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# Design and Analysis of Scalable Wireless Sensor Network for Real-time Medical Applications

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## ABSTRACT

Wireless Sensor Networks (WSNs) are emerging as one of the most reliable technologies for implementing ubiquitous computing ultimately leading to an all-pervasive paradigm of computing infrastructure that can be utilized for several interesting applications. A wireless network consisting of a large number of small sensors with low-power transceivers can be an effective tool for gathering data in a variety of environments like civil and military applications. The data collected by each sensor is communicated through the network to a single processing centre called base station that uses all reported data to determine characteristics of the environment or detect an event. In this paper, we analyze the performance of a scalable WSN infrastructure with respect to medical applications and find out how such systems respond in scenarios which are simulated to mimic real-time behavior. All simulations have been done in MATLAB.

**Keywords -** WSN, Medical Sensing, Sensor Network, Wireless Technology, Mesh Network

## 1. INTRODUCTION

The recent drive in the information technology industry towards new wireless communication devices and systems and their utilization in addressing a wide variety of real-world problems have resulted in several new areas of active research, wireless sensor networks being one such hot topic. As we know, the Internet has been able to provide a large number of users with the ability to move diverse forms of information readily and thus revolutionized business, defense, education, industry, research, and science. Sensor networking may, in the long run, be equally significant by providing measurement of the physical phenomena around us, leading to their understanding and ultimately the utilization of this information for a wide range of practical applications. Potential applications of sensor networking include defense, environmental and habitat monitoring, healthcare monitoring, transportation, manufacturing, and search and rescue.

One such important application is in healthcare industry. WSN for medical industry can be used to effectively treat and diagnose patients through continuous monitoring of important parameters like blood pressure, glucose levels, body temperature, haemoglobin levels etc. Through continuous monitoring of these parameters, decisions regarding the patient’s treatment can be taken at any time rather than having to wait for the doctor to visit the patient at certain times.

Naturally, WSNs for medical applications must be massive and has to be highly secure because of its critical importance. Any slight error in the network can be critical to the life of the patients. Hence, WSNs for medical application must be developed keeping these points in mind and specifically keeping its security in mind. Tampering of medical data and history of patients can become a matter of life and death.

In this work, we analyze the performance of a scalable WSN infrastructure with respect to medical applications and find out how such systems respond in scenarios which are simulated to mimic real-time behavior. All simulations have been done in MATLAB.

## 2. WIRELESS SENSOR NETWORK FOR MEDICAL APPLICATIONS

A typical wireless sensor network consists of a base station and several nodes distributed or positioned in the environment of interest. Each node is expected to detect events of interest and estimate parameters that characterize these events. The resulting information at a node needs to be transmitted to the base station either directly or in “multi-hop” fashion involving automatic routing through several other nodes in the network. Implementation of such a network requires hardware components and corresponding software modules to program these components in a cooperative manner.

As the technology gains popularity, research is becoming important in both theoretical and application domains. We identify two classes of application examples below.

2.1 Stationary Network: We define a stationary network as a network of sensor nodes, in which, each sensor node’s position is fixed relative to the base station and other nodes in the network. A demonstrated application in this direction is humidity monitoring in a vineyard. Data acquired by a mote is transmitted to the base station which then processes the information and triggers necessary actions such as localized watering.

2.2 Network in Motion: An example in this category is a herd of animals on an extensive farm, where each animal is equipped with a sensor node. The animals are in constant motion relative to each other as well as the base station. Such a complicated mobility management requires an even more sophisticated implementation of routing algorithms. In order to maximally benefit from wireless sensor networks of this type, we foresee additional hardware requirements like GPS devices and other forms of mote location.

As part of the on-going work, a comprehensive "design framework" of an intelligent wireless patient-monitoring system has been developed. This framework includes real-time sensing of patient's vital parameters using the motes, and wireless transmission of such critical information over radio frequencies to the base-station. Subsequent data processing on a PC will allow detection of certain medical emergencies, and automatic alerting of medical staff. The overall framework is shown below.

