to take account on some additional characteristics, as temperature range, the stability of energy density vs. temperature variation and the discharge profile. Most common battery types provide the maximum energy around of 20°C, but the discharge profile may vary from flat curve to slope curve with different slope rates (Fig. 2.).

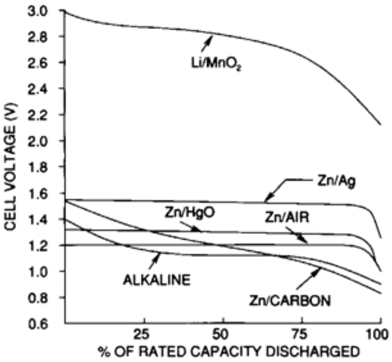


Fig. 2. Typical discharge curves of different dry type cells and Li/MnO$_2$ cells at 20°C. Source: NAVSO P-3676: Navy Primary and Secondary Batteries

Harvesting energy

Another solution to prolong the network life is to exploit energy sources ubiquitous to the operating space of the sensor nodes. This not means the renunciation to the battery but its replacement with rechargeable ones, from at least three reasons:

- the harvest energy is not available all the time (for example the solar and the wind energy)
- the harvest energy may not be sufficient to provide sensor functioning, see table 1.
- the current vs. voltage characteristic of harvesting device may not match the consumption variations of sensor. For instance, the I-V characteristic of a solar cell shows a behavior rather close to the current source characteristic, which is inappropriate to supply a device having important supply current variations (Fig. 3.).

Table 1. Power density for some energy sources [3]

Harvesting technology	Power density
Solar cells (outdoors at noon)	15mW/cm^3
Piezoelectric (shoe inserts)	330µW/cm^3
Vibration (small microwave oven)	116µW/cm^3
Thermoelectric (10°C gradient)	40µW/cm^3
Acoustic noise (100dB)	960nW/cm^3

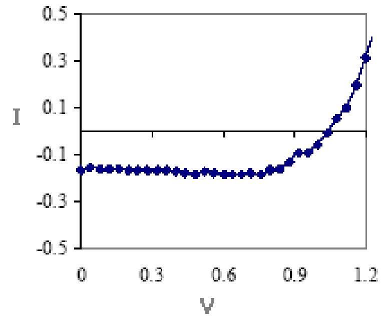


Fig. 3. Output characteristic for a typical solar cell

Despite the present technologies provide feasible and reliable solutions to harvest and store energy, this doesn't automatically increase the system lifetime. In a sensor network the conditions of harvesting energy may differ from a node to another and the type of energy may also differ. As a consequence the harvesting system must be efficiently integrated into an embedded system to translate that harvested energy into increased application performance and system lifetime. One way to prolong the system lifetime is to choose a proper routing protocol, as it is shown in next section.

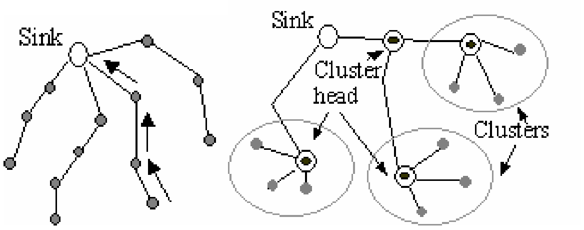
Reducing expenditure and extending lifetime

In a battery-powered device, as network sensor, the typical power management design goals are to minimize the energy consumption or to maximize the lifetime achieved while meeting required performance constraints. The advances in technology are already providing low energy consumption circuits as microcontrollers or memory. Nowadays, simple microcontrollers operate near one milliwatt while running at about 10 MHz. Most of the circuits can be powered off, so the standby power can be lowered to about one microwatt. If such a device is active 1 percent of the time, its average power consumption is just a few microwatts. This scale of power can be obtained in many ways. Solar cells generate about 15 milliwatts per square centimeter outdoors and 10 to 100 microwatts per square centimeter indoors. Mechanical sources of energy, such as the vibration of windows and air conditioning ducts, can generate about 100 microwatts [1]. A typical Li-Mn button battery stores about 130 milliamp-hours, so centimeter-scale devices can run almost 4 or 5 years in many environments.

