Aid of Compressed Sensing in Wireless Sensor Network – A Case Study

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Abstract— This paper considers an environment in which a network of large number of wireless sensor nodes is deployed to collect and transmit information. The sparsity in the number of nodes with vital information is considered for compressed sensing. The experiment shows that the entire information can be recovered using the received data which is limited in number. This avoids collision of packets and eliminates the need of additional channels.

Key words: Compressed Sensing; Wireless Sensors; Nodes; Sparsity; Channel

I. INTRODUCTION

Compressed sensing can reconstruct signal from far fewer samples than is possible using Nyquist sampling rate. This recovery is exact if signal being sensed has a low information rate that is, if the signal is sparse in original or some transform domain. Number of samples needed for exact recovery depends on particular reconstruction algorithm being used. Compressed sensing handles noise gracefully and reconstruction error is bounded for bounded perturbations in data.

The Wireless sensor network is built of nodes- from a few to several hundreds or even thousands, where each node is connected to one or sometimes several sensors. The development of wireless sensor networks was motivated by Military applications such as battlefield surveillance[1]. Today such networks are used in many industrial and consumer applications such as industrial process monitoring and control, machine health monitoring and so on. Each sensor network nodes has several parts: A radio transceiver, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size, from that of a shoebox down to the size of a grain. Functioning motes of genuine microscopic dimensions are yet to be created. Size and cost constraints on sensor node result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. Topology of wireless sensor networks can vary from a simple Star Network to an advanced multi hop wireless mesh network.

II. SYSTEM MODEL

We consider a wireless sensor network consisting of N sensor nodes deployed to sense certain natural phenomenon. The sensors report their data measurements to a single receiver by sharing a wireless fading channel with M degrees of freedom[2]. Here, the degrees of freedom M means the dimension of received signal vector which represents the number of samples obtained in either time or frequency. The duration of one reporting period is T, which we refer to as one time frame. T is assumed to be less than the coherence time of both the wireless channel and the natural phenomenon. This ensures that both the monitored environment and the channel remain static in one time frame, implying that each sensor only needs to report its data measurement once during one entire frame if it is active. This is achieved by assuming that each sensor node is equipped with a Bernoulli random generator with success probability λ and at the beginning of one time frame T, each sensor performs one Bernoulli trial independently, the outcome of which indicates whether sensor node n will transmit its data measurement d_n to the receiver.

We define $A = \{a_1, ..., a_K\}$ as the set of active sensor nodes in one time frame with cardinality K, which is a random variable following a Binomial distribution with parameters N and λ. In addition, we denote the data vector from all the sensor nodes as $d = [d_1, \ldots, d_N]^T$ and that from only the active sensor nodes as $d_A = [d_{A,\ldots\ldots}, d_K]^T$.

We consider that each time frame is divided into I time slots. The length of each time slot is defined as the time for each sensor to transmit one data packet. Assume that the data packets from all the sensor nodes are of the same length P. Then, for a given channel capacity C, the maximum number of data packets that can be successfully transmitted to the receiver, or equivalently, the maximum number of time slots in one time frame T, is given by I = CT/P. Besides, we assume that channel knowledge is available at the receiver side. In time slot i of one time frame, each active sensor node n ε A transmits the symbol s_n modulated from the data measurement $d_{n'}$ multiplied by a random sensing vector $\Phi_n(i)\ \varepsilon\ C^{M\times 1.}$ The received signal at the receiver is given by

$$y(i) = \Sigma_n \Phi_n(i)h_n s_n + w(i)$$
$$= \Sigma_n \Phi_n(i)x_n + w(i) = \Phi(i)\, x + w(i) \qquad (1)$$

where $w(i)\ \varepsilon\ C^{M\times 1}$ denotes the measurement noise, $x =[x_1,\ldots.., x_N]^T$ with $x_n = h_n s_n\|_{n\varepsilon A}$ being the product of channel gain and the transmitted symbol of the active sensor node n, where the notation $n\varepsilon A$ equals 1 for n ε A and 0 otherwise. Since the number of active sensor nodes in time slot i satisfy $K << N$, x is sparse in the dictionary of an identity matrix. The sensing matrix $\Phi(i)$ is randomly selected from a random orthonormal basis, where $\varphi_n(i)$ is referred to as the sensing vector used by sensor node n.

