Power Aware Methodologies for Wireless Microsensors

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***Abstract*- Microsensors are used in monitoring functions in several hazardous and non reachable places. At such places human intervention is impossible so battery replacement is impossible and hence nodes do not have access to unlimited energy. Thus, designing fault-tolerant wireless microsensor networks with long system lifetimes can be challenging. In order to prolong system lifetimes, energy-efficient algorithms and protocols should be used. So, in this paper we study the techniques which are used for low power consumption as these are necessary for system to achieve both flexibility and energy efficiency and maximize the lifetime. Energy is minimized through the use of highly dedicated computational fabrics and through careful conditioning of logic based on signal statistics and by using techniques like DVS, CIMS.**

***Keywords*- Low Power Consumption, Wireless Sensor Network, DVS, Energy Saving, Energy Harvesting**

I. INTRODUCTION

Microsensors are used for variety of operations including environmental data collection, battlefield monitoring, biomedical etc. Sensor nodes are deployed for such purposes by letting them fall randomly from air planes. These sensors are very small, cost effective and energy efficient devices with very low initial power. The sensor nodes sense the data, process it and then communicate it to central base station. Despite the increasing capabilities of sensor nodes, there are some limitations; they have a limited amount of memory, processing power and most importantly energy. Sensor nodes are typically battery powered and battery replacement is infrequent or even impossible in many sensing applications. The need to minimize energy consumption while maintaining user constraints makes the design of wireless microsensor networks challenging. While techniques to minimize the energy consumption of portable, multimedia devices have been studied extensively these techniques may not be applicable to wireless microsensors. For example, while conventional hand-held devices only need to last hours or days, microsensor nodes need to last several years. Therefore, different energy-efficient techniques will need to be applied.In this paper we will study several methodologies for lowering the power consumption. Methods like DVS and reducing the stand by leakage at low duty cycles can be used. The CMOS Integrated Microsystems (CIMS) process may provide high performance, as the advancement in CMOS can be integrated with sensors by providing system flexibility to update the technology at later stage of the design. As sensors have initial very low energy, so the energy can be harnessed from the environment i.e., using ambient energy to power electronic circuits. Latency and performance requirement are met for low power methods by using energy aware approaches by employing energy aware circuits. We have laid so much stress on lowering the energy consumption, because it enhances the lifetime of the node, moreover reducing the power consumption results in cost effective, light weight and more compact design of sensors nodes. This paper addresses some of the key design consideration for future microsensor systems including the network protocols required for collaborative sensing and information distribution, system partitioning considering computation and communication costs, low energy electronics, power system design and energy harvesting techniques.

II. ARCHITECTURE FOR A POWER-AWARE DISTRIBUTED MICROSENSOR NODE

An initial design of a sensor node that illustrates power-aware design methodologies is shown in Fig 1. This system, the first prototype of our µAMPS (micro-Adaptive Multi-domain Power-aware Sensors) effort is designed with commercial off-the-shelf components for rapid prototyping and modularity [1].

A. Power Supply:

Power for the sensor node is supplied by a single 3.6V DC source, which can be provided by a single li-ion cell or 3 NiCD or NiMH cells. Regulators generate 5V, 3.3V and adjustable 0.9-1.5V supplies from the battery. The 5V supply powers the analog sensor circuitry and A/D converter. The 3.3V supply powers all digital components on the sensor node with the exception of the processor core. The core is powered by a digitally adjustable switching regulator that can provide 0.9V to 1.6V in twenty discrete increments.

B. Sensors:

The node includes seismic and acoustic sensors. The seismic sensor is a MEMS accelerometer capable of resolving 2mg. The acoustic sensor is an electret microphone with low-noise bias and amplification. The analog signals from these sensors are conditioned with 8^{th}order analog filters and are sampled by a 12-bit A/D. The high-order filters eliminate the need for oversampling and additional digital filtering in the SA-1100. All components are carefully chosen for low power dissipation; a sensor, filter, and A/D typically require only 5mA at 5 Volts.