Although research continues to reduce the power energy consumption of CPUs, user interface and storage devices, the transmission energy for a packet in wireless channels is the most important, the transmitting unit being the highest energy-consuming component of the sensors. Indeed, considering omni-directional antennae having the emitting power P, at the distance r from the antennae the power density is given by

$$\mathcal{P} = \frac{P}{4\pi r^2}. \qquad (1)$$

Therefore the power for each surface unity decreases with the square of the distance. Because the receivers have finite sensitivity, about -90dBm, the emitting power of transmitting nodes increase with the square of the distance. For individual nodes the antennae gain and the efficacy of emitting unit are fixed and we cannot expect major progresses in this field. Hence there is a need for designing minimum energy consumption routing protocols that ensure a longer battery life. For such a protocol design, the existing minimum-hop routing scheme cannot be applied because the amount of energy required to communicate increases rapidly with distance, eqn 1. As a consequence, new, power-aware routing schemes, that take explicitly into consideration the transmission energy, are now investigated [5]. There are two routing models, which can accommodate with this approach: the multi-hop planar model and cluster-based hierarchical model. The first one uses intermediate nodes to route date packets to the sink node, fig,2 a. Much closer the nodes are, less energy wasted in each node. The latter one breaks the network into clusters, each cluster having a cluster head responsible for routing data to other head cluster or to sink node, fig.2b.



a) b)

Fig. 4. Routing models: a – Multi-hop model, b – Cluster based hierarchical model

The complexity of designing such protocol consists in the numerous criteria that algorithms have to carry out concomitantly: simple with small footprints, robust and fault tolerant, scalability, location awareness, etc. [6].

In an energy-harvesting node one may consider the harvested energy as a primary power source or as a supplement to the battery energy. Further we will discuss a new approach in designing the routing protocols, which takes account on the availability of harvesting energy [3].

Lets' consider a particular case of a node which, in order to transmit data to the sink node, has to chose between two routes, the first one via node A and the second one via the node B, as shown in figure 5.

From some reasons, the node A can receive the energy only in the morning since the node B can receive the energy only in the afternoon.

In the morning both battery of nodes A and B have the same amount of energy, E_b.

Lets' note the harvest energy with Eh and the energy for routing E_r, $E_h > E_r$.

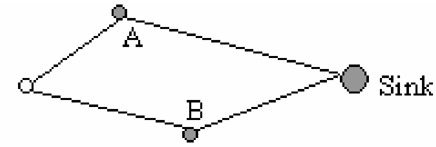


Fig. 5. Simple routing example

Lets' also assume that the battery round trip efficiency is $\eta<1$ and there are two transmissions every day, one in the morning and other in the afternoon.. The protocol $\mathcal{H}$ that uses information on the availability of energy for nodes A and B will choose, in the morning, the node A for routing packets to the sink, because it knows that node A receive energy during the morning. It follows that in the noon, the amount of energy of node A is $E_b+(E_h-E_r)\eta$. This value arises from the assumption that the routing activity and the harvesting process are concurrently and $E_h > E_r$, see fig.6.

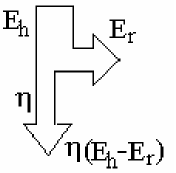


Fig. 6. The energy added to the battery of node A with protocol $\mathcal{H}$

All the morning the energy of node B remains E_b. In the afternoon, the protocol $\mathcal{H}$ will use the node B to perform the routing, thus, in the evening, the energy of node B is $E_b+(E_h-E_r)\eta$. Because the node A doesn't receive energy in the afternoon, in the evening its energy is the same with that it had in the noon and equal with the energy of node B in the afternoon.

