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Storage-Less and Converter-Less Energy Harvesting using Internet of Thinking Technology

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Abstract**—** *Wide Energy harvesting is a shows potential option to mitigate battery replacement, but the current energy harvesting methods still rely on batteries or equivalent and power converters for the maximum power point tracking (MPPT). Regrettably, batteries are subject to wear and tear, which is a primary factor to prevent from being maintenance free. Power converters are expensive, heavy and loss as well. In this paper, we introduce a novel energy harvesting and management technique to power the IoT, which does not require any long-term energy storages or voltage converters unlike traditional energy harvesting systems. Extensive simulations and measurements from our prototype demonstrate that the proposed method harvests 8% more energy and extends the operation time of the device 60% more during a day. This paper also demonstrates a UV (ultraviolet) level meter for skin protect, named Smart Patch, using the proposed energy harvesting method. The proposed method is not limited to photovoltaic energy harvesting but applicable to most energy harvesting IoT power supplies that require impedance tracking.*

Keywords**—** *Power management unit, internet of things, energy harvesting device.*

I. INTRODUCTION

Internet of Things (IoTs) have been widely spread past several years, and the number of connected devices to the inter-net is expected to be more than 50 billion by 2020 [1]. For reaching the full potential of IoT, the devices in IoT need to be self-sustainable including the power sources. Changing batteries of such a huge number of devices deployed across many places or providing power outlets is not practical.

This explains that powering self-sustainable IoT is an important issue. Energy harvesting, where the energy is generated from environments, is a promising solution to be free from battery replacement. An energy harvesting device serves as a renewable power source, which relieves the burden of maintenance due to battery replacement.

Fig. 1 shows a conventional architecture of energy harvesting devices with the maximum power point tracking (MPPT) [2]. In general, the power generation of the energy harvesting devices is vulnerable to changes in the surrounding environments while the target applications demand un-interruptible power supply. Most energy harvesting devices exhibit voltage-current characteristics that are far from the ideal power source. Conventional energy harvesting devices have rechargeable batteries as a long-term energy storage and volt-age converters (regulators), by default, for pursuing the MPPT

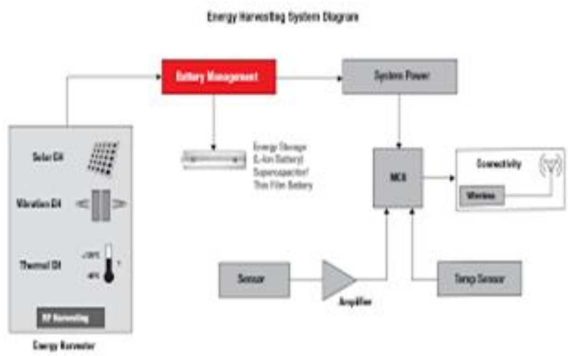

Fig. 1. Shows a conventional architecture.

One of the most serious downsides of the conventional MPPT is such that it mandates a rechargeable battery. The current rechargeable batteries have a limited cycle life and require periodic replacement. This makes the IoT device not maintenance free. Power converters are expensive, heavy and lossy as well.

In addition, the power converter and a recharge-able battery seriously limit exploiting traditional energy harvesting architectures for the IoT in many aspects including the weight, form factor and cost. The long-life expectancy of energy harvesting would also pay off in terms of cost.

Recently, it turns out that removing long-term energy storages and power converters from energy harvesting devices is possible by directly supplying the harvested energy to the tar-get devices. The paper also proved that supplying the harvested energy directly to the target device increases the energy efficiency by minimizing the energy loss during the energy storing and voltage conversion.

However this work is based on a threshold-based simple power management unit (PMU), which results in inefficient.

The PMU used in [3] is mainly controlled by an upper and a lower threshold voltage determined at the design time that makes it difficult to deal with irradiance level variation during runtime. Most of all, no previous work provided a clue for “Things” in the IoT where the storage- and converter-less energy harvesting is applicable.

In this paper, we introduce a novel energy harvesting and management technique to power IoT, which does not require any long-term energy storage or voltage converters unlike the traditional energy harvesting devices. For realizing this Technique, we first design a circuit of PMU capable of perform.

