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New Testing Method in Wireless Sensor Networks with Compressed Sensing Theory

Mohammadreza Balouchestani, Kaamran Raahemifar, and Sridhar Krishnan

Department of Electrical and Computer Engineering
Ryerson University, Toronto, Canada
mbalouch@ee.ryerson.ca, kraahemi@ee.ryerson.ca, krishnan@ee.ryerson.ca

Abstract. Wireless sensor networks consist of a large number of small devices or wireless nodes each with sensing unit, processing unit, communication unit and power supply unit. The wireless nodes can be deployed for monitoring scenarios such as industrial automation community, traffic controlling, electronic wars, transportation automation, electronic health and web controlling In Wireless Sensor Networks (WSNs) with N wireless Nodes, individual wireless node availability must be tested into the design ensure the WSN is online and available. The wireless node behavior should be tested in the real word environments. WSNs are adopted in many applications such as, industrial automation, military, transportation, environmental monitoring, web controlling, and energy management and biomedical. As Wireless sensor Network continue to grow, so does the need new mechanisms to reduce parameters such as power consumption, cost, delay, traffic, volume of information for testing. The Compressed sensing theory holds promising improvements to these parameters. Compressed Sensing shows that spars signals and test-results in wireless sensor networks can be exactly reconstructed from a small number of random linear measurements. Wireless sensor networks are one area that have not yet experimented the benefits that compressed sensing might produce. With this in mind, we introduce a new mechanism of testing in wireless sensor network with compressed sensing theory. This paper introduces the mathematical results of compressed sensing theory, and then describes important parameters in wireless sensor networks, and finally our research combines the compressed sensing theory with wireless sensor network to introduce a new method for testing of wireless sensor networks with compressed sensing theory.

Keywords
Compressed sensing, wireless sensor networks, Software testing, lifetime, online testing.

1. Introduction

Wireless nodes have very low energy resources and therefore energy consumption is the most important factor to determine the lifetime in wireless sensor networks. The compressed sensing offers to optimize energy usage to reduce energy consumption [1].We also will design lower time delay and inexpensive wireless sensor networks which are capable of local processing and wireless communication. The compressed sensing offers that spars signal of information in wireless sensor networks can be exactly reconstructed from a small number of random linear measurements of information in wireless sensor network [9]. In the other word, compressed sensing is a new method of mathematical results that can recover data vector $X \in R^N$ with N number of information form $Y \in R^M$ with $M \ll N$ number of information in wireless sensor networks. In fact, compressed sensing offers a stable measurements matrix ϕ of result of tests that do not depend in any way on the information of ordinal tests. In order to find, a new mechanism for testing in wireless nodes, we discuss the major topic in compressed sensing to wireless sensor networks. This paper is organized as follow: First, the compressed sensing theory is presented. Secondly, wireless sensor networks and important limiting characteristics are discussed. Thirdly, the combining of compressed sensing to wireless sensor networks are suggested. The rest of paper organized follows: the first currently testing methods are discussed; second software based testing is suggested networks and after that a new testing method with compressed sensing to wireless sensor networks are introduced. Finally we include the paper with some discussions about future works.

2. Compressed Sensing Background

CS is a new theory of sampling in many applications, including data network, sensor network, digital image and video camera, medical systems and analog-to-digital convertors [1]. CS also offers links between applied mathematics, information theory, data acquisition and optimization theory in advanced digital signal processing [8]. In fact, CS offers a new method of compression and coding, in order to minimize storage and cost. This revolutionary technique results in a smaller number of random linear projections of a compressible signal that contains sufficient information for approximation or exact reconstruction [16].

2.1. Compressed Sensing scenario

Any compressible signal $\mathcal{X} \in \mathbb{R}^{N}$ can be represented in the form of:

$$\mathbb{X} = \sum_{J=1}^{N} z_J \, \psi_J \quad \text{or} \quad \mathbb{X} = Z\,\psi \tag{1}$$

$\mathbb{X}$ is in time domain and Z is in ψ domain. The compressible signal $\mathbb{X}$ can be shown as a linear combination of K vectors with $K \ll N$, and K nonzero coefficients and $N-K$ zero coefficients in Eq. (1). In many application signals have only a few large coefficients. These few large coefficients signals can be approximated by K [10]. One would then select K largest coefficients and discard $(N-K)$ smallest coefficients. Traditionally, one is required to acquire the full N-sample of signal $\mathbb{X}$ to compute the complete group of transform coefficients. The traditional compression techniques suffer from an important inherent inefficiency since it computes all N coefficients and records all the nonzero, although $K \ll N$ [9]. The CS can replace the traditional sampling with new sampling scheme and reduce the number of measurements. In fact, CS combines acquisition step and compression step into one step and can directly acquire signals without going through the intermediate steps. As a result, a small number of coefficients can be transmitted or stored rather than the full set of signal coefficients. Consequently, CS provides a scheme that reduces power consumption, size and cost. The CS offers M measurements with $(K < M \ll N)$ and enough information to reconstruct $\mathcal{X}$ [11]. The other transform matrix ϕ is used to obtain the compressed signal $\mathbb{y}$:

