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Critical Study on Constraints in Wireless Sensor Network Applications

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Abstract

Wireless sensor networks (WSN) are a revolution, promising a significant impact in society, dwarfing previous milestones in information revolution. It is considered a platform that defines interactions with the physical world where needed. WSN is considered a future platform for a pervasive Internet. Their demand is spurred by many applications requiring unattended, high-precision real-time observations over a vast area. They are applied in military, medicine, and environmental monitoring. Though WSN performance is dependent on several factors, Network coverage is critical in a WSN to monitor a region of interest. VLSI technology developments have made it possible to embed micro-processors in sensor nodes, making them intelligent and efficient. Though the sensors have limited computing power they operate under constrained environments. Current WSN deployments rely on microcontrollers which are less optimized for energy. Many Researches have proposed protocols that facilitate efficient communication or sensing operations. This paper is critical study on factors that influence a WSN in terms of constraints and recommendations to overcome the constraints.

1. Introduction

The past witnessed growth of the Internet which brought great business promises. The Internet became a communication channel for people to contact each other, do online shopping or bank from home. Advances in VLSI, wireless communication combined with the internet, is fast becoming a platform for interactions between computers and the physical world [1]. Wireless networks with different kinds of sensors are a bridge between the environment and human needs where thousands of sensor nodes occupy a geographic area [2]. These Sensors can be used in seismic, visual, thermal and many other activities, since they provide a practical method for humans to monitor the environment. WSNs environment sensing can be categorized into two based on their application areas, namely Military applications and non-military applications. Military applications contain surveillance, enemy target tracking. WSNs can be deployed in battle fields and be operated without any human intervention [3]. Civil applications of WSNs include pollution, traffic density and road monitoring, ecological and environmental monitoring. WSN data is transmitted across networks and embedded CPUs support organization and complex communication protocols. The UWB (Ultra-wide band), IEEE 802.15.4, Bluetooth, have incorporated lower power requirements in their modulation and protocol [4] For Example IEEE 802.15.4 uses a duty cycle, where nodes are in a sleep mode periodically. Protocols for energy efficient routing and organization have been proposed and deployed. Any WSN can be organized in two ways, homogenous and heterogeneous. All the sensor nodes have the same capabilities in sensing, computing and wireless communication, in a homogenous WSN. Heterogeneous WSN relies on different types of sensor nodes where some nodes have more power and better communication capability. Large scale deployments of WSNs have many constraints in efficient sensing and effective communication. This paper attempts to list and suggest solutions to such constraints.

2. Factors influencing WSN Design

A sensor network is influenced by many factors right from its design stage. The factors considered in design are fault tolerance, costs, scalability, operating environment, topology and several constraints. These factors are important since they serve as a guideline to design.

Fault tolerance: Sensor nodes generally fail due to lack of power or due to physical damage or environmental interferences and such failures should not affect the WSNs designated task. Fault tolerance is the ability of a WSN to sustain sensor functionalities without interruptions due to node failures. Protocols and algorithms designed for fault tolerance have to address their defined levels of performance. For example in a home the level can be low but in a battlefield or environmental monitoring the tolerance level has to be very high to sustain its functionality.

Scalability: The number of nodes deployed may vary from hundreds to thousands based on the application and topography. The density of the sensors also can range from one to hundred within a region of the target area. Designs and protocols need to consider this sensor density before designing the application to accommodate sensor density, duplication of signals and consolidating a unified data.

Production costs: WSN itself is deployment of a large number of sensor nodes and the cost of a single node becomes the underlying factor in the overall cost of the networks. WSN can be deployed only when their cost is lesser than the regular or traditional sensors. Though the cost of a Bluetooth radio (a low-cost device) is 10 times more expensive than a sensor node, when deployed in magnitude it becomes expensive to deploy WSN sensors. A bit of data transmitted by radio can cost more than 1, 000 MCU instructions. Thus the cost of a sensor node is a challenging issue since it has to have functionalities but at a very cheap cost. Figure 1 depicts the power draw of different Instruments.

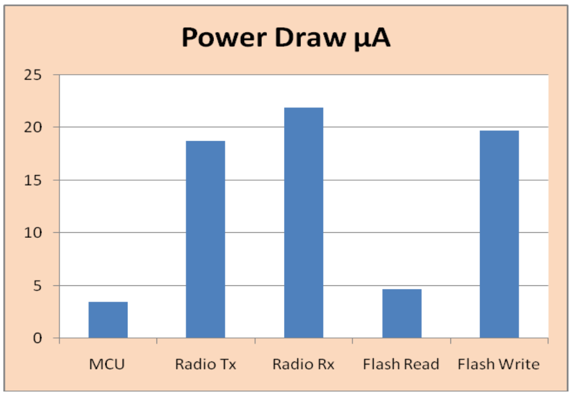

Figure 1: Per-component power-draw of a WSN node as per Texas Instruments. MSP430x2xx Family User's guide

3. Constraints

WSNs consist of battery-powered sensor nodes endowed with a multitude of features. They operate under a set of unique constraints that demand improvements of, traditional technologies. A WSN sensor node can vary in size from the tiniest to the largest. The cost of sensors is similarly variable based on their capabilities and complexity. These Size and cost constraints result in corresponding resource constraints like energy, computational speed, memory or bandwidth.

