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Poster Abstract: Energy-Harvesting Wireless Sensor Networks

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***Abstract*—Energy Harvesting comprises a promising solution to one of the key problems faced by battery-powered Wireless Sensor Networks, namely the limited nature of the energy supply (finite battery capacity). By harvesting energy from the surrounding environment, the sensors can have a continuous lifetime without any needs for battery recharge or replacement. However, energy harvesting introduces a change to the fundamental principles based on which WSNs are designed and realized. In this poster we sketch some of the key research challenges as well as our ongoing work in designing and realizing Wireless Sensor Networks with energy harvesting capability.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are systems of multiple small and inexpensive embedded devices that can sense, measure and gather information from the environment they are deployed. Examples of application range from environmental monitoring and control to healthcare monitoring and traffic control, to name only a few. WSNs are typically required to run for long periods of time, often several years, only powered by batteries. This makes *energy-awareness* a particular important issue when designing WSNs. Indeed, one of the major limitation of battery-powered nodes is finite battery capacity [1], which means nodes operate for a finite duration, only as long as the battery lasts. Finite node lifetime implies finite lifetime of the WSN applications or additional cost and complexity to regularly change batteries. Indeed, batteries cannot easily be replaced, since typically WSNs consist of hundreds to thousands of sensors and may be deployed in unreachable places, such as mountains or underground. To make matters worse, depleted batteries constitute environmental problems.

Energy Harvesting Wireless Sensor Networks (EH-WSNs) can provide a solution to the energy problem by harvesting energy that already exists in the surrounding environment. Energy harvesting refers to harnessing energy from the environment and converting it to electrical energy. If the harvested energy source is large and continuously (or periodically) available, a sensor node can be powered perpetually. In this way, energy is essentially infinite; however, not always available.

Energy harvesting introduces a change to the fundamental principles based on which protocols for WSNs are designed. Instead of focusing on energy efficient protocols that aim to maximize sensors lifetime, the main design objective in EH-WSNs is to maximize the performance of the network given the rate of energy that is available to be harvested from the environment. In other words, the surplus of harvested energy can be used to improve the performance of the network.

Another important element that differentiates EH-WSNs from classical WSNs is that in EH-WSNs some sensor nodes can be more capable than others. This is due to the non-uniformly distribution of ambient energy. As an example, consider a solar-based EH-WSN where some nodes are covered by shadows while others are under direct sun light. In such environment, the more capable nodes can be used for performing the energy consuming tasks, on behalf of the incapable nodes that need to sleep and recharge.

Example: WSNs Powered by Vibration. *Vibration energy harvesting is the process by which otherwise wasted vibration (such as from a piece of industrial machinery) is harvested and converted to useful electrical energy to perpetually power wireless sensor nodes. One of the most prevailing applications for WSNs is to monitor the health and status of essential industrial machinery assets within light and heavy industrial manufacturing environments. As an example of health monitoring application, a WSN can be used for monitoring vibrations of a rotating machine and by analyzing the frequency domain of vibrations it is possible to determine when the machine is going to fail and schedule the maintenance in time, before malfunction of the machine. The fact that the WSN is being powered by the same vibration its measuring allows the system to continuously monitor the operation of the machine without the risk of the node running out of power.*

In this poster we sketch some of the key research challenges as well as our ongoing work in designing and realizing Wireless Sensor Networks with energy harvesting capability.

II. CHALLENGE: ENERGY HARVESTING

Potential sources of energy harvesting are all around us. Light, radio signals propagating through the air, wind, different kinds of vibration and movement, heat flow, just to mention only a few. With new materials and new ways of transforming energy, efficiency of harvesting has risen to the level that can be used for powering WSNs. Nevertheless, harvesting sources are not powerful enough yet to allow continuous operation of sensor nodes powered by energy harvesting. Therefore careful planning is needed in every stage of design.

First stage of design is finding a way of converting ambient energy to electrical energy. Our group will focus on harvesting light and vibration energy through use of small scale solar cells for light harvesting and macro fiber composites for capturing vibration energy. The main challenge at this stage is efficient harvesting of available energy and storing the produced charge in a way so it could be used when needed. This task is not trivial due to the fact that, in order to harvest the most energy from the source, the load on the circuit producing energy needs to be matched through appropriate circuitry and the load is always application specific making it even harder to implement.

