Optimization Techniques in Wireless Sensor Networks: A Survey

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Abstract

Wireless sensor networks (WSNs) deal with the major issue of energy limitation in their deployments. There are several issues that constrain the WSNs and challenges posed by the environment of handling traffic and the lifetime of the battery in the nodes. We discuss the different optimization techniques proposed by current studies used to deal with these challenges. We briefly illustrate different factors and aspects to evaluate the value each optimization technique provides from scalability to reliability. In this paper, we will discuss the different ways of Optimizing Wireless Sensor Networks to conserve Energy and Lifetime of the Sensors.

Keywords: *IOT, wireless sensor network, Quality of services*

I. INTRODUCTION

A Wireless Sensor Network (WSN) is a distributed network and it comprises a large number of distributed, self-directed, tiny, low powered devices called sensor nodes. WSN naturally encompasses a large number of spatially dispersed, petite, battery-operated, embedded devices that are networked to supportively collect, process, and convey data to the users, and it has restricted computing and processing capabilities.

In current day's wireless network is the most popular services utilized in industrial and commercial applications, because of its technical advancement in processor, communication, and usage of low power embedded computing devices. Sensor nodes are used to monitor environmental conditions like temperature, pressure, humidity, sound, vibration, position etc. In many real time applications the sensor nodes are performing different tasks like neighbor node discovery, smart sensing, data storage and processing, data aggregation, target tracking, control and monitoring, node localization, synchronization and efficient routing between nodes and base station.

Most of the currently adopted technologies for WSNs are based on low cost processors, resulting in limited energy budget and restricted memory space. In many applications, it is expected that the sensor node last for a long time because in most of the cases these networks are used in remote areas and recharging and/or replacing power supply units is considered difficult or prohibitive due to hazardous and inaccessible places where they are supposed to operate. Further, due to the availability of cheap hardware and various possibilities for the radio communication frequency, numerous topologies for WSN can be adopted.

The below figures gives us an idea of how a Wireless sensor networks looks like along with the various WSN applications.