Deployment constraints: Sensor deployment is a fundamental constraint in a WSN. Deployment issues are directly involved with the mobility of sensors which is limited. Deployment types, number of sensors and target locations of devices determine intrinsic properties of a WSN like connectivity, coverage, cost and life. Two major functions of a WSN are sensing and communication. Sensors sense and report the data needed by the end-user. The network coverage and connectivity are the main factors that determine the efficiency of a WSN. A sensing area is considered covered when every point in the field is within the sensing range of a desired degree. The coverage can be ensured by an apt deployment strategy, which determines the place and type of every sensor node. Field surveillance applications play a major role in several civilian and military scenarios. Any surveillance application has a strict lifetime requirement needed to operate for a designated period of time. Sensor coverage and network lifetime have been studied extensively in sensor network literature [5]. Network lifetime constrains focus on the area of coverage and not the location coverage [6] A WSN is connected when all nodes deliver data to a destination like a Base Station Deployment and communication mechanisms are critical to provide connectivity. Deployment can be Pre-fixed or traceable and pre-determining sensing points while planning a WSN. The location and the number of sensor nodes are determined. Deployment can also be the Co-existence of heterogeneous devices, each sensing different areas like sensing, routing, data processing or aggregating, clustering and coordinating. Sensing-and-transmitting (ST) is the capability of observing by conducting Analog to Digital conversion, signal processing, generating and transmitting the data. Routing or relaying (RR) is forwarding the received sensor data to a defined destination over a long distance. Aggregating (AG) is combining raw data into a single unit or stream. Coordinating (CO) is managing other nodes by scheduling and instructing. Data Sink (DS) represents the destination of all data transmissions which typically is a part of the Base Station (BS).

Recommendations: For optimal results, a WSN should have 25 medium energy nodes for a point and one RR with higher energy for listening and forwarding data from these 25 sensor nodes. Every 25 RR could have one to three High Energy AG sensor to filter redundant data and forward to the BS. The BS could then transmit data through the internet to the Application as input for further processing. For a given a sensing task, determining the number and deployment of heterogeneous devices minimizes the network cost and attempts to overcome deployment constraints. The optimal deployment scheme is depicted in Figure 2.

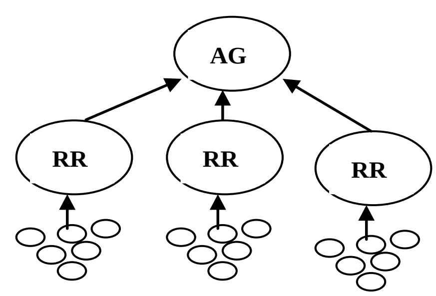

Figure 2 – Optimal Deployment Scheme

Energy constraints: Energy resource is a constraint in wireless sensor networking. Though Processor design and computing have significant improvements, the battery technology needs improvement. Processing of sensed data before transmitting can save energy due to the reduction in the amount of data to be transported through the network [7]. Since, the sensor node is a micro-electronic device it can have limited power (<0.5 Ah, 1.2 V). The node lifetime has a strong dependence on battery lifetime. Generally, in a multi-hop ad WSN nodes play a dual role of being data originator and router. Malfunctions in these devices can cause significant topological changes and require re-routing of packets or re-organization of the WSN. Since, WSNs are large, it is energy-expensive to transport sensed data individually for centralized processing. Localized processing of sensed data is a more viable approach for reducing the burden of data transportation, almost similar to centralized processing [8]. Combining sensed information with fusion can also improve the sensing accuracy. Sensors sometimes operate in a very hostile environment, and nodes become unavailable due to resource constrains. The Nodes can be put to sleep mode periodically to save energy [9]. This temporary unavailability affects the sensing accuracy, since, the number of available sensors to perform local fusion are lesser. The transmission range has to be at least double of the sensing range so that local data fusion can be performed. Thus, the requirement of sensing range by the sensing accuracy also determines the energy needed in the communication for local fusion. The network lifetime is dependent on numerous factors: how the sensed data is forwarded to the infrastructure, how the whole network is organized, how the traffic congestion is how the events are distributed, etc. The complexity in event detection has an important role in determining energy consumption.