Second stage is to manage the energy stored in the most efficient way. This block is in charge of selecting when and how the energy is distributed throughout the system being powered by it. Furthermore this block needs to minimize the leakage from the storage and have the smallest possible quiescent current.

Third stage is the application that is run on the node. For battery powered systems the main challenge lies in prolonging of the battery life, but with energy harvesting the designer is aware hat the energy storage will be replenished, therefore other approaches can be utilized, such as using the power when harvesting and keeping dormant when no energy is harvested. Changing the duty cycle of operation depending on energy levels is also one of the options.

The fact that energy harvesting is application specific and all parts in the design are much interconnected makes this kind of systems a big challenge to design in a robust way guaranteeing a very long, maintenance free operation.

III. Challenge: Networking

Communication has always been a major issue in WSNs due to the amount of energy it requires and the numerous performance benchmarks that depend on it, such as the delay and the delivery rate of measurements. Energy harvesting provides the wireless sensor nodes with an energy supply that varies over time and space. Communication protocols supporting the sensor network need to be adaptable; so that whenever there is an excess of energy, it is used to improve the performance of the system and whenever there is a shortage of energy, the sensors downgrade their performance, and thus their energy consumption, to an operation state that is sustainable by the available energy. In other words, the goal of the system is to operate at the maximum sustainable performance. Furthermore, communication protocols need to have certain additional qualities. First, they need to provide flexibility so that the network load is distributed to the nodes that have access to more environmental energy at any given time. Secondly, they need to support applications that have different performance requirements. For example, there are alarming applications that require low delays and monitoring applications that require a consistent data set. Last but not least, cross-layer optimization is important so that the energy is consumed in the most efficient way.

All these qualities constitute important considerations for designing communication protocols for EH-WSNs. In particular, MAC protocols need to efficiently support individual duty cycles to allow each node to effectively adapt its energy consumption to sustainable levels. Hence, the "traditional" approach where nodes have coordinated and synchronized duty cycles is insufficient. Individual duty cycles can also support distributed autonomous load balancing. If each node is able to freely choose its own duty cycle based on its energy capabilities, the node with more access to energy will be awake more frequently and eventually perform more energy consuming tasks. Moreover, routing protocols need to select the path that best fits the energy conditions of the network as well as the requirements of the application. For instance, the paths that minimize the end-to-end delay might be the best candidates for a delay-sensitive application. Lastly, opportunistic routing schemes can be used to decrease the sleeping delay caused by the duty cycles. Instead of waiting for a node to wake up, a node may transmit to the node that wakes up first out of a set of nodes that meet certain criteria.

IV. Challenge: Security

Security is an extremely important issue for sensor networks, due to the various kind of data, in many cases sensitive, gathered by the network. The introduction of energy scavenging capabilities completely redefines how security in WSNs can be approached. For instance, energy independent attacks (e.g. node replication) become much more effective since the average lifespan of a node is greatly increased. On the other hand, power related attacks (e.g. energy depletion) can be neutralized by the fact that a node can reacquire energy over time. Furthermore, the potential of having more energy available could make possible to use better security tools such as sturdier encryption algorithms, longer keys and computationally heavier hash functions, just to name a few. Another class of approaches are the ones similar to what proposed in [2], where the amount of "strength" used in the active security scheme is function of the available harvested energy.

For these reasons, we aim to systematically analyze and classify attacks in EH-WSNs, so that distinctive characteristics can be pointed out and possible new attacks identified. As a first result, a taxonomy of attacks for EH-WSNs has been determined, with focus on how scavenging capabilities affect the network and which new and specific attacks can be depicted. This classification represents the basis for specifically tailored security solutions.

V. Conclusion

Energy harvesting is introducing some changes to the fundamental principles based on which Wireless Sensor Networks are designed and realized. In this poster we have sketched some of the key research challenges as well as our ongoing work in designing and realizing Wireless Sensor Networks with energy harvesting capability.

References

[1] S. Sudevalayam and P. Kulkarni, "Energy harvesting sensor nodes: Survey and implications," *Communications Surveys Tutorials, IEEE*, vol. 13, no. 3, pp. 443 –461, quarter 2011.

[2] A. V. Taddeo, M. Mura, and A. Ferrante, "Qos and security in energy-harvesting wireless sensor networks," in *SECRYPT*, S. K. Katsikas and P. Samarati, Eds. SciTePress, 2010, pp. 241–250.