The MPPT of solar energy while providing almost

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constant voltage to the IoT devices without using those components. The proposed PMU circuit enables a fine-grained control of the photovoltaic (PV) cell voltage, which leads to better MPPT performance and higher energy efficiency, especially under low solar irradiance.

Our extensive simulations and measurements from our prototype demonstrate that the proposed PMU circuit collects 8% more energy and extends the operation time of the device 60% more during a day operation compared with the PMU used in [3]. As a pilot application of the proposed energy harvesting method, this paper demonstrates a UV (ultraviolet) meter for skin protect, named Smart Patch. Smart Patch accumulates UV exposure over time and notifies when to apply UV protection lotion again on the beach, ski resort, etc.

Smart Patch is a self-sustainable devices as well as disposable thanks to the storage-less and converter-less energy harvesting method. Smart Patch is a self-sustainable strategy as well as throwaway thanks to the storage-less and converter-less energy harvest technique

The proposed energy harvesting method is not limited to photo-voltaic energy harvesting but applicable to most energy harvesting power sources that require impedance tracking. The demonstrated Smart Patch is not equipped with a wireless communication feature, but it is easy to include a low-power radio frequency communication.

II. Energy Harvesting Techniques

Energy harvesting architectures are classified into harvest-store-use and harvest-use architectures [4]. This section briefly describes the proposed storage-less and converter-less energy harvesting technique that is classified as harvest use architecture compared with the traditional harvest-store-use architecture.

A. *Traditional Harvest-Store-Use Architecture*

Harvest-store-use shown in Fig. 1 has been an conventional architecture in most energy harvesting systems. Rechargeable batteries have been used to mitigate the problems of the unstable harvested energy source depending on many environmental conditions. However using rechargeable battery seriously limits the self-sustainability of the IoT de-vices because of the limited lifetime of the rechargeable battery.

Some design practices started to use a super capacitor instead of using rechargeable batteries where the super capacitor shows pretty much longer lifetime than that of the rechargeable battery [5, 6].

This replacement seems to mitigate the lifetime problem of using rechargeable batteries. However, using a super capacitor generates another problem such as relatively high cost and leakage. Especially the leakage problem seriously limits the wide use of super capacitors for real IoT devices.

Another problem in the traditional harvest-store-use architecture is to require more than two voltage converters; one for performing the MPPT charging the battery (or super capacitor) and the other one for providing a constant voltage to the tar-get device. Converter is most expensive and bulky components, which makes the target devices more expensive and bigger.

Although recent technologies on designing voltage converter minimize the energy loss during the voltage conversion, still there is a non-negligible energy loss during the volt-age conversion [7], which makes the target devices more expensive and bigger.

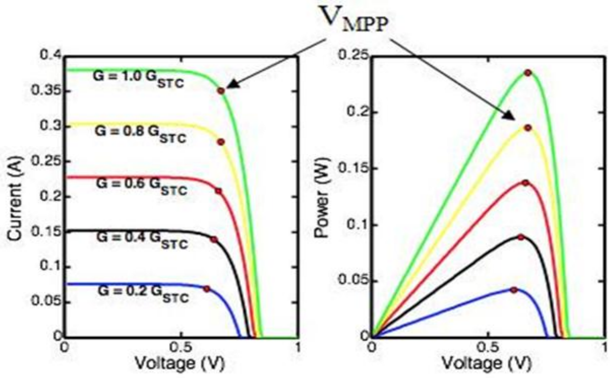

Fig. 2. PV cell voltages versus the load current and the power consumption on the target device, and solar irradiance.

B. *Harvest-Use Architecture*

The main idea of harvest-use architecture is to remove the long-term energy storages (storage-less) and voltage converters (converter-less) as shown in Fig. 2. This helps reducing the cost of the energy harvesting system while increasing its energy efficiency. The questions regarding this architecture are; (1) is this concept feasible for real IoT devices, and (2) what if the harvested energy is not sufficient to operate the target devices? The answers are given at the later two subsections.

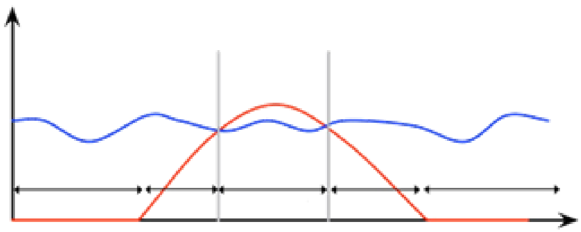

Fig. 3. Converter-less operation.

