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# Energy as data: Revolutionizing energy efficiency of IoT devices

Energy is not merely a tangible quantity that we can sense, measure, or utilize. It can also be conceptualized as a chronicle of environmental transformations, whether they occur in our physical surroundings that we interact with, or in the digital realm as perceived by an intelligent device.

In the 2020s, it is expected that more than 40 billion active IoT (Internet of Things) devices will be connected worldwide. The rapid development of ubiquitous wireless sensing and 4G/5G, as well as the near-future 6G, telecommunication networks will make human lives more autonomous, accessible, secure, and productive in the future IoT-powered society. Perpetual and autonomous operation with minimal on-site maintenance is crucial to ensure the successful application of any IoT device.

However, the limited lifespan of the power source is considered a bottleneck in this regard. In the current IoT architecture, batteries are the most likely power source. Yet, the power requirements for IoT devices are increasing drastically due to boosted functionalities, for ex-

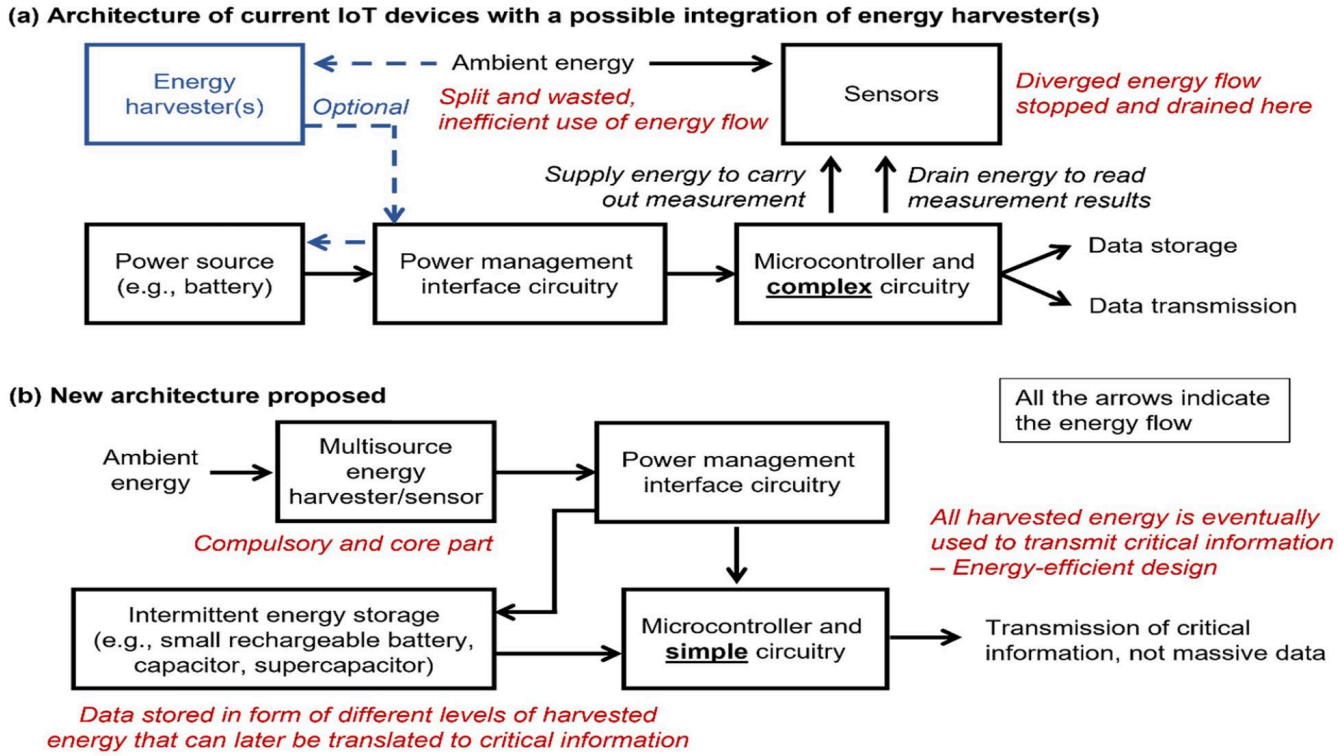
ample, due to the increasing requirement for data transmission frequency, resulting in a battery lifespan of a few years at most without recharging or replacement, while IoT devices are expected to operate for 10-20 years without service interruption.