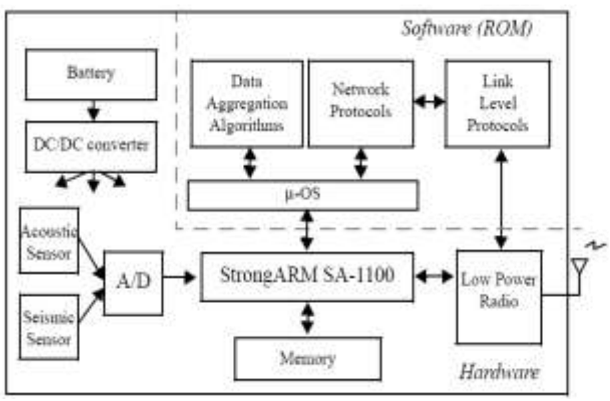

Fig 1: A sensor node hardware & software framework [10]

C. Microprocessor and Operating System:

A Strong ARM SA-1100 microprocessor is selected for its low power consumption, sufficient performance for signal processing algorithms, and static CMOS design. The memory map mimics the SA- 1100 "Brutus" evaluation platform and thus supports up to 16MB of RAM and 512KB of ROM. The OS, data aggregation algorithms, and networking firmware are embedded into ROM.

D. Radio:

The radio is based on a commercial single-chip transceiver optimized for ISM 2.45GHz wireless systems. The PLL, transmitter chain, and receiver chain are capable of being shut-off under software or hardware control for energy savings. To transmit data, an external voltage-controlled oscillator (VCO) is directly modulated, providing simplicity at the circuit level and reduced power consumption at the expense of limits on the amount of data that can be transmitted continuously. The radio module is capable of transmitting up to 1Mbps at a range of up to 15 meters.

III. Power-Aware Methodologies

In this section, we present energy-scalable design methodologies geared specifically toward our microsensor application [1]. At the hardware level, we note the unusual energy consumption characteristics affected by the low duty cycle operation of a sensor node, and adapt to varying active workload conditions with DVS. At the software level, energy-agile algorithms such as adaptive beam forming provide energy-quality tradeoffs that are accessible to the user.

A. Low Duty Cycle Issues:

The energy consumption characteristics of the components in a microsensor node provide a context for the power-aware software to make energy-quality tradeoffs. Energy consumption in a static CMOS-based processor can be classified into switching and leakage components. The switching energy is expressed as:

$$Eswitch = C_{tot} * V_{dd} * V_{dd} \quad (1)$$

Where C_{tot} is the total capacitance switched by the computation and V_{dd} is the supply voltage. Energy lost due to leakage currents is modeled with an exponential relation to the supply voltage:

$$Eleak = (V_{dd} * t)\, Ioexp(V_{dd}/nV_t) \quad (2)$$

While switching energy is usually the more dominant of the two components, the low duty cycle operation of a sensor node can induce precisely the opposite behavior. For sufficiently low duty cycles or high supply voltages, leakage energy can exceed switching energy. For example, when the duty cycle of the Strong ARM SA-1100 is 10%, the leakage energy is more than 50% of the total energy consumed. Techniques such as DVS and the progressive shutdown of idle components in the sensor node mitigate the energy consumption penalties of low duty cycle processor operation [2]. Low duty cycle characteristics are also observable in the radio.

B. Dynamic Voltage Scaling

DVS exploits variability in processor workload and latency constraints and realizes this energy-quality tradeoff at the circuit level. As discussed above, the switching energy of any particular computation is $Eswitch = C_{tot} * V_{dd} * V_{dd}$, a quantity that is independent of time. Reducing V_{dd} offers a quadratic savings in switching energy at the expense of additional propagation delay through static logic. Hence, if the workload on the processor is light, or the latency tolerable by the computation is high, we can reduce V_{dd} and the processor clock frequency together to trade off latency for energy savings.