We note that the knowledge of the orthonormal basis $\Phi\ \varepsilon\ R^{N\times N}$ at both the transmitters and the receiver is a required to apply compressed sensing based data reconstruction. The data measurements acquired from sensing natural phenomena have compressible representation in the frequency or the wavelet domain. In other words, discrete Fourier transform (DFT) and discrete wavelet transform (DWT) of the sensor readings d can be sparse[3]. For example, the data of the temperature sensor readings provided by the Intel Berkeley Research lab over a period of one month exhibits both sparsity in the frequency domain (by examining the readings from all the sensor nodes in one time instant) and sparsity in the wavelet domain (by examining the data readings from one sensor nodes in consecutive time intervals). Hence, compressed sensing can be utilized to recover both the spatially and temporally correlated data measurements.

III. System under Consideration

The system under consideration in this paper is a college environment. Suppose we have a chemistry laboratory in the college. And for certain experiment, some reactions have to take place in the presence of sunlight. Reaction will take place only in the presence of sunlight and at the same time, temperature above 45 degree Celsius is not tolerable. The number of apparatus in which reaction has to take place is 500. Laboratory technicians prefer to keep these 500 apparatus at different parts of the college ground. They also have to monitor the temperature constantly and have to make sure that the temperature is not going up to 45 degree Celsius. And if such a situation occurs, they should be able to remove the apparatus suddenly to avoid harmful reactions. But, it is not practical for a person to stand on the ground and measure the temperature for long duration. So we decide to take the aid of Wireless sensor nodes.

Wireless sensor nodes are deployed at different parts of the ground to monitor the temperature continuously. Temperature may remain same or vary according to the intensity of sunlight received. Some parts of the ground may be under shade and receive less sunlight. Some parts will be receiving medium amount of sunlight. And in some parts reception of sunlight will be more due to some causes and the temperature would be high. The situation varies with location and time. Wireless sensor nodes can measure the temperature and can transmit the data to a receiver which is placed in the ground. Using GSM technology, the data can be reported at the same time at the laboratory. An alarm is also fixed, in order to alert the laboratory technicians if the temperature is rising beyond a limit. The area under risk can also be detected using the identity information displayed in the system. So, if necessary concerned people can come to the ground and remove the apparatus and thus harmful reactions can be avoided. And required results can be obtained without failure.

A. *Problems Existing in the system*

The number of nodes deployed to measure the temperature is very large. If all the nodes are allowed to sense the temperature and if all nodes are trying to report their data to the single receiver placed on the ground, it will end up in great mess. Since the number of data is large, chances for packet collisions are very high. When packet collisions are more, data will be lost. It will not reach the receiver properly. Nodes will have to retransmit the data, and this will lead to additional power consumption. Wireless nodes will die off easily. And transfer of bulk data will demand more spectrum utilization. And above all, required information may not reach the laboratory. This would again lead to the failure of experiment conducted.

B. *Required Solution*

The required solution is nothing but an energy efficient and spectral efficient multiple access scheme. Such a mechanism is been discussed in this paper. We are discussing about efficient multiple access schemes. The scheme is made efficient by the proper use of compressed sensing technology.

IV. The Scheme using Compressed Sensing

This scheme utilizes sparsity from a relatively small number of active sensor nodes. In the system 2000 nodes are deployed to sense the temperature. Each sensor node only transmits one data packet with a probability λ in one time frame, the number of sensor nodes being active at one time instance, *K*, is small, resulting in a sparse signal in the process of medium access. Accordingly, this scheme makes use of this "medium access" sparsity to recover the readings from the few active sensors. The key issue in this step is to determine a proper value for the access probability λ[2]. The value of this parameter shall affect the feasibility of data recovery if spatial correlation is considered. Assume the spatial sparsity as rs. Then, the required number of observations ms for successful data recovery can be obtained by setting λ = ms/N, it is ensured that the number of data measurements recovered is sufficient for data reconstruction.