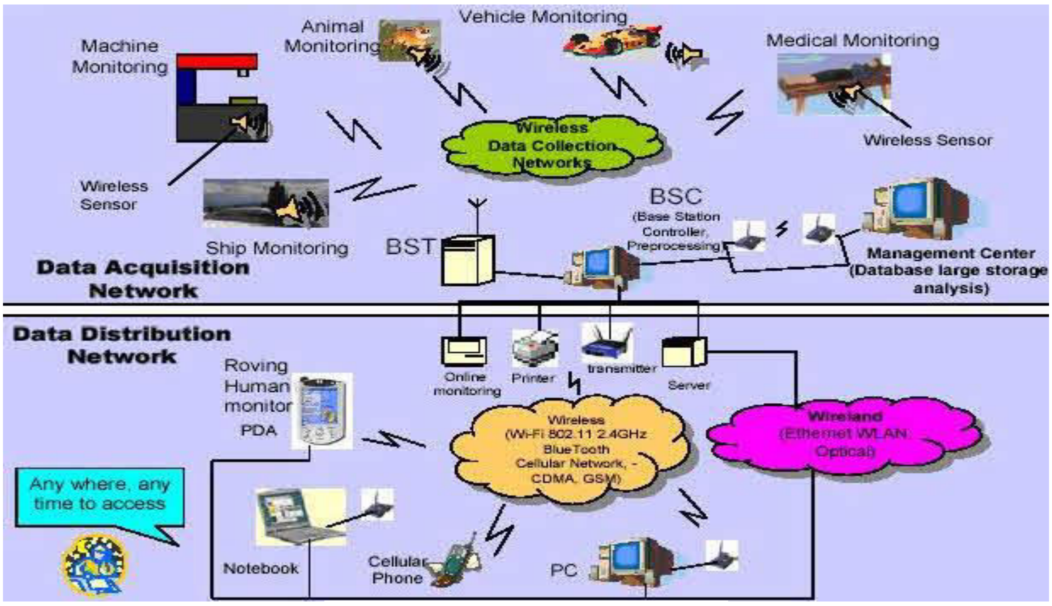

Figure: Wireless Sensor Networks

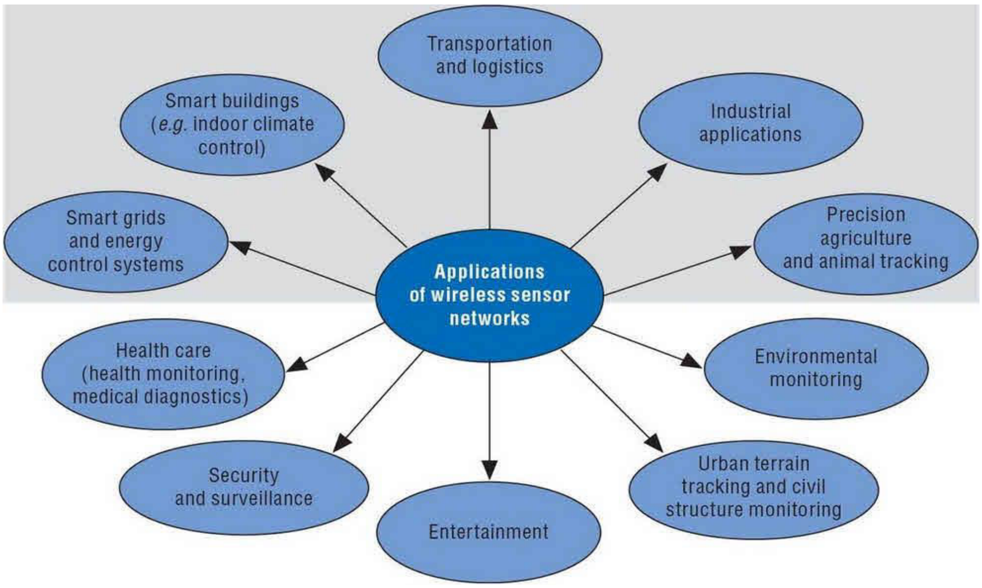

Figure: Wireless Sensor Networks Applications

II. OPTIMIZATION TECHNIQUES

A: Adaptive design optimization of wireless sensor networks using genetic algorithms

This technique presents a multi-objective optimization methodology for self-organizing, adaptive wireless sensor network design and energy management, taking into consideration application-specific requirements, communication constraints and energy-conservation characteristics [1]. A precision agriculture application of sensor networks is used as an example. Genetic algorithms are used as the optimization tool of the developed system and an appropriate fitness function is developed to incorporate many aspects of network performance. The design characteristics optimized by the genetic algorithm system include the status of sensor nodes (whether they are active or inactive), network clustering with the choice of appropriate cluster heads and finally the choice between two signal ranges for the simple sensor nodes. The optimal sensor network designs constructed by the genetic algorithm system satisfy all application-specific requirements, fulfill the existent connectivity constraints and incorporate energy-conservation characteristics. Energy management is optimized to guarantee maximum life span of the network without lack of the network characteristics that are required by the specific application.

The methodology of WSN design that has been developed in this work, although general takes into account several application-specific characteristics, such as those posed in the framework of precision agriculture, to show the performance of the developed algorithm. Precision agriculture refers to the approach of agricultural control and management based on direct chemical, biological and environmental sensing. Sensor networks play a vital role in that approach by maximizing the quantity, diversity and accuracy of information extracted from a WSN deployment.

There are several interesting approaches to tackling such problems, but one of the most powerful heuristics, which is also appropriate to apply in the multi objective optimization problem, is based on Genetic Algorithms (GAs) [8]. GAs try to imitate natural evolution by assigning a fitness value to each candidate solution of the problem and by applying the principle of survival of the fittest. Their basic components are the representation of candidate solutions to the problem in a ‘‘genetic’’ form (genotype), the creation of an initial, usually random population of solutions, the establishment of a fitness function that rates each solution in the population, the application of genetic operators of crossover and mutation to produce new individuals from existing ones and finally the tuning of the algorithm parameters like population size and probabilities of performing the pre-mentioned genetic operators. The successful application of GAs in a sensor network design in [9] led to the development of several other GA-based application-specific approaches in WSN design, mostly by the construction of a single fitness function [10–13], but also by considering Pareto optimality in the evaluation of fitness values [14]. However, in most of these approaches, either very limited network characteristics are considered, or several requirements of the application cases are not incorporated into the performance measure of the algorithm.