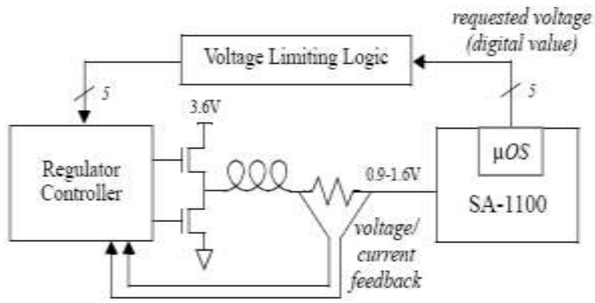

Fig 2: Regulation scheme for DVS [1]

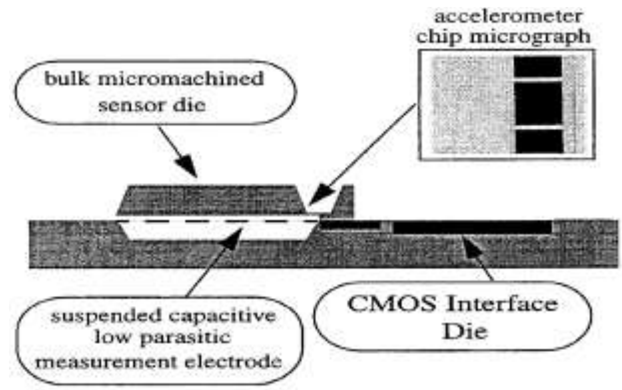

Fig 3: The Accelerometer [4]

IV. Low Power Wireless Microsensors

A distributed, low power, wireless, integrated microsensor (LWIM) [4] technology can have set of unique requirements exist for distributed wireless microsensor networks. The individual low cost sensor nodes must be

- reconfigurable by their base station,
- Autonomous to permit local control of operation and power management,
- Self-monitoring reliability,
- Power efficient for long term operation, and Must incorporate diverse sensor capability with highly capable, low power microelectronics.

LWIM nodes are fabricated by the new CMOS Integrated Microsystems (CIMS) process. CIMS provides high sensitivity devices for vibration, acoustic signals, infrared radiation and other diverse signal sources. The central challenges for low cost, manufacturable LWIM devices are the requirements for microcropower operation and the complete integration of a CMOS RF transceiver.

A. Low Power Wireless Microsensors: CMOS Microsensor Integration

The low power electronics for wireless microsensors exploits a new CMOS microsensor integration technology. The rapid reductions in the fabrication cost of CMOS digital circuit technology, along with improvements in performance, provide motivation for the development of CMOS compatible microsensor structures and measurement circuits. CIMS [3] combines commercial CMOS (post-processed after foundry-fabrication by XeF_2 micromachining) with high performance bulk micro machined sensor and actuator structures (Fig.3) by flip chip bonding. As an example, a CIMS accelerometer structure is shown in Fig 3.The CIMS process employs an Interface Die that supports a sensor element, the CMOS interface die is fabricated by commercial foundries and may be post-processed after fabrication. The interface die may support measurement, control, and communication systems.

The CIMS process offers several advances over previous techniques. First, by separating the CMOS and bulk micro-machining processes, conventional low cost CMOS technology may be directly applied. This offers system development flexibility to update the circuit technology rapidly to exploit the most optimum processes that become available. In addition, separation of CMOS and sensor element fabrication permits the introduction of novel materials, eg. pyroelectric systems without disturbing critical CMOS processing.

B. Idle-mode Leakage Control

Microsensors typically spend most of their time in a standby mode, waiting for significant events to occur. Hence, powered components dissipate leakage energy over long periods of time. One approach to reducing idle mode energy dissipation is simply to shut off all unused electronics during idle mode. However, any energy savings from shutdown can be negated by the potentially large latencies and energy overheads required to power up the node from its off state. Idle mode energy is therefore best addressed at its source, the leakage currents flowing through idle circuits. Multiple-Threshold CMOS (MTCMOS), for instance, reduces idle mode leakage by employing high-V_{th} transistors to gate the power supplies to the logic blocks which are designed with low- V_{th} transistors. MTCMOS designs are prone to “sneak” (unexpected) leakage paths [5] through low- V_{th} gates. Leakage feedback flip-flops utilize leakage to hold state while avoiding sneak leakage paths .This circuit achieves performance close to a traditional low- V_{th} flip-flop while retaining the low leakage of a high-V_{th} flip-flop.

