Inexhaustible Wireless Nodes Using Harvesting RF Energy

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I. Introduction

Recently, there has been increased market demand of Internet of Things (IoTs) for wireless services such as wireless sensor networks (WSNs). These systems can enable services such as temperature and health monitoring, environmental sensing, fire alarms, etc. and can be integrated into IoTs. Figure 1 shows a WSN node which includes an antenna, transceiver, microprocessor, and an analog to digital converter (ADC). In general, the data rate requirement for these applications can be low (10 Kbits/s to 1 Mbits/s), while long operational lifetimes (months or years) are required. A low power transceiver is one of the key blocks in such a system. Recently, there have been several low power receivers reported, such as the OOK receiver [1-2] and the FSK receiver [3]. However, in the current technology, there still exist power gaps between the required transceiver operational power in long duration and the limited battery storage power.

This paper proposes to use the recently developed radio frequency (RF) energy harvester [4-5] as a power solution (virtual battery) for low power electronics. By combining the low power transceiver and an ambient RF energy harvester, the paper presents calculations to demonstrate the possibility of an inexhaustibly powered wireless system.

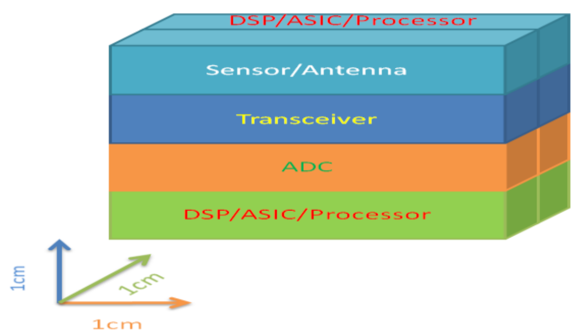

Figure 1 A sensor node of wireless sensor network (WSN).

II. INEXHAUSTIBLE SYSTEM

As minimal device length continues to be scaled down, the required digital energy to process one bit (switch inverter) continues to decrease. Meanwhile, the transceiver power consumption continues decreasing in both active mode and sleep mode. For example, the transceiver power in the active mode can be as low as hundreds of μW [3], while the low power Zigbee transceiver [6] only consumes 0.06 μW in sleep mode. The amount of sleep power (leakage power) is expected to be further reduced using emerging FinFet technology. Those power values are close to ambient RF energy which can be in the neighborhood of 10μW. Harvesting energy presents a promising power solution for low power, long duration communication nodes.

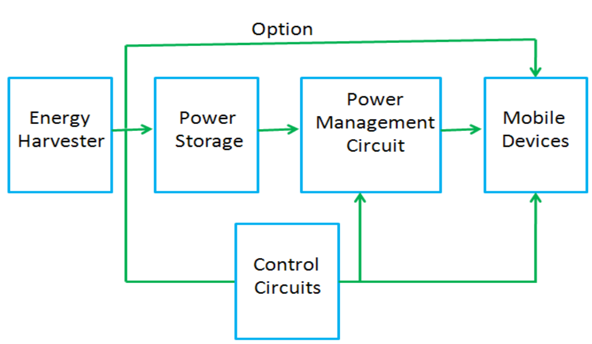

Figure 2 Scheme for power solutions suitable for nodes of WSNs.

Figure 2 shows a scheme for future designs of WSN nodes. In the scheme, each node uses harvested energy as a virtual battery. When the devices work in sleep mode, the harvested power is stored. The stored power can be used when the devices wake up and work in active mode. In this scheme, the transceiver is required to obtain low power consumption in both the active and sleep modes. Most importantly, in sleep mode, the power consumption is required to be less than the harvested power in order to enable an inexhaustible node. This is explained below:

The required energy of nodes of a WSN on each day can be defined as follows:

$$E = [P_{active} \times \eta + (1-\eta) \times P_{sleep}] \times 86400 \quad (1)$$

where E, P_{active}, P_{sleep}, and η are the required energy for each day, the required device power in active mode and sleep mode, and percentage of time the device spends in active mode, respectively. The number 86400 is the total seconds in one day. The available power from the environment on each day is described by Equation 2:

$$E_{avail} = 86400 \times P_{harvester} = 86400 \times \beta \times P_{env} \quad (2)$$

where E_{avail}, β, P_{env} and $P_{harvester}$ are the harvesting energy for each day, the harvesting efficiency, the average power in the environment and harvested power.

The mobile device can work inexhaustibly if harvested energy is more than consumed energy which can be described by Equation 3:

$$E_{avail} = 86400 \times \beta \times P_{env} \geq E = [P_{active} \times \eta + (1-\eta) \times P_{sleep}] \times 86400$$
$$P_{harvester} = \beta \times P_{env} \geq P_{active} \times \eta + (1-\eta) \times P_{sleep} \quad (3)$$

If the transceiver sleep mode power (P_{sleep}) is smaller than the average harvesting power ($P_{harvester}$), Equation 4 can always be satisfied by adjusting the percentage of sleep time per day. By taking 0.06μW sleep mode power as reported in [6] and 1.5mW active mode power [2] and 9% power conversion efficiency in 10μW environmental power level [3], the percentage of active time of the node needs to satisfy Equation 4 in order to work inexhaustibly:

$$\eta \leq 5.6 \times 10^{-4} \quad (4)$$

The above calculation shows that mobile devices can work inexhaustibly if they are awake 0.056% of the time (48.6 seconds per day with 1Mbits/s data rate). Such a percentage is sufficient to enable new applications such as environmental monitoring, health monitoring, etc.

IV. Conclusions

This paper discusses system power solutions to build inexhaustibly powered wireless nodes. Based on previous RF receiver power consumption and the recently developed harvesting circuit performance [5], calculations show that mobile devices can work inexhaustibly if they are awake less than 0.056% of the time (48.6 seconds per day). Such a long duration communication system can enable low data rate applications such as environmental monitoring, health monitoring etc. and can be integrated into the internet of things (IoTs).

References

[1] Bo Li, Thomas Salter, Yiming Zhai, Bo Yang, George Metez and Neil Goldsman, “An integrated low power transceiver System”, *Proceedings Of International Microwave Symposium (MTT-S),* June 2011.

[2] T. S. Salter. "Low Power Smartdust Receiver with Noval Applications and improvements of an RF Power Harvesting Circuit", PhD Theisis, University of Maryland, College Park, 2009.

[3] Bo Li, Yiming Zhai, Bo Yang, Thomas Salter, Martin Peckerar and Neil Goldsman, "Ultra low power phase detector and phase-locked loop designs and their application as a receiver", *Mircoelectronics Journal,* vol. 42, number 2, pp 358-364, Feb. 2011.

[4] Bo Li, Bo Yang, Thomas Salter, Yiming Zhai and Neil Goldsman, "20GHz low power CMOS single chip receiver using resonant transformer techniques for enhanced demodulation efficiency", *Proceedings of International Semiconductor Device Research Symposium s(ISDRS)*, 2009.

[5] Li, B., Shao, X., Shahshahan, N., Goldsman, N., Salter, T., Metze, G.M., "An Antenna Co-Design Dual Band RF Energy Harvester," *IEEE Transactions on Circuits and Systems I: Regular Papers* , 2013

[6] M. T. Penella, J. Albesa, M. Gasulla, “Powering wireless sensor nodes: Primary sbatteries versus energy harvesting”, *IEEE Instrumentation and Measurement Technology Conference*, May 2009.