B: Radio Sleep Mode Optimization in Wireless Sensor Networks

Energy-efficiency is a central challenge in sensor networks, and the radio is a major contributor to overall energy node consumption. Current energy-efficient MAC protocols for sensor networks use a fixed low power radio mode for putting the radio to sleep [2]. Fixed low power modes involve an inherent tradeoff: deep sleep modes have low current draw and high energy cost and latency for switching the radio to active mode, while light sleep modes have quick and inexpensive switching to active mode with a higher current draw. This technique proposes adaptive radio low power sleep modes based on current traffic conditions in the network. It first introduces a comprehensive node energy model, which includes energy components for radio switching, transmission, reception, listening, and sleeping, as well as the often disregarded micro-controller energy component for determining the optimal sleep mode and MAC protocol to use for given traffic scenarios. The model is then used for evaluating the energy-related performance of our recently proposed RFID Impulse protocol enhanced with adaptive low power modes, and comparing it against BMAC and IEEE 802.15.4, for both MicaZ and TelosB platforms under varying data rates. The comparative analysis confirms that RFIDImpulse with adaptive low power modes provides up to 20 times lower energy consumption than IEEE 802.15.4 in low traffic scenario. The evaluation also yields the optimal settings of low power modes on the basis of data rates for each node platform, and it provides guidelines and a simple algorithm for the selection of appropriate MAC protocol, low power mode, and node platform for a given set of traffic requirements of a sensor network application.

C: Particle Swarm Optimization in Wireless Sensor Networks

Wireless sensor networks (WSNs) are networks of autonomous nodes used for monitoring an environment. Developers of WSNs face challenges that arise from communication link failures, memory and computational constraints, and limited energy [3]. Many issues in WSNs are formulated as multidimensional optimization problems, and approached through bio-inspired techniques. Particle swarm optimization (PSO) is a simple, effective and computationally efficient optimization algorithm. It has been applied to address WSN issues such as optimal deployment, node localization, clustering and data-aggregation. It has been applied to address WSN issues such as optimal deployment, node localization, clustering and data-aggregation. This paper outlines issues in WSNs, introduces PSO and discusses its suitability for WSN applications. It also presents a brief survey of how PSO is tailored to address these issues. Bio-inspired optimization methods are computationally efficient alternatives to analytical methods.

Particle swarm optimization (PSO) is a popular multidimensional optimization technique [3]. Ease of implementation high quality of solutions, computational efficiency and speed of convergence are strengths of PSO.

The PSO Algorithm

PSO models social behaviour of a flock of birds. It consists of a swarm of *s* candidate solutions called particles, which explore an *n*-dimensional hyperspace in search of the global solution (*n* represents the number of optimal parameters to be determined). A particle *i* occupies position *Xid* and velocity *Vid* in the *d*th dimension of the hyperspace, 1 · *i* · *s* and 1 · *d* · *n*. Each particle is evaluated through an objective function *f*(*x*1*; x*2*;* ¢ ¢ ¢ *; xn*), where *f* : R*n* ! R. The cost (fitness) of a particle close to the global solution is lower (higher) than that of a particle that is farther. PSO thrives
to minimize (maximize) the cost (fitness) function. In the global-best version of PSO, the position where the particle *i* has its lowest cost is stored as (*pbestid*). Besides, *gbestd*, the position of the best particle. In each iteration *k*, velocity *V* and position *X* are updated using (1) and (2). The update process is iteratively repeated until either an acceptable *gbest* is achieved or a fixed number of iterations *k*max is reached.

D: Network Lifetime Optimization in Wireless Sensor Networks

Network lifetime (NL) is a critical metric in the design of energy-constrained wireless sensor networks (WSNs) [4]. In this technique, a joint optimal design of the physical, medium access control (MAC) and routing layers to maximize NL of a multiple-sources and single-sink (MSSS) WSN with energy constraints is investigated. The problem of NL maximization (NLM) can be formulated as a mixed integer-convex optimization problem with adoption of time division multiple access (TDMA) technique. When the integer constraints are relaxed to take real values, the problem can be transformed into a convex problem and the solution achieves the upper bounds. We provide an analytical framework for the relaxed NLM problem of a WSN in general planar topology. We first restrict the topologies to the planar networks on a small scale, including triangle and regular quadrangle topologies. In this special case, we employ the Karush-Kuhn-Tucker (KKT) optimality conditions to derive analytical expressions of the globally optimal NL, which take the influence of data rate, link access and routing into account. To handle larger scale planar networks, an iterative algorithm is proposed using the D&C approach. Numerical results illustrate that the proposed algorithm can be extended to the large planar case and its performance is close to globally optimal performance.