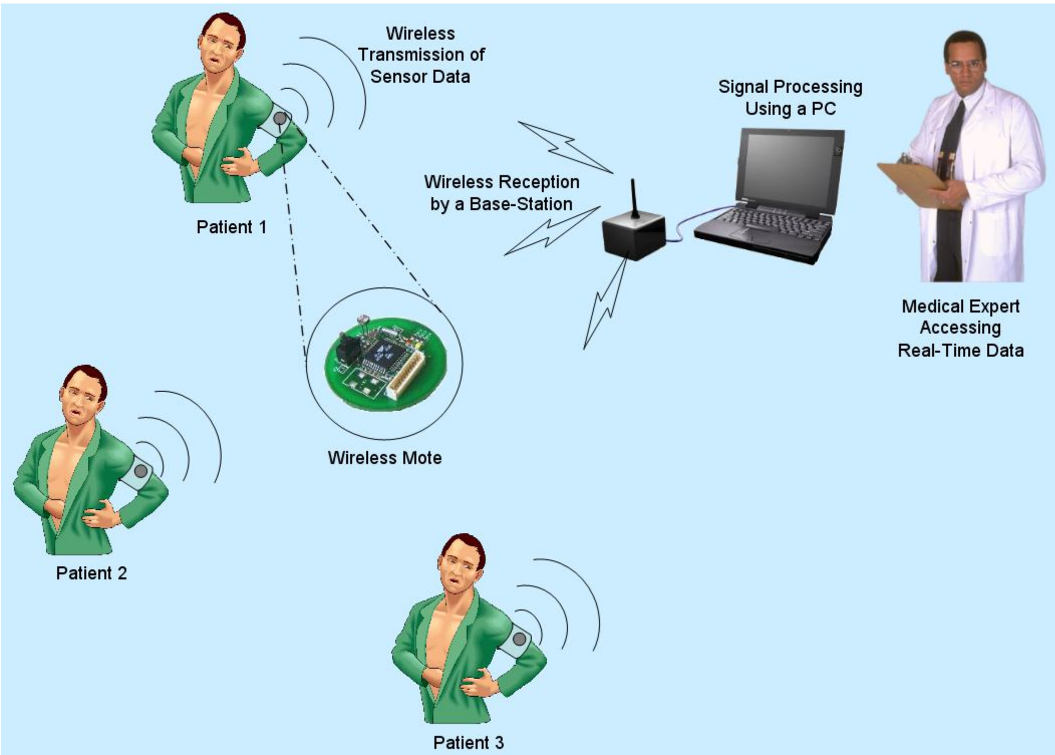


**Figure 1:** Conceptual Demonstration of WSN for Medical Applications.

## 2.1. DESIGN GOALS

In order to design good protocols for wireless microsensor networks, it is important to understand the parameters that are important to the sensor applications. While there are many ways in which protocols are beneficial to the application, we use the following metrics:

2.1.1. Ease of deployment: - Sensor networks may contain hundreds or thousands of nodes, and they may need to be deployed in remote or dangerous environments. If these nodes are small enough and cheap enough, we can imagine throwing hundreds or thousands of microsensors from a plane flying over a remote or dangerous area to allow us to extract information in a way that would not be possible otherwise. This requires self-configuring protocols that do not rely on a fixed infrastructure

2.1.2. System lifetime: - These networks should function as long as possible. System lifetime can be measured using generic parameters, such as the time until the nodes die, or it can be measured using application-specific parameters, such as the time until the sensor network is no longer providing acceptable quality results (e.g., there are too many missed events).

2.1.3. Latency: - Data from sensor networks are typically time-sensitive, so it is important to receive the data in a timely manner. Long delays due to processing or communication may be unacceptable.

2.1.4. Quality: - This parameter measures the accuracy with which the result of the sensor network matches what is actually occurring in the environment. Although this is an application-specific and data-dependent quantity, one possible application-independent method of determining quality is to determine the amount of data (either actual or aggregate) received at the base station. The more data the base station receives, the more accurate will be its view of the remote environment.

Tradeoffs can be made among these different parameters, and algorithms can be created that are scalable and adaptive to change the relative importance of the different parameters. For example, when energy is plentiful, the end-user may desire high-quality results. As the energy gets depleted, the end-user may request that the quality of the results be reduced in order to reduce the energy dissipation in the nodes and hence lengthen the total system lifetime. Thus microsensor network algorithms and protocols should be power aware such that energy usage is scaled appropriately for a given quality specification.

