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Energy Harvesting Aspects of Wireless Sensor Networks: A Review

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***Abstract*—**Energy harvesting is the process by which energy is derived from external sources e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy captured and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks.Energy harvesters provide a very small amount of power for low-energy electronics. The energy sourced from energy harvesters is present as ambient background and is free.

***Keywords*—** *Energy harvesting, MAC, Routing, Wireless Sensor Networks*

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I. INTRODUCTION

Wireless Sensor Networks playa major role in the research field of multi-hop wireless network applications ranging from environmental and structural monitoring to border security and human health control. Research within this field has covered a wide spectrum of topics, leading to advances in node hardware, protocol stack design, localization and tracking techniques and energy management. Research on WSNs has been driven by a common focus: Energy efficiency. Nodes of a WSN are typically powered by batteries. Once their energy is depleted, the node is “dead.” Only in very particular applications batteries can be replaced or recharged. However, even when this is possible, the replacement/recharging operation is slow and expensive, and decreases network performance. Different techniques have therefore been proposed to slow down the depletion of battery energy, which include power control and the use of duty cycle-based operation. Figure-1 shows the block diagram of Wireless sensor network with energy harvester. In this wireless sensor node is placed in the network to perform the specific function. It gets energy from the energy source via Energy harvester. This way energy is harvested continuously by any of natural resource available and finally increasing the network lifetime.

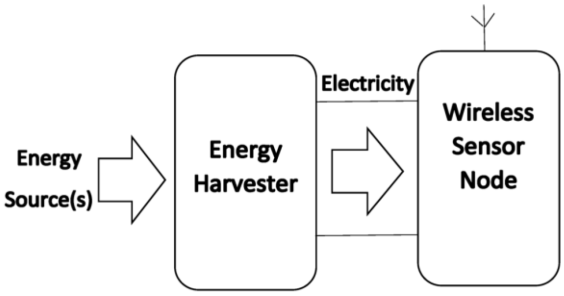

Figure-1

II. ENERGY HARVESTING TECHNIQUES

(i)RF energy harvesting: It **i**s the process of converting electromagnetic waves into electricity by a rectifying antenna. Energy can be harvested from either ambient RF power from sources such as radio and television broadcasting, cellphones, Wi-Fi communications and microwaves or from EM signals generated at a specific wavelength. Although there is a large number of potential ambient RF power, the energy of existing EM waves are extremely low because energy rapidly decreases as the signal spreads farther from the source. Therefore, in order to scavenge RF energy efficiently from existing ambient waves, the harvester must remain close to the RF source. Another possible solution is to use a dedicated RF transmitter to generate more powerful EM signals merely for the purpose of powering sensor nodes. Such RF energy harvesting is able to efficiently deliver powers from micro-watts to few milliwatts, depending on the distance between the RF transmitter and the harvester. Figure-2 shows the RF Energy harvesting.

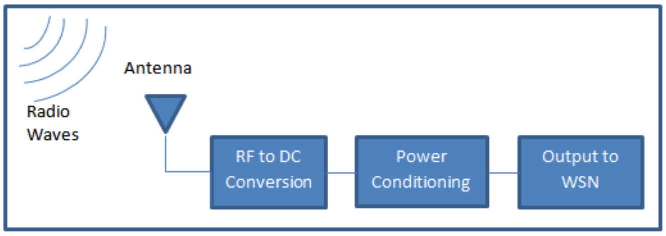

Figure-2

(ii)Resonant energy harvesting:It is also called resonant inductive coupling and is the process of transferring and harvesting electrical energy between two coils, which are highly resonant at the same frequency. Specifically, an external inductive transformer device, coupled to a primary coil, can send power through the air to a device equipped with a secondary coil. The primary coil produces a time-varying magnetic flux that crosses the secondary coil, inducing a voltage**.**

In general, there are two possible implementations of resonant inductive coupling:Weak inductive coupling and strong inductive coupling. In the first case, the distance between the coils must be very small (few centimeters). However, if the receiving coil is properly tuned to match the external powered coil, a “strong coupling” between electromagnetic resonant devices can be established and powering is possible over longer distances. Since the primary and secondary coil are not physically connected, resonant inductive coupling is considered a wireless energy harvesting technique.