Even without any voltage converter, target devices may not experience the power supply problem if a tolerable range of volt-age is provided from the PMU to the target devices. Fig. 2 shows the general characteristics of PV cell voltages versus the current and power consumption on the load, I_{load}, and normalized solar irradiance, G. We observe that the PV cell voltage at the maximum power point (MPP), V_{MPP}, does not change appreciably regardless of solar irradiance level.

This means that the PV cell provides almost constant voltage directly to the tar-get device without using a voltage converter if the MPPT is properly performed, and V_{MPP} is equal to the recommended Operating voltage of the target device, V_{load}. $V_{load} = V_{MPP}$ is mostly achieved by selecting the appropriate PV cell becauseV_{MPP} is fixed on each PV cell in general. The next question is how to achieve the MPPT. In other words, how to keep the I_{load} to the MPP current, I_{MPP} The basic idea is to exploit a fine-grained dynamic power management (DPM) [3].

The other requirement for achieving harvest-use architecture is to realize the storage-less architecture. This goal is achieved by properly controlling the operation modes depending on the amount of the harvested energy. Fig. 3 shows the operation mode changes considering the required load power on the tar-get device and the amount of harvested energy during the time of a day.

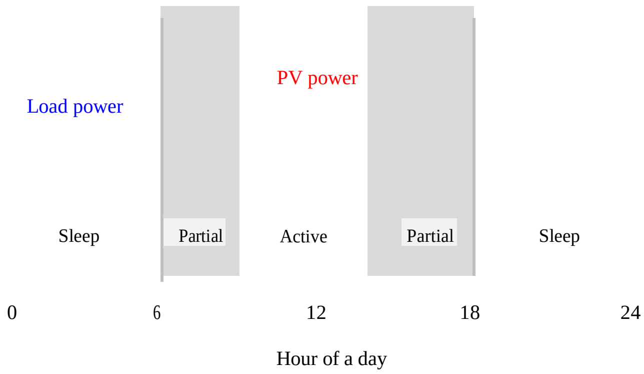

Fig. 4. Operation mode changes depending on the time of a day.

Obviously, the target system is in an active mode if the harvested PV power is greater than the required power while the target system is in a sleep mode if the PV power is lower than the required power. Based on this simple mode change, in our storage-less architecture, we are aggressively exploiting the region where the harvested energy is obviously greater than zero but less than the required power (grayed boxes in the figure).

We define these regions as a partial operation region where the target system is partially in an active mode and partially in an sleep mode. The partial operation is also controlled by a fine-grained DPM. The detail of designing a find-grained DPM including its energy efficiency is explained at the next section.

The ratio of active and sleep time during a day is largely depending on the size of PV cell. The active time will be relatively long if the PV cell size is big. However in this case, we have to pay more cost on the big size of PV cell. This means that selecting a proper size of PV cell is very important as well as properly designing a PMU to support the proposed storage-less and converter-less energy harvesting.

No matter how the PV cell size, the system never operates if no harvested energy (eg. during the night). This seems to still limit the area of the applications seriously. We demonstrate the usefulness of the proposed storage-less architecture by showing a useful pilot application in the later section.

III. Design of Power Management Unit

A. Threshold-controlled PMU

The main role of the PMU in our storage-less and converter-less energy harvesting system is to provide an almost constant voltage to the target system by properly turning it on and off, Keeping I_{load} to I_{MPP}. The one intuitive way of implementing the PMU is to use two thresholds, V_U and V_L, as shown in

Fig. 4(a). We name it threshold-controlled PMU. The PMU turns off the power switch to the target system once the PV cell voltage reaches down to V_L. The PMU turns on the power switch if the PV cell voltage reaches up to V_U. Fig. 4(b) shows the expected PV cell voltage according to the power switch control.