A viable option to meet such power demand is to improve the battery lifespan via smart energy management schemes while introducing energy harvesting technology. Energy harvesters scavenge ambient energy sources that would be wasted if not harvested from the devices' working environment, including light, thermal, and kinetic energy, and convert them into electricity to power the host devices and systems.

## The problem: Inefficient IoT systems will never be self-sufficient

Despite the demand, the current IoT devices are not working on a superior efficiency. The figure (a) below depicts the current IoT architecture, where the battery still acts as the main power source, and energy harvesters are introduced as an optional and supplementary power source to extend the battery's lifespan. In this standard structure, although energy harvesting is introduced as a new scheme, the sensors and harvesters are separate components without any sharing or integration of the sensing and powering functions.

In comparison, figure (b) outlines an advanced architecture where an emerging concept, Energy-as-Data, is integrated, serving as both the main power source and sensing component. Combining the sensing and powering functions creates a fundamental advantage for the optimization of IoT devices’ energy efficiency.




Schematics of IoT architectures for (a) the mainstream battery-powered systems with possible integration of energy harvesters, and (b) the Energy-as-Data compatible architecture.

The problem lies in the fact that IoT devices collect data via dedicated sensors for stimuli such as temperature, acceleration, and light, while the data actually exist in the form of certain types of corresponding energy such as thermal, kinetic, and light energy, respectively. Current IoT designs, on one hand, rarely harvest ambient energy as it is often insufficient to power the device in real-time. On the other hand, they consume a significant portion of the precious scavenged energy for sensing the same types of energy. This approach is akin to borrowing higher-interest debt to repay lower-interest debt, resulting in the debt never being fully paid off.

Similarly, if the sensing function keeps consuming the same type of harvested energy, an IoT system will never be self-sufficient. This issue has sparked controversy and debate around using energy harvesters to power wireless sensing systems. While energy harvesting researchers are making every effort to improve the capability of harvesters, electronic engineers claim that the power from energy harvesters is too small to make a substantial change. The major misunderstanding here is that in a conventional design, energy harvesters are directly plugged into the battery-powered systems without optimizing the sensing and data acquisition protocol as well as the power management for data storage and transmission.

## The solution: Energy-as-Data concept for battery life extension in IoT devices

Here, adoption of the Energy-as-Data concept is suggested by implementing a simultaneous and multisource energy harvesting and sensing scheme on low-power commercial IoT platforms. As has been depicted in figure (b), this approach challenges the conventional practice of embedding multiple sensors in a single sensing platform to capture diverse types of data.

Instead, the proposed solution introduces two revolutionary changes: (i) On the sensing part, energy harvesters act as both power sources and sensors; and (ii) On the data processing and transmission part, power consumption is minimized to match the capabilities of corresponding energy harvesters. This approach is expected to greatly extend the battery life in IoT devices.

Pioneer works have been carried out to validate the Energy-as-Data concept (see the linked relevant publication below). In the pioneer work, a wearable IoT device that can reliably detect cough which offers a significant battery life extension by up to 21 times has been developed. This early evidence shines light on the bright future of interpreting ambient energy as the data to be collected by an IoT system which runs on superior energy efficiency.

This blog follows the previous one: What else can we do towards an energy sustainable world, beside keep building solar cells and wind turbines? (https://www.oulu.fi/en/blogs/science-arctic-attitude/what-else-can-we-do-towards-energy-sustainable-world-beside-keep-building-solar-cells-and-wind)

More details about the concept and pioneer works can be found in the publication: Exploring challenges and potential for a commercially viable piezoelectric energy harvesting system – Can Energy-as-Data concept thrive? | Applied Physics Letters | AIP Publishing (https://pubs.aip.org/aip/apl/article/124/11/110502/3272549/Exploring-challenges-and-potential-for-a)

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The Science with Arctic Attitude blog is edited by communications specialists Kukka Haapaniemi (editor in chief), Anna-Maria Hietapelto and Meri Rova

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