(iii)Wind energy harvesting:It is the process of converting air flow (e.g. wind) energy into electrical energy. A properly sized wind turbine is used to exploit linear motion coming from wind for generating electrical energy. Miniature wind turbines exist that are capable of producing enough energy to power WSN nodes. However, efficient design of small-scale wind energy harvesting is still an ongoing research, challenged by very low flow rates, fluctuations in wind strength, the unpredictability of flow sources, etc. Furthermore, even though the performance of large-scale wind turbines is highly efficient, small-scale wind turbines show inferior efficiency due to the relatively high viscous drag on the blades at low Reynolds numbers.

(iv)Biochemical energy harvesting:It is the process of converting oxygen and endogenous substances into electricity via electrochemical reactions. In particular, biofuel cells acting as active enzymes and catalysts can be used to harvest the biochemical energy in bio-fluids into electrical energy. Human body fluids include many kinds of substances that have harvesting potential. Among these, glucose is the most common used fuel source. It theoretically releases 24 free electrons per molecule when oxidized into carbon dioxide and water. Even though biochemical energy harvesting can be superior to other energy harvesting techniques in terms of continuous power output and biocompatibility, its performance depends on the type and availability of fuel cells.

(v)Acoustic energy harvesting:It is the process of converting high and continuous acoustic waves from the environment into electrical energy by using an acoustic transducer or resonator. The harvestable acoustic emissions can be in the form of longitudinal, transverse, bending, and hydrostatic waves ranging from very low to high frequencies. Typically, acoustic energy harvesting is used where local long term power is not available, as in the case of remote or isolated locations, or where cabling and electrical commutations are difficult to use such as inside sealed or rotating systems. However, the efficiency of harvested acoustic power is low and such energy can only be harvested in very noisy environments. Harvestable energy from acoustic waves theoretically yields 0.96μW/cm3, which is much lower than what is achievable by other energy harvesting techniques.

All these harvesting techniques can be combined and concurrently used on a single platform to achieve the maximum battery life,this is called Hybrid Energy Harvesting.

The amount of energy harvestable from different sources using different energy harvesting technique depends upon:

(a) Power Density: The power density expresses the harvested energy per unit volume, area, or mass. Common unit measures of power density include watts per square centimeter and watts per cubic centimeter.

(b) Conversion efficiency:Conversion efficiency is defined as the ratio of the harvested electrical power to the harvestable input power. The energy conversion efficiency is a dimensionless number between 0 and 100%.

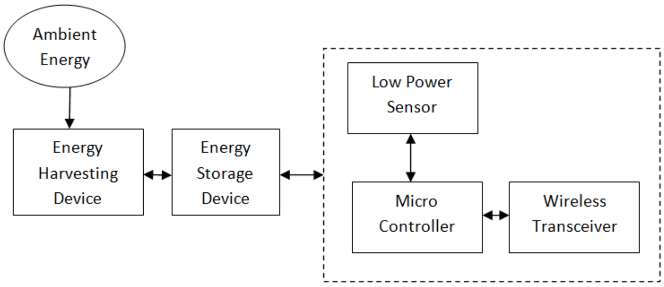

Figure-3

Figure-3 shows the Energy Harvesting Wireless Sensor node. In this the Ambient Energy in the form of Solar Energy,Wind Energy,Thermal Energy,Acoustic Energy, Vibrational Energy or RF Energy is scavanged using Energy Harvesting Devices(Microgenerator,Rectenna,Photovoltaic,Thermoelectric) which is then stored in the rechargeable batteries. This stored energy is fed to the low power wireless sensor node and the wireless communiction starts using wireless Transceiver .