V. Energy Harvesting

As the power dissipation of entire sensor systems is reduced to hundreds of microwatts, it becomes possible to use ambient energy sources to power electronic systems. Various schemes have been proposed to eliminate the need for batteries in a portable digital system by converting ambient energy in the environment into electrical form [6]. The harvested electrical energy can be stored and utilized by the node's electronic circuits. The most familiar sources of ambient energy include solar power. Table 1 lists potential power output for a wide variety of energy sources [2].

TABLE I: EXAMPLES OF AMBIENT ENERGY SOURCE

Energy Source	**Transducer**	**Power**
Walking (Direct Conversion)	Piezoelectric	5 W
Solar	Photovoltaic Cell	20mW
Magnetic Field	Coil	1.5mW
Walking (Vibration)	Discrete Moving Coil	400mW
High Frequency Vibration	MEMS Moving Coil	100mW
RF Field	Antenna	5mW

Two examples of power generation using mechanical vibration are shown here:

A. Vibration Based Power Generator

One particular approach to using ambient energy sources for power involves transduction of mechanical vibration to electrical energy [7]. A generator based on transducing mechanical vibrations has some distinct advantages: it can be enclosed and protected from the outside environment, it functions in a constant temperature field, and it can be activated by a person.

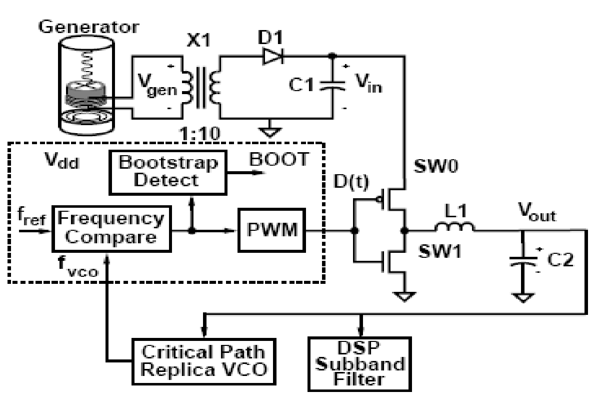

Fig 4(a): Vibration based self powered system [7]

It is particularly suited for machine mounted sensors, where the vibration of the machinery provides the power, or body area sensors, where the movement of the human body generates vibrations that can be used as a power source and leads to a power output of 400mW. Fig 5(a) is a detailed block diagram of our self-powered system. A moving coil generator is used which consists of a mass attached to a spring, which is attached to a rigid housing. The generator and rectifier subsystem is shown at the top. Transformer X1 (with a 1:10 turns ratio) converts the output voltage of the generator V_{gen} to a higher voltage that can be rectified by the half-wave rectifier formed by diode D1 and capacitor C1. Note that with proper electromechanical design, the transformer can be eliminated. Voltage V_{in} is the time-varying input voltage to the regulator. The regulator consists of five main subsystems: a VCO, frequency comparator, pulse-width modulated (PWM) waveform generator, bootstrap detection circuit, and a Buck converter. To achieve the lowest possible power consumption, the converter down converts V_{in} to the lowest voltage at which the DSP can run and still produce correct results at the rate set by f_{ref}.

*B. MEMS Generator*Advances in MEMS technology have enabled the construction of a self-powered system in which a MEMS device acts a power source for a digital load. The MEMS device [8] is a variable capacitor that converts mechanical vibration into electrical energy. The capacitor plates are charged and then moved apart by vibration, resulting in the conversion of mechanical energy into electrical energy. The device consists of three basic parts: a floating mass, a folded spring, and two sets of interdigitated combs. With appropriate regulation circuitry, this device delivers 10µW of power