## 2.2. THE CONCEPT OF AUTONOMIC WSN

The dramatic increase in computing devices increased computing capacity and complexity combined with popularity of internet resulted in phenomenal growth in heterogeneous networks and network applications. With this increasing system complexity, network management issues and communication protocols are reaching a level beyond human ability to manage and secure so the stability of current infrastructure, systems, and data is at an increasingly greater risk to suffer outages and general disrepair. Future network algorithms need to be adaptive, robust, and scalable with fully distributed and self-organizing architectures.

As the concept of self management rooted up, the most direct inspiration one can think of was the autonomic function of the human central nervous system, where autonomic controls use motor neurons to send indirect messages to organs at a sub-conscious level. These messages regulate temperature, breathing, and heart rate without conscious thought. Observation and analysis of these complex adaptive systems found in nature became a major source of inspiration to design algorithms for self-managed, self-organized, self-configuring and self-protecting systems.

Autonomic System works independently on predefined policies and rules without any human interaction thereby managing and configuring itself on its own, based on predefined rules and gained knowledge over the time. IBM has defined the following four functional areas for self management of Autonomic System:

- Self-Configuration: Automatic configuration of components.
- Self-Healing: Automatic discovery, and correction of faults.
- Self-Optimization: Automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements.
- Self-Protection: Proactive identification and protection from arbitrary attacks.

## 3. PROPOSED SYSTEM MODEL

For the design and analysis of the proposed WSN for medical applications, we created an autonomic WSN architecture configured as a wireless mesh. We assume the presence of several nodes which will mimic the functioning of the sensor nodes. They may be thought of as commercial processor cum radio boards commonly referred to as “motes”. Each mote being a battery-powered device, consisting of a sensor unit, a power unit, a two-way ISM band radio transceiver unit (includes an RF antenna), an ADC unit, a processor that runs embedded C code, and logger memory capable of storing up to 100, 000 measurements. However, hardware level intricacies are not dealt with in this work as we confine our attention to system level performance only. Each of these nodes conveys their information to a base station which is interfaced to a PC through parallel port.

The architecture of the WSN created followed a policy based approach. Policy-based management has presented its robust ability to support designing of self-adaptive decentralized management service in WSNs. Davy S. et al. proposed an autonomic communications architecture that manages complexity through policy-based management by incorporating a shared information model integrated with knowledge-based reasoning mechanisms to provide self-governing behavior. The architecture is organized using four distinct architectural constructs i.e. Shared Information, Virtual Software, Infrastructure and Policy.

The shared information over the network is managed through a virtual software which support autonomic functionality for different heterogeneous networks and components combined with network infrastructure which include network elements and other computing devices. All these three modules are governed by policy module.

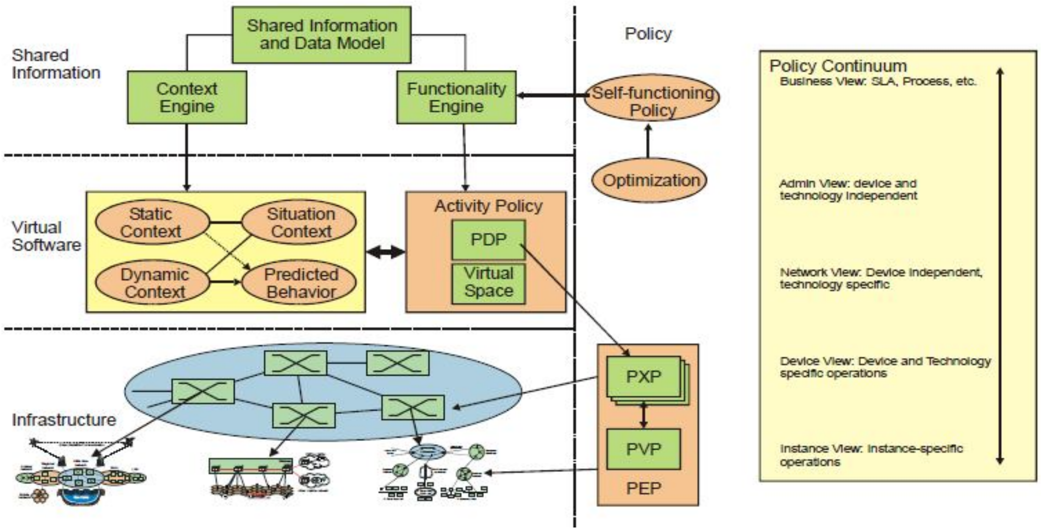


**Figure 3:** Proposed Policy Based Autonomic Architecture

This model is based on three important concepts of autonomic computing: (1) the sharing and reusing of common information and knowledge, (2) the application of machine learning and knowledge-based reasoning to guide the changes in behavior of the system, and (3) an extensible and flexible governance model that forms a closed control loop that learns from its decisions.