III. HARVESTING-AWARE COMMUNICATION PROTOCOLS: MEDIA ACCESS CONTROL (MAC)

Harvesting capabilities have changed the design objectives of communication protocols for EHWSNs from energy conservation to opportunistic optimization of use of harvested energy. This fundamental change calls for novel communication protocols. Medium access control (MAC) protocols forEHWSNs, include ODMAC, EA-MAC, MTTP and PP-MAC.

(i) ODMAC:It is an On Demand MAC protocol for EHWSNs. It isbased on three basic ideas:

a) Minimizing wasting energy by moving the idle listening time from the receiver to the transmitter;
b) Adapt the duty cycle of the node to operate in the energy neutral operation state,
c) Reducing the end-to-end delay by employing an opportunistic forwarding scheme.

In ODMAC, transmission scheduling is accomplished by having available receivers broadcasting a beacon packet periodically. Nodes wishing to transmit listen to the channel, waiting for a beacon. Upon receiving a beacon, the transmitter attempts packet transmission to the source of the beacon.

Setting the beacon period imposes a trade-off between energy consumption and end-to-end latency: When the beacon period is short, more energy is consumed for transmitting beacons. Longer beacon periods result in higher energy conservation. ODMAC supports a dynamic duty cycle mode, in which the sensing period and the beacon periods of each node is periodically adjusted according to the current power harvesting rate. To this end, a battery level threshold is selected and periodically compared the current battery level to determine if the duty cycle should be increased or decreased. ODMAC also includes the concept of opportunistic forwarding, in which, instead of waiting for a specific beacon, each frame is forwarded to the sender of the first beacon received as long as it is included in a list of potential forwarders. In ODMAC it is assumed that charging (harvesting) is independent of sensor node operations and thus a sensor can harvest available energy during all operational states, i.e., irrespective of whether it is sleeping, listening, transmitting, etc. ODMAC is not suitable to be used in lossy environment, as it does not acknowledge and retransmits packets.

(ii) EA-MAC:It is anEnergy Adaptive MAC protocol proposed for EHWSNs with RF energy transfer. EA-MAC uses the node energy harvesting status as a control variable to tune the node duty cycles and back-off times.

In this scenario, two adaptive methods, energy adaptive duty cycle and energy adaptive contention algorithm, are proposed to manage the node duty cycle and back-off time depending on the harvested power rate. EA-MAC is similar to the un-slotted CSMA/CA algorithm in IEEE 802.15.4, but its sleep duration, back-off times, and state transitions are controlled by the average amount of harvestable energy. When a node harvested energy level is equal to the energy required to transmit a packet, the node transitions from sleep state to active state. Then it follows a CSMA/CA scheme to transmit the packet. If the channel is idle during the clear channel assessment (CCA) period, the node transmits a data packet. If the channel is busy, the node decides to either perform the random back-off procedure or terminate the CSMA/CA algorithm. The number ofback-off slots depends on the current energy harvesting rate. Similar to ODMAC, EA-MAC assumes the sensor node can harvest energy in any operational states. EA-MAC does not consider some important application requirements, such as end-to-end delay, and provides no mechanism to optimize network performance and lifetime. In addition, EA-MAC suffers from the hidden terminal problem, which results in increased collisions. Finally, its performance is not compared

(iii)The multi-tier probabilistic polling (MTPP) protocol:It extends probabilistic polling PP-MAC to multi-hop data delivery in EHWSNs with no energy storage, i.e., whose operations are powered solely by energy currently harvested (charge-and-spend harvesting policy). The polling packets generated by the sink are sent to the immediate neighbors of the sink, and these nodes forward them to nodes in following tiers, in a “wave-expanding” fashion. Polling packets and data packets are broadcast and relayed, respectively, from tier to tier until they reach their destination. As the number of tiers increases, the overhead of polling packets and packet collisions also increase, imposing higher latencies.