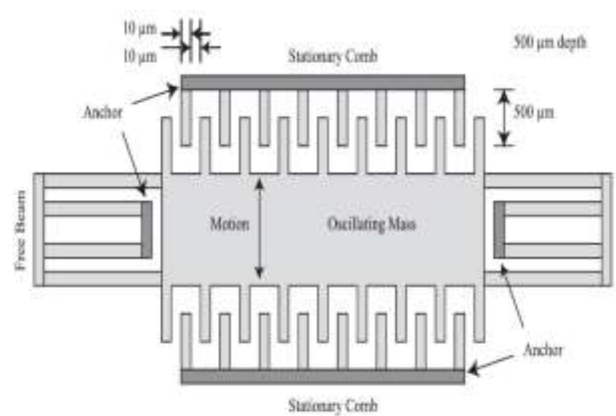

Fig 4(b): A plan view of MEMS generator [8]

VI. ENERGY-AWARE COMPUTING

Energy scalability is an important trend that involves the system adapting to time-varying operating conditions. This is in contrast to current low-power approaches, which target the worst-case operating scenario. An energy-aware circuit monitors its available energy resources and dynamically adapts hardware parameters to meet latency and performance requirements. For instance, an arithmetic circuit such as a multiplier is subject to diversity in operand width. Multiplier circuits are typically designed for a fixed operand size, such as 32 bits per input; calculating an 8-bit multiplication on a 32-bit multiplier results in unnecessary switching of the high-order bits.

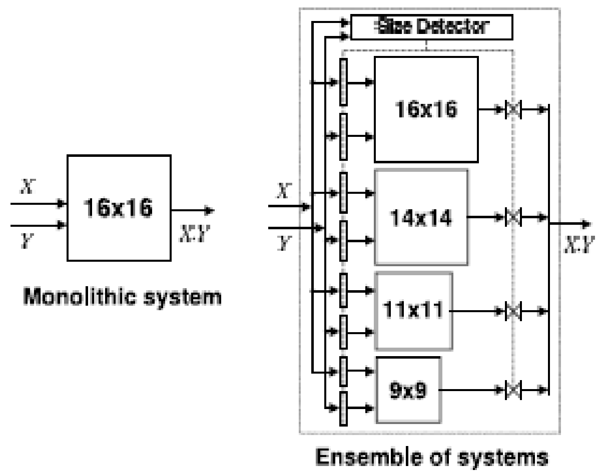

Fig 5: Comparison of Monolithic System and Ensemble of Systems [3]

This excess switching would not have occurred if the 8-bit multiplication had been performed on an 8-bit multiplier [9]. As small operands can result in inefficient computation on larger multipliers, an architectural solution that improves energy awareness is the incorporation of additional, smaller multipliers of varying sizes, as shown in Fig6. Incoming multiplications are routed to the smallest multiplier that can compute the correct result, reducing the energy overhead of unused bits. An ensemble of point systems, each of which is energy-efficient for a small range of input widths, takes the place of a single system whose energy consumption does not scale as gracefully with input diversity. For an operand bit width distribution typical of a speech application, the ensemble of Fig6 consumes 57% less energy than a monolithic multiplier.

VII. CONCLUSION

This paper describes the challenges facing wireless microsensor design and presents general microsensor node architecture. The challenge for next generation nodes is to further reduce energy consumption by optimizing energy awareness over all levels of design. Energy harvesting techniques that eliminate the need for battery source and provide "infinite" lifetime will become critical as the size of sensor systems grows. Energy scalability is also an important design consideration in these distributed sensors. Reducing startup time improves the energy efficiency of a transmitter for short packets and multihop routing reduces energy for long distance communication. The amount of resources available (e.g., battery life), the quality requirements (e.g., accuracy of sensing results), and the latency requirements can vary as a function of time. For example, system-level power down can be exploited to scale quality or latency with respect to energy dissipation. At the circuit level, techniques such as DVS allow the energy dissipation of a processor to be scaled with computation latency or Quality of Service. Lowering of the energy consumption is not the only goal but making system more power aware is our task. A power aware system priorities its need in terms of several parameters like increasing the life time or enhancing the quality on user's request inherent to its property of adapting the changes according to the environment. Lowering the power consumption makes the system more reliable and increases the lifetime. The techniques we studied here must be implemented in a mixed fashion so that benefits of combination of them can be used. A total-system approach is required for reliable, self-powered microsensor networks that deliver maximal system lifetime in the most challenging environments.

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