At the beginning of one time frame, the active sensor nodes transmit simultaneously in the first time slot and the receiver obtains M observations. To ensure that the receiver has sufficiently large number of observations, these active sensor nodes shall keep on transmitting the same data packets in the subsequent time slots. By the end of the i^{-th} time slot, based on the i × M observations, the receiver performs data recovery by solving a basis pursuit problem. It should be noted that as the number of observations at the receiver increases, the accuracy of the data recovery also increases[1]. By comparing the reconstructed data from two consecutive time slots, the active sensor nodes will be deactivated if the difference is less than a certain threshold η[4]. Otherwise, the sensor nodes will keep on transmitting till the end of this frame. Note that in order to decrease the overhead for signal processing, the receiver only starts to recover data from time slot α = floor(3*ms/M). When data has been successfully recovered, the data measurement d_A can be obtained and thereby d_n by compensating the effect of channel fading. The case of recovery failure is addressed in Method 3.

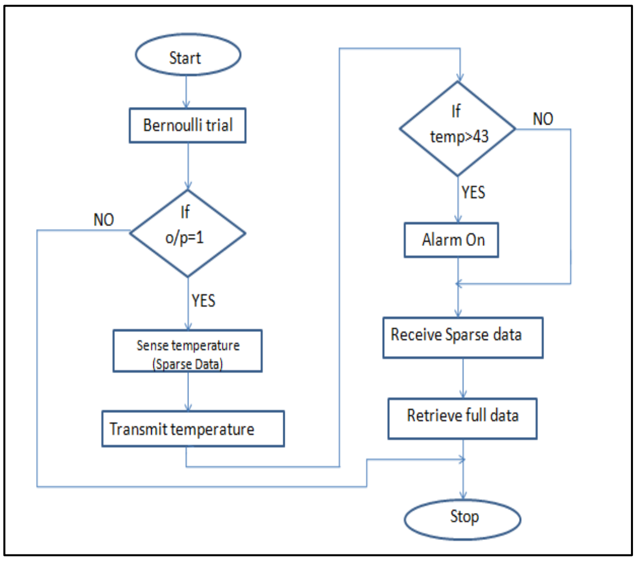

Fig. 1: Flowchart

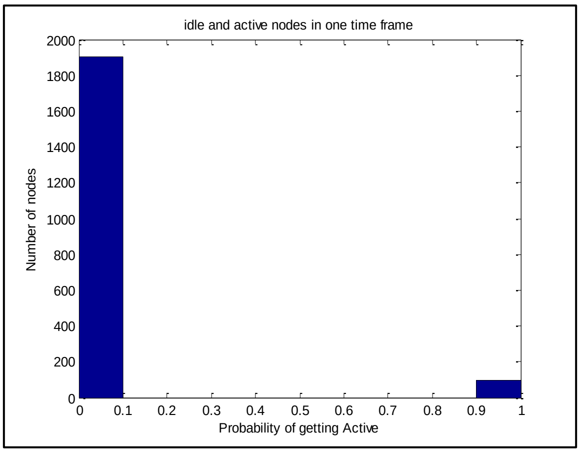

Fig. 2: Active nodes

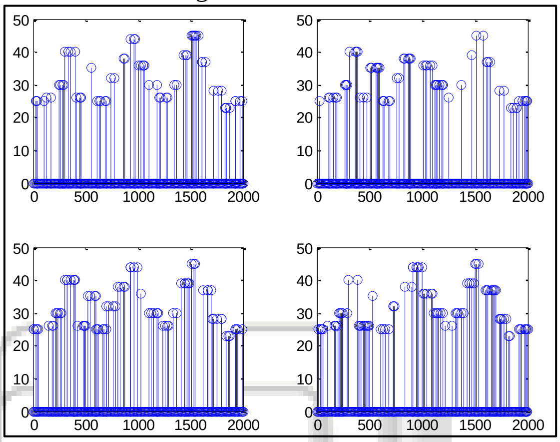

Fig. 3: Temperature detected by active nodes in 4 different time instants

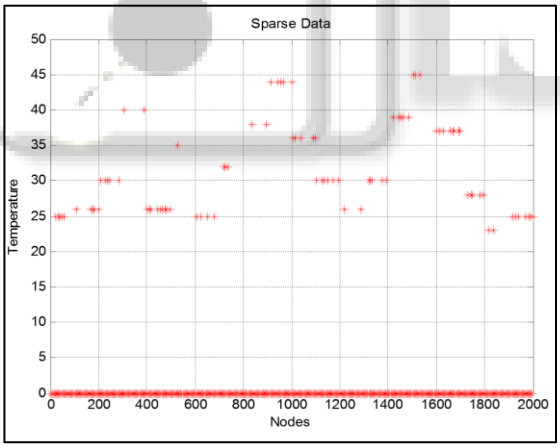

Fig. 4: Sparse Data detected at Receiver

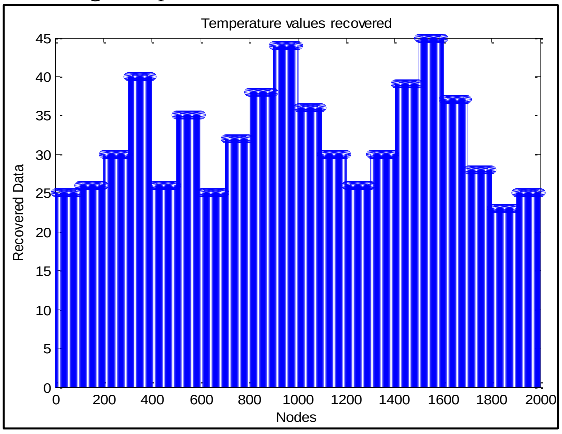

Fig. 5: Stemmed plot of recovered data

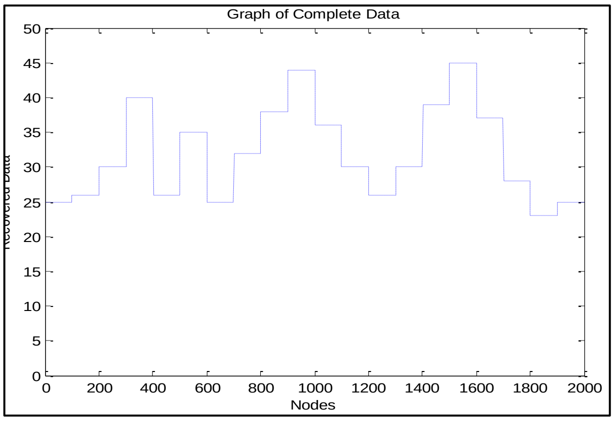

Fig. 6: Plot of complete data

The Histogram shows the number of active nodes at one time instant. It is evident from the plot that, out of 2000 nodes deployed on the ground, less than 100 nodes only get active at one time instant. Therefore, sparsity in the medium access is obtained. The number of data transmitted to the receiver at a particular time instant will be very less compared to the number of nodes deployed.