(iv)The Probabilistic polling (PP-MAC) protocol:It is a polling-based MAC mechanism that leverages the energy characteristics of EHWSNs to enhance the performance of traditional polling schemes in terms of throughput, fairness and scalability. The sink broadcasts a polling packet and the polled sensor responds with a packet transmission (single-hop topology). Instead of carrying the ID of a specific sensor, the polling packet contains a contention probability that the receiving sensor nodes use to decide whether to transmit their packet or not. The contention probability is computed based on current energy harvesting rate, number of nodes, and packet collisions. The probabilistic polling protocol increases the contention probability gradually when no sensor responds to the polling packet. It decreases it whenever there is a collision between two or more sensor nodes. As a result, and based on an additive increase multiplicative-decrease (AIMD) mechanism, the contention probability is decreased when more nodes are added to the EHWSN, and increased when nodes fail or are removed from the network. Moreover, in case of increase/decrease of the average energy harvesting rates, the contention probability is decreased/increased accordingly. PP-MAC uses the charge-and-spend harvesting strategy in which it first accumulates enough energy and then goes to the receive state to listen and receive the polling packet. Nodes return back to charging state either when their energy falls below the energy required to transmit a data packet or after transmitting their packet. Energy is assumed to be harvested only while in charging state. Analytical formulas and analysis of the throughput performance of PP-MAC is presented and validated by simulations. PP-MAC does not support multi-hop EHWSNs.

IV. HARVESTING-AWARE COMMUNICATION PROTOCOLS: ROUTING PROTOCOLS

Routing protocols: Energy-efficient routing has been widely explored for battery operated WSNs. EHWSNs exhibit unique characteristics and among their main objective there is not only extending the network lifetime, but also the maximization of the workload that the network can sustain, given the source-dependent energy availability of the nodes.

(i) Hybrid Energy Storage Systems (HESS): Itis a routing protocol which combines a supercapacitor with a rechargeable battery, as well as a power management device that controls all the operations in the energy system.The HESS is a crucial part of the node since it supplies all electronic components. The power management has to tune-up the energy flow to optimize the lifetime of the node. Their approach is to favourthe routes that use more energy from supercapacitors and that go through nodes with higher harvesting rates. Their work stems from the fact that a rechargeable battery can only sustain a limited amount of recharge cycles before its capacity falls below 80% of its original capacity. Such a function considers several factors, including the relay hop count, its residual battery and supercapacitor energy, the energy it harvested previously, the remaining cycles of its battery and its queue occupancy. Nodes with higher residual energy, harvesting rate and remaining battery cycles are preferred as relays. The overall goal of HESS is to minimize the cost of each end-to-end transmission.At the same time, it is necessary to buffer the RB with a SC in order to prevent constant and direct recharges of the RB which place significant stress on it.

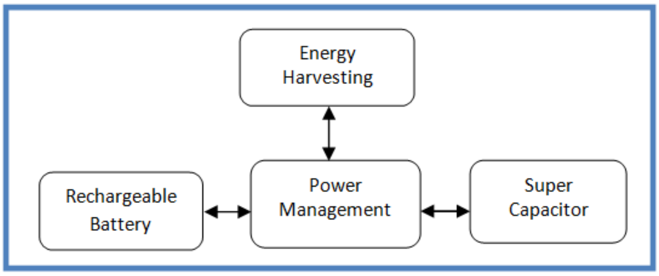

Figure-4

(ii) Distributed Energy Harvesting Aware Routing Algorithm(DEHAR):It is an adaptive and distributed routing for EHWSNs that calculates the shortest paths to the sink based on hop count and the energy availability of the nodes. To add energy-harvesting awareness to the algorithm, a local penalty is assigned to each node. This penalty, dynamically updated, is inversely proportional to the fraction of energy available to the node. When the energy buffer of the node is fully charged, this penalty should ideally be zero, while it should tend to infinity when the node has depleted its energy. When a change in the local penalty of a node occurs, it advertises it to its immediate neighbors. For each node, the local penalty is combined with distance from the sink to define the node energy distance, which is used by other nodes when choosing a potential relay. The energy distance of a node may become a local minimum if the penalty of a node neighbor is changed due to variations in its energy availability. To solve this problem, distributed penalties are introduced. Each time a node receives an energy update from a neighbor, it checks if it has become a local minimum. If this is the case, it increases its distributed distance penalty and advertises it to its immediate neighbors. Distributed and local penalty of a node are finally merged in a total penalty that is distributed to neighbor nodes.