The rising and falling slopes in this PMU architecture are largely depending on the PV cell voltage and load current. The rising slope is a function of the internal resistance and parasitic capacitance in the PV cell while the falling slope is a function of PV cell voltage and the required load current and parasitic capacitance on the target device. We expect to have faster rising slope than the falling slope in general. The higher irradiance results in the higher rising slope and the lower falling slop

We do not simulate the regions where the irradiance level is below 125 W/m^2 or over 500 W/m^2 be-cause the PMU never turns on or turns off the target system in these regions, respectively. The ranges of these regions are varied on the PV cell size and the load current.

As expected, the DPM overhead and under clocking loss of the proposed duty-controlled PMU are almost constant while those of the threshold-controlled PMU are varying on the irradiance level. The proposed PMU offers more stable performance and low under clocking loss due to fixed DPM overheads though our proposed PMU shows less energy effectiveness than value on the 8-bit up/down counter determines the duty ratio of the power switch while the clock frequency of the 8-bit counter determines the PWM frequency.

The clock frequency of the up/down counter reflects the response time of switch

C. Evaluations of Two PMUs

We perform a simulation-based design space exploration to figure out the effectiveness of the proposed PMU. The details of the simulation parameters are shown in Table I.

Fig. 5 compares the performance of our duty-controlled PMU with the threshold-controlled PMU by varying the irradiance level in terms of actual computing power, DPM overhead, and under clocking loss. We do not simulate the regions where the irradiance level is below 125 W/m^2 or over 500 W/m^2 be-cause the PMU never turns on or turns off the target system in these regions, respectively. The ranges of these regions are varied on the PV cell size and the load current.

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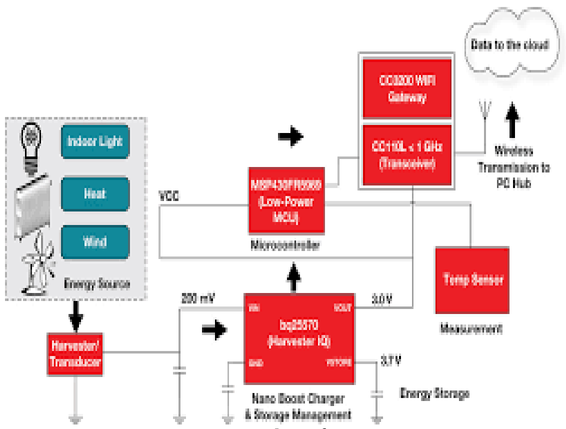

Fig. 5. Quality of service.

Simulated System Parameters.

Parameters	Values
Target device	
Current, I_{load}	20 mW
Voltage, V_{load}	2.68 V
DPM overhead	3 us for waking up and 8 us for sleep transition [3]
PV cell	
VMPP	2.68 V
Size	20mW@500W/m^2
PMU	
V_U on Threshold-controlled	2.65 V
V_L on Threshold-controlled	2.70 V
Ref. V_{MPP} on Duty-controlled	2.68 V

that of the threshold-controlled PMU in some regions. In our duty-controlled PMU, almost 85% of the total harvested energy is used for actual computing regardless of the irradiance level while the power efficiency of the threshold-controlled PMU is varying from 77% to 89% depending on the irradiance level.

The stability and controllability are more important factors in real applications because the irradiance level is always varying on many environmental conditions. We demonstrate this fact by performing more analysis on the irradiance changes during the time of a day as shown in Fig. 7. We evaluate the actual harvested energy purely used for the target system and the on-duty ratio of the target system.

Fig. 5 shows the irradiance level changes used in the evaluation. We use irradiance profiles of a clean and sunny day. The same size of the PV cell and load current are used in both configurations. The total harvested energy on our PMU is 8% more than that on the threshold-controlled PMU during a day as shown in Fig. 5 shows the variance of duty ratio. The duty ratio is more important than the total energy gain in real applications because the quality of service (QoS) is tightly coupled with the duty ratio in general. For example, let's assume that the minimum QoS is achieved if the on-duty ratio is over 0.50. Under this assumption, our proposed PMU operates the target system almost for 8 hours (from 9:00 AM to 5:00 PM) while the threshold-controlled PMU operates the target system only for 5 hours (from 10:30 AM to 3:30 PM). This is almost 60% enhancement of the operation hours where the minimum QoS is guaranteed.