The other protocol, $\mathcal{B}$, will choose the node B in the morning because it has the same energy as the node A. In the noon the remaining energy of node B is E_b-E_r since the energy of node A is $E_b+\eta E_h$. In the afternoon the protocol $\mathcal{B}$ will chose the node A for routing, so the energy of this node will be, in the evening, $E_b-E_r+\eta E_h$. During the afternoon the node B receives energy and in the evening its energy is $E_b-E_r+\eta E_h$. For each protocol used the energy of nodes A and B are equal in the evening, but the energy level depends on the protocol. The difference between the remaining energy of each node, when using the protocol $\mathcal{H}$ and $\mathcal{B}$ is given by

$$E_b+(E_h-E_r)\eta- E_b+E_r-\eta E_h = E_r(1-\eta)> 1. \qquad (2)$$

The result is summarized in table 2. The example above shows that two different routing protocols, both having the goal of mitigating the battery consumption of the network nodes (both use alternatively the two available routes) have different results. The protocol B, which is based on the residual battery energy, wastes the total energy of the node since the protocol H, which is based on information about the availability of the harvesting energy, uses the battery energy more efficient. In the discussed example the harvested energy marginally supplement the battery supply and the objective was to maximize the system lifetime.

Table 2. Energy variation in nodes A and B depending on the used protocol

	Node A			Node B		
	morning	noon	evening	morning	noon	evening
Protocol $\mathcal{H}$	E_b	$E_b+(E_h-E_r)\eta$	$E_b+(E_h-E_r)\eta$	E_b	E_b	$E_b+(E_h-E_r)\eta$
Protocol $\mathcal{B}$	E_b	$E_b+\eta E_h$	$E_b-E_h+\eta E_h$	E_b	E_b-E_h	$E_b-E_r+\eta E_h$

A more interesting case is when the harvested energy is used as the primary source of energy for the system with the objective of achieving indefinitely long system lifetime.

In such cases, the power management objective is to achieve energy neutral operation. In other words, the system should only use as much energy as harvested from the environment and attempt to maximize performance within this available energy budget. The researches in this field are very recent but some important contributions already have been reported [4]. The most recent approach is designing protocols, which use the battery energy according the importance of the message to be sent or to be routed. [7]. In this approach a fixed number of energy levels are set for the battery energy ant the same number of levels are set for the message priority. When the battery energy decreases to lower levels, only the messages of higher level priority are transmitted or routed.

Concluding remarks

The issue of efficient usage of energy in battery-supplied devices, in particular in wireless network sensor, is an important and, in the same time, complicated one. It begins with the choosing of the appropriate battery type, continues with the management of various harvesting energy sources and ends with the aware usage of the available energy. In this paper we tried to reveal the main aspects of the problem and to set a starting point for our future researches.

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Doru E. Tiliute. Battery Management in Wireless Sensor Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007.– No. 4(76). – P. 9–12.

Nowadays the wireless networks are widely spread in many civilian and military applications. The sensor networks, which are continuous developing, have to solve a lot of problems in order to ensure a reliable functionality and a reasonable lifetime. This paper presents some present issues regarding the energy preservation in wireless sensor network. Ill. 6, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

Дору Е. Тилюте. Применение батерий в беспроводной сети // Электроника и электротехника. – Каунас: Технология, 2007. – №. 4(76). – С. 9–12.

Описываются методы применения микро батерии в разных беспроводных сетей связи. Указано, что данная тенденция особенно важна для оптимального использования энергии в субантенных технологических устройствах безпроводной сети. Доказано, что такое решение проблемы в микроэлектронике обеспечивает безотказную функциональность сетей и максимальное время работы батерии. Ил. 6, библ. 7 (на английском, русском и литовском яз.).

Doru E. Tiliute. Baterijų pritaikymas bevieliame tinkle // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 4(76). – P. 9–12.

Išanalizuotos galimybės panaudoti baterijų energiją besiplėtojančiame bevieliame tinkle. Šiuo metu sparčiai tobulėjant technologijoms bevieliai tinklai taip pat plečiasi. Šių prietaisų pagrindinis tikslas – užtikrinti patikimą darbą. Jei šiuose prietaisuose naudojamos baterijos, tuomet pagrindinis tikslas yra užtikrinti baterijų funkcionalumą ir maksimalią eksploatavimo trukmę. Il. 6, bibl. 7, (lietuvių kalba; santraukos anglų, rusų ir lietuvių k.).

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