**3.1. SYSTEM PERFORMANCE**

Figure 4 shows the performance of the proposed iterative algorithm for WSN routing. ASNR is 6 dB, $N_p = L$. Figure 4.a. shows that within a few numbers of iterations the algorithm converges to the optimum point from the initial point, which is the equal power allocation for all the sensor nodes. Figure 4.b. shows the computed lambda. As it is expected, the value is the same for all data subchannel, which satisfies the analytical computation.

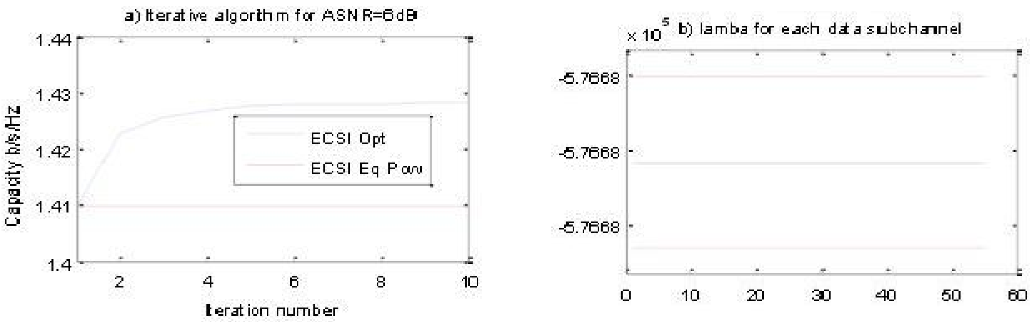


**Figure 4:** the performance of the proposed iterative algorithm for WSN routing.

Figure 5 shows that the worse the estimated subchannel response is, the less the amount of power allocated to that subchannel is. Figure 6 is the same as figure 5, but the ASNR is 15dB. It can be seen that power allocation strategy has a tendency to allocate power among data subcarriers equally which is what we expect from a self configuring autonomic WSN architecture.

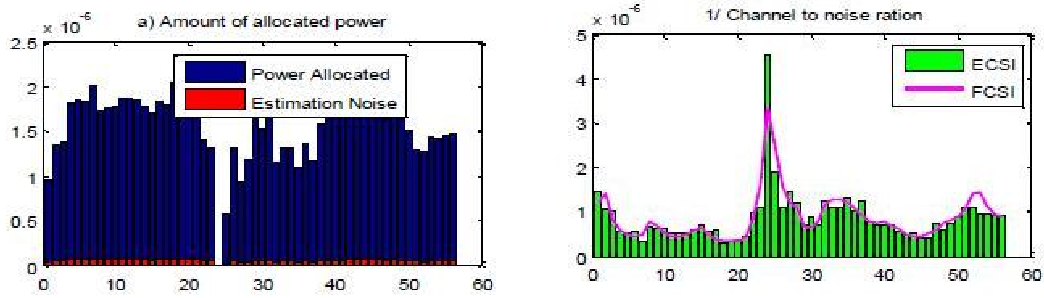


**Figure 5:** Distribution of Power with respect to Channel State Information in WSN

To further evaluate the iterative algorithm, other feasible initial points have been chosen and all converge to the optimum solution but with different number of iteration. Among all, equal power distribution generally has a lowest number of iteration to converge. For figures 7, 8, the iterative algorithm is used to find the optimum result. The value of lambda for each data subcarriers is computed and if these values were in the region on uncertainty we end the iteration.