Recommendations: Designing of power-aware protocols, algorithms or Creation of Application specific protocols by ignoring less important to save energy in nodes, is a viable solution to saving energy. Also if local fusion is executed with three sensors for reducing redundant data and achieving sensing accuracy, it has an element of optimality and can save energy consumption especially for larger ranges or higher node density is higher.

Hardware constraints: Any WSN sensor has four basic components namely sensing unit, transceiver unit, processing unit and a power unit. Sensing units typically have a sensor and analog to digital converter (ADC). Analog signals of the sensors based are converted to digital signals by the ADC and fed to the processing unit. This processing unit manages node collaborations to carry out the assigned tasks. A transceiver connects the sensor to the network. These units are powered by a Power unit. The sensor also needs to fit into a matchbox-sized device [10]. Sensor requirements, sometimes, may be smaller than even a cubic centimeter [11] light enough to remain suspended in the air. Other than size constraints there are also other stringent constraints for sensor nodes like extremely low power consumption, have low production costs, operate unattended and be adaptive to the environment [12]. The lifetime of a sensor depends on the lifetime of the power resources and Sensor nodes become inaccessible due to loss of energy. An integrated WSN (WINS) the total average system supply must be less than 30 µA to provide a long operating life [13]. The Power in nodes is also a limited due to size limitations. The transceiver can be an optical device like smart dust motes or a radio frequency (RF) device. Generally, RF communications require modulation, filtering, band pass, demodulation and multiplexing circuitry making it more complex and expensive. The loss in transmitted signal between two sensor nodes may high since the antennas of the sensor nodes are closer to the ground. It is possible to use low duty cycle radio electronics for sensor networks. However, designing energy efficient and low duty cycle radio circuits is still technically challenging. Current radio technologies like Bluetooth are not efficient enough for sensor networks because turning them on and off consumes much energy [14]. Though higher computational processors are small, memory units of sensor nodes are still limited. For Example the processing unit of a smart dust mote prototype is a 4 MHz Atmel AVR8535 micro-controller with 8 KB instruction flash memory, .512 Kb RAM and .5Kb EEPROM, with TinyOS operating system. It has 3500 bytes for OS code and another 4500 bytes as code space. The processing unit of another sensor node called lAMPS wireless sensor node, has a 59–206 MHz SA-1110 micro-processor, running a multithreaded l-OS operating system. Sensor nodes battery are powered by lithium (Li) coin cells which measure 2.5 cm in diameter and 1 cm in thickness. Table 1 depicts the evolution of the Mica2 and Mica2dot Motes [15] [16].

Recommendation: Using Solar cells to power the sensors similar to the Solar lights on the Highways can help overcome complex hardware built for WSNs.

Table 1 Motes Hardware Evolution

Mote Type	**WeC**	**Rene**	**Mica**	**Mica2**	**Mica2Dot**	**Mica3**	**Micaz**
Microprocessor							
MicroprocessorType	AT90LS835	Atmega163	Atmega128	Atmega128	Atmega128	Atmega128	Atmega128
CPU Clock(MHz)	4	4	4	7.3827	4	4	4
Memory (KB)	8	16	128	128	128	128	128
Ram(KB)	.5	1	4	4	4	4	4
Radio communication							
CommunicationRadio Type	RFMTR1000	RFMTR1000	RFMTR1000	Chipcon CC1000	Chipcon CC1000	CC1020	Chipcon CC2420*
Frequency	433/916 MHz (single freq.)	433/916 MHz (single freq.)	433/916 MHz (single freq.)	916/433/315 MHz (multiple channels)	916/433/315 MHz (multiple channels)	916/433/315 MHz (multiple channels)	2.4 GHz (multiple channels)
Radio Speed (kbps)	10	10	40	38.4	38.4	76	250