(iii) Energy Harvesting Opportunistic Routing(EHOR):It is an opportunistic routing protocol for EHWSNs powered solely by energy harvesters (no batteries). Nodes of EHWSNs powered only by harvested energy are normally awake for a short period of time, then they shut down to recharge. After receiving a data packet, the potential relay that is the closest to the sink rebroadcasts it. Each node in the network follows a charging cycle consisting of a charging phase, during which the power consumption is minimal and the node waits to be recharged by the harvested energy, a receive phase, to which the node switch when it is fully charged, and an optional transmit phase. EHOR, however, assumes that the network topology is PROTOCOLS 25 linear, i.e., that nodes are uniformly deployed over a given interval and does not work in 2D topologies.EHORis used in some short-distance links instead of long-distance ones. As it will increase the number of source nodes and there will be increased MAC contention due to more transmissions by the nodes.

(iv)Duty cycle-based Adaptive topological algorithm(D-APOLLO): It isa harvesting-aware geographic routing protocol. Its aim is to maximize the utilization of the harvested energy and reduce latency by dynamically and periodically adapt the duty-cycle and the knowledge range (KR) of each node. The knowledge range of each node is the topological extent of the information that it collects. Dimensioning the KR involves a trade-off between the optimality of the path produced by the routing algorithm and the energy needed to collect and maintain a larger quantity of information about a node neighbors. The duty cycle of the nodes and their knowledge range are usually fixed in battery-operated WSNs. DAPOLLO, instead, periodically tries to find the duty cycle and the knowledge range that maximize utilization of the harvested energy based on the expected harvesting power rate, the residual energy of the node and the predicted energy consumption. This facilitates a low latency routing scheme which considers both geographic and duty-cycle information about the neighbors of a node, so that data can be routed efficiently and delivered to the sink as quickly as possible.

V. CONCLUSION

In this paper, a technical overview of the Energy Harvesting Techniques has been presented. Combinations of different types of energy harvesting techniques can further reduce dependence on batteries, particularly in environments where the available ambient energy types change periodically. Also various MAC protocols and Routing protocols have been explained. These protocols help to maximize the workload that a network can sustain. This type of complementary balanced energy harvesting has the potential to increase reliability of various wireless sensor networks applications.

VI. REFERENCES

[1] Holger Karl and Andreas Willig, “Protocols and architectures for wireless sensor networks, chapter 2 single-node architecture,” John Wiley & Sons, pp. 18–57, April 2005.

[2] IEEE Computer Society, “Part 15.4: Wireless medium access control (mac) and physical layer (phy) specifications for low-rate wireless personal area networks (wpans),” IEEE Std 802.15.4-2006, 2006.

[3] A. Prayati, Ch. Antonopoulos, T. Stoyanova, C. Koulamas, and G. Papadopoulos, “A modeling approach on the telosbwsn platform power consumption,” The Journal of Systems and Software, vol. 83(8), pp. 1355–1363, Aug 2010.

[4] Johan Pouwelse, Koen Langendoen, and Henk Sips, “Dynamic voltage scaling on a low-power microprocessor,”Proceedings of the 7th annual international conference on Mobile computing and networking, pp. 251–259, 2001.

[5] Holger Karl and Andreas Willig, “Protocols and architectures for wireless sensor networks, chapter 5 mac protocols,” John Wiley & Sons, pp. 111–148, April 2005.

[6] Vijay Raghunathan, Saurabh Ganeriwal, and Mani Srivastava, “Emerging techniques for long lived wireless sensor networks,” IEEE Communications Magazine, vol. 44(4), pp. 108–114, April 2006

[7] Giuseppe Anastasi, Marco Conti, Mario Di Francesco, and Andrea Passarella, “Energy conservation in wireless sensor networks: A survey,” Ad Hoc Networks, vol. 7(3), pp. 537–568, May 2009.