$$\mathbb{y} = \phi\,\mathbb{X} \tag{2}$$

where Θ is a $M\times N$ matrix and $\mathbb{y}$ is an $M\times1$ vector. The measurement process for M is non-adaptive and hence, ϕ is independent on the signal $\mathbb{X}$. Since the measurement algorithm is linear and defined in terms of the matrices ϕ and ψ, solving for s given $\mathbb{y}$ in (4) is a linear algebraic method. The CS offers a Gaussian random matrix ϕ as an independent and identically distributed (iid). The matrix ϕ is incoherent and Θ has the Restricted Isometry Property (RIP) with high probability if $M \le c$ K log (N/K) such that c is a small constant with $c > 0$[15]. Therefore CS transfers $\mathbb{X} \in \mathbb{R}^{N}$ to $\mathbb{y} \in \mathbb{R}^{M}$ [5].

2.2 Signal Recovery

According to the results, CS theory shows that sparse signals can be exactly reconstructed from a small number of linear measurements [4]. The CS theory illustrates that original signal can be fully described by the M measurements in $\mathbb{y}$ [13]. It is possible to reconstruct K-sparse vectors with high probability via ℓ_1 optimization as [15]:

$$z^{\wedge} = \text{argmin} \parallel s' \parallel_1 \text{ such that } \Theta z' = y \quad (3)$$

Clearly, the CS data acquisition algorithm considers random measurements based on ϕ followed by linear mechanism reconstruction to obtain original signal $\mathbb{X}$.

3. Wireless sensor network background

Wireless Sensor Network has opened the doors to many applications that need monitoring, processing and control. A WSN system is ideal for an application like environmental monitoring in which the requirements mandate a long-term deployed solution to acquire water, soil, or climate measurement. For utilities such as the electricity grid, streetlights, and water municipals, wireless sensors offer a lower-cost method for collecting system data to reduce energy usage and better manage resources. WSN is used to effectively monitor highways, bridges, and tunnels. This section presents the basic theory of WSN and its limiting characteristics such as power and delay in wireless nodes. In the following subsections, the components of WSN nodes are discussed.

3.1 Basic Units of Wireless Sensor Network

WSN consists of spatially distributed autonomous nodes that use sensors to monitor physical or environmental conditions. Each wireless node has four main sections including sensing unit, processing unit, communication unit and an energy supply unit [2]. The wireless sensor nodes are usually deployed to acquire measurements such as temperature, pressure, flow, humidity, position and torque to the gateway. The gateway collects the measurement from each node and sends it over a wired connection, typically Ethernet, to a host controller. Wireless nodes in gateway sense information around their monitoring distance except the sink nodes in end layer that only get the information from other nodes and make decisions [17]. Power is a primary constraint in the wireless nodes and the power supply should provide power for sensing unit, communication unit, processing unit. This fundamental power constraint further limits everything from data sensing rates and bandwidth, to node size, cost, security and weight [7]. The power supply unit in most of the cases is a battery. The battery lifetime is related to the discharge rate or amount of current drawn. Therefore, the amount of information decreases when CS is used and the current drawn in power supply drops. It is anticipated that CS would extend the battery lifetime to more than current lifetime. There is a focus on increasing the lifetimes of power supply through power management. This is all due to the fact that maintenance and replacement of power supply is expensive and difficult. Today, power management technologies in WSNs are constantly evolving due to extensive research. The primary limiting factor for the lifetime of a wireless node is the energy supply. Each node must be designed to manage its local supply energy in order to maximize total network lifetime [14].

3.2. Wireless Senor Networks with compressed sensing

The CS can reduce the number of information in WSNs. suppose $\mathbb{X}$ has K-Sparse representation if there is a convenient basis like:

$$\psi = [\psi_1, \psi_2, \ldots, \psi_k]^T \quad (4)$$

Then network data vector is demonstrated like [3]:

$$\mathbb{X} = \sum_{i=1}^{N} S_i \psi_i \text{ or } \mathbb{X} = S\psi \quad (5)$$

CS offers a new sampling model by acquiring compressed information without computing the coefficients. It is possible to offer M information in WSNs and enough information to reconstruct the original information [5]. Thus, information in data networks could be reduced from N to M and transmit M data and save memory space. CS offers a stable information matrix ϕ and suggests that instead of collecting$\mathcal{X}$, compressible network data vector $\mathbb{Y}$ can be collected and $\mathbb{Y}$ is given by[6]:

$$\mathbb{Y} = \phi\mathbb{X} = \phi\, \psi\, S \quad (6)$$

4. New Testing Method in WSNs

This section is presented a new method in-field testing with compressed sensing theory of wireless nodes. First currently testing method is presented and second, software-based self-testing is suggested. The remaining of section is organized testing of wireless nodes with compressed sensing.