D. Implementation of the Duty-Controlled PMU

In order to verify the functionality and effectiveness of the proposed duty-controlled PMU, we implement a prototype of the PMU using commercial off-the-self components. Minimizing the power consumption on the PMU itself is very important in designing PMUs. In addition, the PMU should be operated at a wider range of supply voltages because the PMU must be activated at first and be deactivated at last among all the electric components used in the PMU and the target device so that the PMU properly controls the power switch. During the cold start, the PV cell is at a lower voltage and very low solar ir-radiance cannot maintain V_{MPP} even with a very light load current. We implement the most components of the PMU with high-speed complementary metal-oxide-semiconductor.

Function against the PV cell voltage changes. We set the operating frequency of the up/down counter slower than that of the 8-bit counter (more than 10 times) for avoiding any abrupt changes of the duty ratio while keeping a reasonable response time.

The expected PV cell voltage level according to the power switch control. Irradiance changes do not result in DPM overhead changes because the PWM frequency is fixed in the duty-controlled PMU. The variance of irradiance level slightly changes the V_L and V_U, which may result in under-clocking loss changes. However, this unstability is minimized by adjusting the PWM resolution.

IV. SMARTPATCH: A SOLAR-POWERED UV-LEVEL METER

As a pilot application of the proposed duty-controlled PMU that efficiently supports the storage-less and converter-less energy harvesting architecture, we design and implement a solar-powered UV-level meter, named Smart Patch, The UV-level meter is an ideal application for the proposed storage-less and converter-less energy harvesting system because 1) no need to measure UV level when the Sun is set, 2) little motivation to measure UV level when the solar irradiance is very low, and 3) more frequent UV measure is desirable when the solar ir-radiance is high. This means that no long-term energy storage does not degrade the quality of service in UV-level meter applications because the service is not (or seldom) necessary if the solar energy is not available (or not sufficient). In addition, our UV-level meter provides an efficient solution for caring about the UV exposure with extremely low cost thanks to removing a expensive long-term energy storage and a voltage converter from the UV-level measurement system.

Fig. 5 shows the block diagram and prototype of our Smart-Patch. Smart Patch mainly consists of the PMU part and UV measurement part. We implement a sleep/wake-up controller Synchronized with the power switch in the PMU part. This helps the safe control of the power transition of Smart Patch.

The PV cell size is set to 12.92mW@100mW/cm^2 satisfying the minimum operation time (minimum duty) considering a typical whether condition. V_{MPP} and I_{MPP} of the selected PV cell are 3.4 volt and 3.8 mA, respectively.

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The UV measurement part consists of a ML8511 UV sensor chip from LAPIS-Semi [8], an analog-to-digital converter, a 2-digit LCD to display the measured UV level, and a CPLD to control the measurement process. Our UV-level meter automatically turns on and off by itself depending on the irradiance level. It frequently turns on the power and measures the cur-rent UV-level if the more attention for UV exposure is required because of the high solar irradiance.

Its main another main function is to accumulate UV exposure over time and notifies when to apply UV protection lotion again. This function is very useful on the beach, ski resort; etc.The size of the prototype is 5 cm by 4.6 cm. We do not optimize the size and cost because this is a prototype implementation for verifying the feasibility of proposed storage-less and converter-less energy harvesting system.

The size and cost of UV-level meter will be dramatically reduced if all the logics including the duty-controlled PMU are embedded on a single chip. In addition, Smart Patch is even disposable thanks to the storage-less and converter-less energy harvesting method. The proposed energy harvesting method is not limited to photovoltaic energy harvesting but applicable to most energy harvesting power sources that require impedance tracking.

Finally, we measure the UV-level to confirm the actual operation hours during a day in three different places as shown in Table II. The measurements were performed on sunny and clean day of August. We successfully confirmed that our Smart Patch works during most of day time from early.

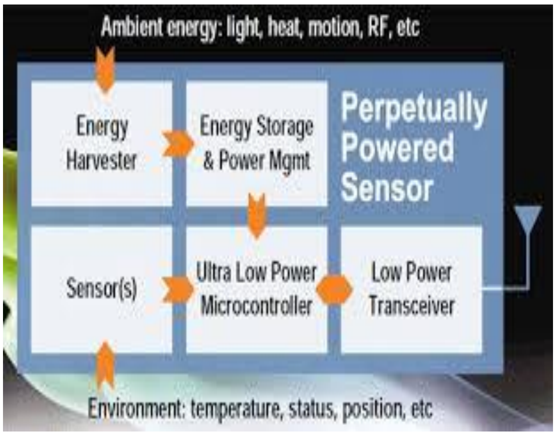

Fig. 6. Duty-Controlled PMU.