Fig 3 shows the temperature values sensed by the active nodes. Four different plots provide the temperature values sensed by nodes which are active at 4 different time slots. Fig 4 presents the sparse data detected at the receiver. If the data received is sparse, the whole information can be recovered. The recovered information is shown in Fig 5 and Fig 6.

V. CONCLUSION

The frequency spectrum is a valuable natural resource. Day by day the requirement for spectrum is increasing. And the Communication Engineers are thriving hard to find and make use of novel ideas that could aid the efficient use of spectrum. Through this paper, we have discussed such a scheme based on compressed sensing. We can make use of compressed sensing in multiple dimensions. But in this paper we have focussed in utilizing compressed sensing in single domain i.e., by adopting a method which uses the sparsity in medium access. If we can convert a signal into a sparse signal, the transmission demands only limited spectrum and thus cost effective. And if a signal is sparse, then whole information can be retrieved. This proves that, this technique is very advantageous in the field of Communication.

In the area of wireless sensor nodes, the approach discussed in this paper can become a milestone. Studies are going on in the field of wireless sensor nodes. These nodes can be deployed in areas where humans are unable to penetrate. Since the nodes are small in size, myriads will be required to take care even a small geographical or industrial environment. During those situations, multiple nodes will have to transmit the sensed data at all time instants. This can create a lot of mess like packet collisions and will demand more frequency channels. All these undesirable events can be avoided if this scheme based on compressed sensing is adopted.

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