4.1 Software Based Testing

Regarding the application of WNSs in military, industrial monitoring, transportation, web controlling, it is often impossible to obtain physical access to the WNs in order to perform functional testing on them. On the other hand, to achieve a high reliability and availability, WNs failure must be detected during WSNs. That is why, a software and online testing method is required. The Software-Based Self-Test (SBST) offers a way to achieve high quality testing in WNs without using dedicate hardware. It utilizes an existing MCU's instruction set of WNs to perform a self-test of all components such as microcontroller unit, communication unit, sensing unit and power supply unit of WNs [12]. In order to uncover any WNs faults, the SBST method produces various test sequences through all of the components in WNs. Then it collects all of the test results and generate a summary of the combined them. A summary of the combined test results call a test signature. After that the test signature is compared to a known-good test stored at MCU of WNs to detect any fault. The SBST method also is sent test results of each WN to sink nodes that know as a Base Station (BS). The BS can generate an announcement to repair or replace failed WNs before availability and reliability of WSN suffers [13].

4.2. Framework Architecture of Software Based Testing with Compressed Sensing

The algorithm of Software Based Testing with Compressed Sensing is presented in this section. In our mind, the combing SBST testing with CS can improve some limits such as limited time testing, limited energy and limited processing capability in WSNs. The framework contains six major steps that are enumerated as follows:

Step1. The SBST produces test vectors for each WN and test vectors development to all units of WN such as power supply, communication and sensing units.

Step2. The test-result is compared with a result known in each WN to uncover any fault. The test-results should be sending to BS. Therefore test-results are compressed and compressive test-result is sent to BS. If BS doesn't receive any test-result of each WN, it is recorded a failure of WN. In the other word failed WN can't send any test-result.

Step3. The BS collects all compressive test-results of all WNs with recovers the original test-result foe each WN. In order to find high accuracy, the BS requests Unit Testing (UT) for failed WN and new test vectors are written in BS.

Step4. The WN is implemented UT that is Test Driven Development (TDD) that produces different test vector than SBST program and new test-result is written on WN.

Step5. The WN is sent the new test-result to BS.

The proposed methodology is shown in Fig.1:

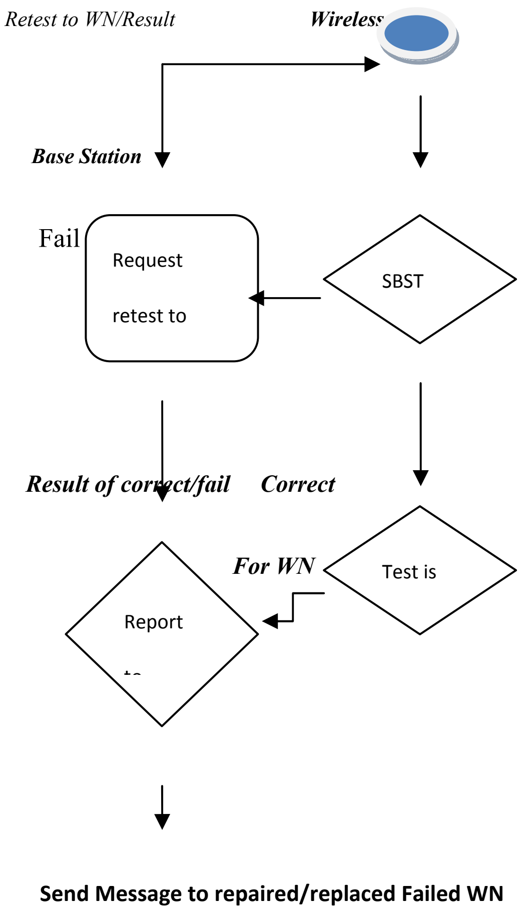

Fig1. Structure of New Testing Method

5. CONCLUSION

This research described how compressed sensing theory could be utilized in wireless sensor networks to design a new mechanism for testing of wireless nodes. It provided two key features, new sampling method for information and data networks and new recovering method. We also investigate the benefit of coming the compressed sensing to wireless sensor network to reduce volume of test information. We have shown compressed sensing holds promising improvements to limiting characteristics of a wireless sensor networks such as power consumption, increasing life time, decreasing traffic, decreasing test times and management time delay. At list, we suggested the new testing mechanism in wireless sensor network with compressed sensing theory. We want to simulate the new testing mechanism wireless sensor network with compressed sensing. It will be part of our future research to devolve it to practical networks. We also will be looking at the combination compressed sensing in biomedical wireless sensor networks with new testing mechanism.

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