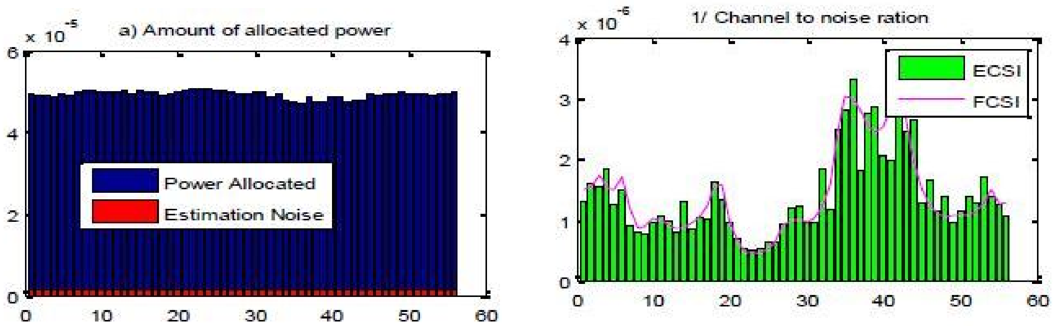


**Figure 6:** Distribution of Power with respect to Channel State Information in WSN when the ASNR is 15dB

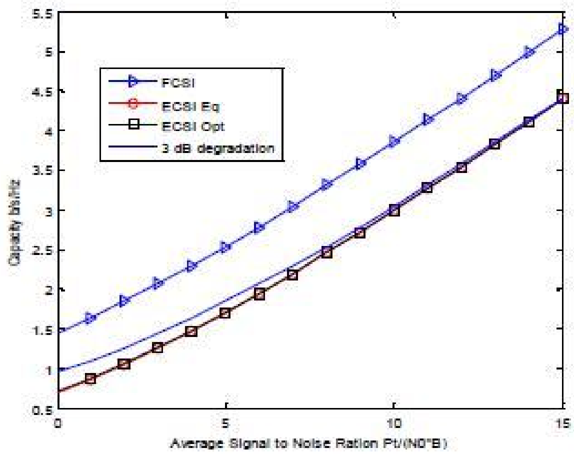


**Figure 7:** System Performance versus ASNR for node to node communication.

In figure 7, the amount of ASNR is sweeped and the system performance is depicted. In this figure alpha is fixed. It is obvious from figure that equal power distribution among all subcarriers is near optimum for ASNR greater than 6 dB. The dashed line is depicted to show the 3dB performance degradation in system capacity as described in. The computation shows that in high SNR for the, the performance relative to full channel state information degrades about 3dB and one can see the issue in this figure.

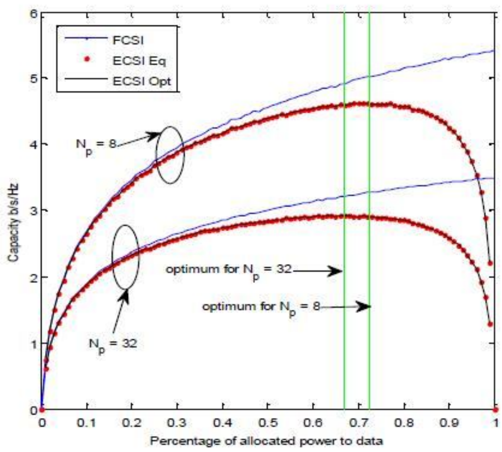


**Figure 8:** System performance versus different values of alpha.

In figure 8, fixed value of ASNR = 15dB, the system performance versus different values of alpha is illustrated. It can be seen that there is an optimum value for parameter alpha, in which the graph peaks. The green dashed lines are the optimum value of alpha computed. Since the ASNR is considered almost high in this simulation, the equation is approximately the optimum one as it is indicated. As stated before, for high ASNR, the alpha converges to optimal value which is also shown in the figure. Moreover, there is little difference between uniform channel power delay profile and uniform ones. However, the difference becomes larger as the ASNR decreases. From the aforementioned graphs, we can see that our autonomic WSN tries to maintain optimal amount of power for each node and also ensures that appropriate data communication occurs for all the nodes in the network. From medical standpoint, this is highly necessary as no data can be allowed to miss from logging into the system as it can be critical for diagnosis.

## 4. CONCLUSIONS

A new area of information technology, namely wireless self organizing sensor networks, is introduced. Application examples are classified into stationary networks and networks in motion. A new application in healthcare sector is proposed and simulated for concept demonstration. This area promises networking of the environment surrounding us. An interesting aspect is that this research area brings together various fields of electrical and computer science engineering including low power design, RF/wireless communications, signal processing, networking and optimization and algorithms.

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