E: Simulation-based optimization of communication protocols for large-scale wireless sensor networks

The design of reliable, dynamic, fault-tolerant services in wireless sensor networks is a big challenge and a hot research topic. In this technique an optimization method is proposed that can be used to tune parameters of the middleware services and applications to provide optimal performance [5]. The optimization method is based on simulation, and is capable of handling 'noisy' error surfaces. The proposed optimization algorithm is illustrated by a new spanning-tree formation algorithm, which can effectively operate even if links between nodes are asymmetrical.

In the near future large-scale sensor networks will be the key elements of embedded systems used in space and aviation related challenges, e.g. monitoring and control of safety critical systems, Smart Surfaces, Smart Dust, or can be used to make everyday life more comfortable, e.g. Intelligent Spaces. These sensor networks often use distributed operating system-like services (called middleware) over wireless communication protocols, which must be fault tolerant and adaptive because of the dynamic network topology and changing mission objectives. The design of such middleware services is not straightforward, since the sensors have limited resources, and thus the used protocols are usually very simple compared to ones used in wired communication schemes. The nondeterministic nature of the environment is another factor making the design more difficult. This technique presents a simulation-based optimization method that can be used to tune the algorithms used in the middleware layer. Also some results are presented that were gained by the proposed method.

F: Coverage and Lifetime Optimization of Wireless Sensor Networks with Gaussian Distribution

A wireless sensor network (WSN) has to maintain a desirable sensing coverage and periodically report sensed data to the administrative center (i.e., base station), and the reporting period may range from months to years. Coverage and lifetime are two paramount problems in a WSN due to constraint of associated battery power. All previous theoretical analyses on the coverage and lifetime are primarily focused on the random uniform distribution of sensors or some specific network scenarios (e.g., a controllable WSN). In this technique, an analytical framework for the coverage and lifetime of a WSN that follows a 2D Gaussian distribution is provided. The coverage and lifetime when the dimensions of Gaussian dispersion (i.e., x, y) admit different Gaussian parameters (i.e., standard deviation, x 6¼ y) is also studied here The intrinsic properties of coverage/lifetime in terms of Gaussian distribution parameters, which is a fundamental issue in designing a WSN is also idenified. Following the results obtained, we further determine the sensor deployment strategies for a WSN that could satisfy a predefined coverage and lifetime. Two deployment algorithms are developed based on using our analytical models and are shown to effectively increase the WSN lifetime.

G: Dynamic Deployment Optimization in Wireless Sensor Networks

Sensor deployment is one of the key topics addressed in wireless sensor networks (WSNs) study. This technique proposes a self-organizing technique for enhancing the coverage of WSNs which consists of mobile and stationary nodes [7]. The mobile nodes will relocate themselves to find the best deployment under various kinds of situations for covering largest area. The new locations of mobile nodes are determined by parallel particle swarm optimization (PPSO) which is suitable for solving multi-dimension function optimization in continuous space. Especially, the mobile nodes deployment with PPSO is useful in situations while some area need cooperative measuring with multiple nodes, and can be adjusted dynamically according to the requirement of environment. The experimental results verify that mobile nodes deployment with PPSO has good performance in quickness, coverage and connectivity.

In WSNs, dynamic deployment optimization has become one of the key topics addressed. T. Wong et al. [15] and S. Zhou et al. [16] proposed the "Virtual Forces" algorithm which can effectively enhance the coverage and connectivity of WSNs in single measurement, but little attention has been focused on the dependability and precision of sensor nodes. Actually, because of the high robust and precision requirement, cooperative measurement is required in most applications. The proposed PPSO based dynamic deployment optimization algorithm is useful in deployment of cooperative measurement with the effective coverage performance taken as criterion while precision and speed of optimization is satisfied.

III. CONCLUSION

This paper briefly surveys the various optimization techniques available in the field of Wireless Sensor Networks. Each technique has its own way of improving the lifetime of sensors and there by optimizing the functioning of Wireless sensor networks. A proper analysis of each technique, looking at the individual techniques merits and demerits can help the researchers get more insight into the ways of optimizing performance and overcoming the hurdles during optimization of Wireless sensor networks.

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