Performance constraints: Although WSNs have a reduced cost in sensor challenges exist in their usage. The sensor node functions in a WSN define the complexity and performances. This increases the probability of network functionalities deviating from its normal operation. Moreover, these constraints reduce the network lifetime of a WSN. The maximum throughput is the maximum amount of stable traffic per unit time (bits/sec) that traverses the network from all the sources and the size of the queue in a network node is bounded. General assumption is, all nodes generate equal amount of network traffic. Two factors can create a constraint in network throughput. The first factor is nearby nodes transmitting at the same time causing signals received to corrupt. Second factor, being relay of information from source to destination in multiple hops , which is proportional to the number of retransmits (multihop traffic constraint). Current sensor nodes hardware is based on RF circuit design. For Example, the lAMPS wireless sensor node uses a Bluetooth-compatible with an integrated frequency synthesizer, Low-power sensors use a single channel RF transceiver and the WINS architecture uses radio links for communication. Infrared transceivers are cheap and easy to build. Laptops, mobile phones and PDAs offer infrared data association interface. The main drawback with infrared is the requirement for a line of sight between sender and receiver, making it a a reluctant choice as transmission medium in WSNs. The transmission medium must be have robust coding and modulation schemes that model different channel characteristics. A sensor expends maximum energy in communication, since it involves both data transmission and reception. Mixers, voltage control oscillators, frequency synthesizers and power amplifiers consume valuable power in the transceiver. Energy spent in data processing is very less compared to data communication. The energy cost of transmitting 1 KB a distance of 100 m is approximately the same as that for executing 3 million instructions by a 100 million instructions per second (MIPS)/W processor. Hence, local data processing is crucial in minimizing power consumption in a multihop sensor network. The LabVIEW WSN Module controls power usage and data acquisition rates[17]. The performances can be improved by deploying LabVIEW code at the node that modifies data acquisition and radio transmissions. he WSN nodes are programmed to send all acquired data to the gateway via a radio message at each sample interval and when the sample interval of the node is set to one second (1 Hz), the radio on the node is powered up at the same rate. Battery life is increased when the programmed node doest not transmit at each sample interval making power savings significant, as listed in Table 2 and depicted in Figure 3. Transmit interval beyond 100 seconds has a limited effect on power savings, since the radio powers up and transmits status information to the gateway every 61 seconds, when no transmissions occur in the time period. Regardless of the transmit interval, the node powers up the radio every 61 seconds to maintain the network connection.

Recommendation: A sensor node must therefore have built-in computational abilities and be capable of interacting with its surroundings. The ISM bands have radio, spectrum allocation, and global availability and not bound to a particular standard. The usage of the ISM bands gives more freedom for implementing power saving strategies in sensor networks. Accuracy can be improved by replacing redundant sensors. WSN applications sense and gather data in a timely manner or based on events. For these WSN applications, it is critical to deploy enough sensor nodes with a specified sensing capability. The size and power consumption of sensor nodes can also be reduced as the use of more advanced VLSI technology.

Sample Interval	**Transmit Interval**	**Battery Life (months)**
1 Second	1 Second	**1.45**
1 Second	10 Seconds	**5.78**
1 Second	100 Seconds	**7.93**
1 Second	1000 Seconds	**8.05**
5 Seconds	**5 Seconds**	**6.39**
5 Seconds	**50 Seconds**	**24.73**
5 Seconds	**500 Seconds**	**25.78**
5 Seconds	**5000 Seconds**	**26.78**
60 Seconds	**60 Seconds**	**36.32**

Table 2: Battery life achieved through slower transmit rates

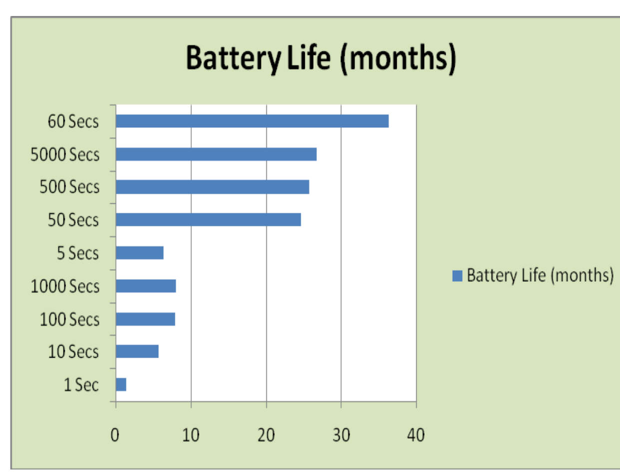

Figure 3: Battery life achieved in slower transmit rates

4. Conclusion

A WSN can be used in important applications like remote ecological monitoring, target tracking due to the availability of sensors that are smaller in size and wireless interfaces that can communicate with one another in a network. Lack of true applications for WSN is analogous to the situation of Internet back some thirty years ago. It is anticipated that real-world sensor network applications will come to life in the near future. It is also challenging to design a practical and long-living WSN. Designing hardware for wireless sensor networks requires a holistic approach in all design areas, since requirements for computation vary in magnitude, size. WSN applications sense and gather data in a timely manner or based on events. For these WSN applications, it is critical to deploy enough sensor nodes with a specified sensing capability. The size and power consumption of sensor nodes can also be reduced as the use of more advanced VLSI technology. Accuracy can be improved by replacing redundant sensors. This paper has presented factors affecting WSN networks and solutions are suggested to overcome them for a long WSN future.

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