Uv-level measurement using smartpatch in real places.

Place (Country)	Operation Hours		Duration (Hours)	Min. UV	Max. UV
Daegu (KOR)	8:30 AM	5:30 PM	9	1	8
San Jose (US)	8:00 AM	7:00 PM	11	1	7.5
Atlanta (US)	7:30 AM	7:30 PM	12	1	10

We observe that the PV cell voltage at the maximum power point (MPP), V_{MPP}, does not change appreciably regardless of solar irradiance level. Implement the most components of the PMU with high-speed complementary metal-oxide-semiconductor.

V. Conclusion

This paper introduces a novel energy harvesting technology for powering self-sustainable IoT device. The proposed energy harvesting technology does not require any long-term energy storage or voltage converters. To realize the proposed architecture, we first design and implement a duty-controlled PMU. Extensive simulations and real measurements from the proto-type demonstrate the effectiveness of the proposed PMU by showing the 8% of energy gain and the almost 60% enhancement of QoS guaranteed operation time during a day. Finally, we verify the feasibility of proposed storage-less and converter-less energy harvesting architectures by implementing real prototypes of the PMU and its pilot application, named Smart-Patch. The proposed energy harvesting method is not limited to photovoltaic energy harvesting but applicable to most energy harvesting power sources that require impedance tracking. The proposed method is not limited to photovoltaic energy harvesting but applicable to most energy harvesting IoT power supplies that require impedance tracking.

References

[1] Gartner: the world's leading information technology research and advisory company. [Online]. http://www.gartner.com/

[2] Eduardo Cuervo et al., "MAUI: Making smartphones last longer with code offload," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*, pp. 49-62, 2010.

[3] Y. Nimmagadda, K. Kumar, Y.-H. Lu, and C. S. George Lee, "Real-time Moving Object Recognition and Tracking Using Computation," in *The 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2449-2455, 2010.

[4] Roelof Kemp et al., "EyeDentify: Multimedia cyber foraging from a smartphone," in *ISM '09 Proceedings of the 2009 11th IEEE International Symposium on Multimedia*, pp. 392399, 2009.

[5] T. Verbelen, P. Simoens, D. T. Filip, and D. Bart, "Cloudlets: Bringing the cloud to the mobile user," in *Proceedings of the third ACM workshop on Mobile cloud computing and services*, pp. 29-36, 2012.

[6] R. Fantacci, D. Tarchi, and A. Tassi, "A novel routing algorithm for mobile pervasive computing," in *Global Telecommunication Conferrence*, pp. 1-5, 2010.

[7] S. Shi, C.-H. Hsu, K. Nahrstedt, and R. Campbell, "Using graphics rendering contexts to enhance the real-time video coding for mobile cloud gaming," in *MM '11 Proceedings of the 19th ACM international conference on Multimedia*, pp. 103-112, 2011.

[8] K. Kumar, J. Liu, Y.-H. Lu, and B. Bhargava, "A survey of computation offloading for mobile systems," in *Mobile Networks and Applications*, pp. 129-140, 2013.

[9] A. Cidon, T. M. London, S. Katti, C. Kozyrakis, and M. Rosenblum, "MARS: Adaptive remote execution for multi-threaded mobile devices," in *MobiHeld '11 Proceedings of the 3rd ACM SOSP Workshop on Networking, Systems, and Applications on Mobile Handhelds, Article No. 1*.

[10] E. E. Marinelli, "Hyrax: Cloud computing on mobile devices using MapReduce," in *Masters Thesis, Carnegie Mellon University*, 2009.

[11] S. Sindia et al., "MobSched: Customizable scheduler for mobile cloud computing," in *45th Southeastern Symposium on System Theory*, pp. 129-134, 2013.

[12] X. Lu, H. Hassanein, and S. Akl, "Energy aware dynamic task allocation in mobile ad hoc networks," in *International Conference on Wireless Networks Communications and Mobile Computing*, pp. 534-539, 2005.