Energy Efficient Information Gathering In Wireless Sensor Network with and without Compressive Sensing At Sensor Node

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Abstract— **Wireless sensor networks are mainly resource constrained with less memory space, limited power supply, processing speed and availability of bandwidth for communication. One of the most important challenges in wireless sensor networks is to design energy-efficient data gathering network which increases the lifetime of wireless sensor networks. Due to an enormous deployment of sensors, a tremendous data is generated by these sensor networks. Processing and transportation of such a huge data increase the energy consumption of sensor nodes along with an increase in network traffic. It is observed that processed data requires less power as compared to transmitting data in the wireless medium. Hence, it is more significant to apply compressed sensing algorithm at sensing node. Compressive sensing (CS) technique generates a sparse signal of few nonzero samples from the original signal at sub-Nyquist sampling rate where reconstruction of the original signal is possible even with few sparse samples. Thus, all the necessary and more accurate information can be obtained from the data gathered by wireless sensor networks with less number of samples. In this paper, we compare three types of data gathering technique.**

Keywords—Wireless sensor network (WSN), compressive sensing, Sub-Nyquist sampling theorem, Digital Signal Processing.

I. INTRODUCTION

Sensing is a technique used to gather or collect information about a physical object or process including the occurrence of events like a change in events such change in temperature, pressure or humidity. The device performing a sensing task is called sensor. The sensor is a device that converts parameters or change in events of the physical world into signals that can be measured or analyzed i.e. into electrical energy. Basically, data gathering process consists of three steps: sensing, signal conditioning and analog-to-digital conversion. After ADC conversion signals are available in digital form and are ready to process further. When many sensors are deployed to monitor a large physical environment they form a wireless sensor network. Sensors of a wireless sensor networks has a sensing component, on-board processing, communication and storage capabilities [1].

Wireless sensor networks have spatially or densely distributed sensors to monitor environmental conditions such as temperature, pressure, sound etc. Structural Health Monitoring, Traffic Control, Health Care, Pipeline Monitoring, Precision Agriculture, Active Volcano, Underground Mining, Military area surveillance monitoring are the main application areas of wireless sensor networks. Wireless sensor networks (WSN) consists of thousands of sensor nodes for monitoring process. Data gathering is the fundamental function of a wireless sensor network where sensors sensed the change in an event or physical parameter, processed them and en-route it in the network [1].

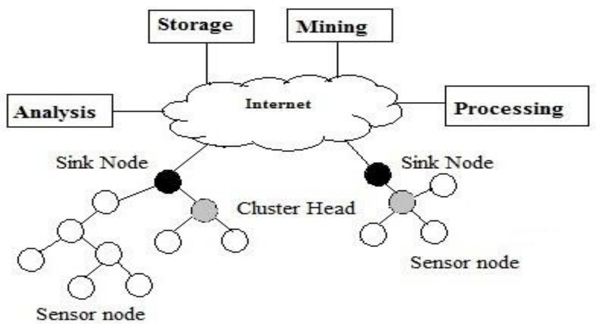


Fig. 1 Wireless Sensor Network [1]

Various energy-consuming aspects of wireless sensor networks are as shown in figure1. With the recent development of technology and in sensing devices, data collection has become easier and faster. Along with the rapid growth of sensors in wireless sensor networks, the tremendous amount of data is generated. This has resulted in heavy network traffic, processing and transportation of such a huge data increase more power consumption of wireless sensor networks. In many situations, gathered data by a sensor node cannot be efficiently transmitted to the destination because of a limited range of wireless communication [1].

Compressive sensing is the emerging technology in the field of information industry to handle such a tremendous data with which data or signal can be efficiently compressed and can be easily reconstructed with fewer samples than that of

Shannon-Nyquist sampling theorem. CS theory relies on Sub-Nyquist sampling theorem which asserts that original signal or image can be recover far from fewer samples or measurements. In compressive sensing sparsity and incoherence are two important principles, where sparsity pertains to the signal of interest and incoherence pertains to sensing modality. CS theory completely relies on the principle of sparsity and incoherence. Sparse representation of signal means an original signal of data length N, with K number of finite nonzero samples. Incoherence expands the duality between time and frequency and explains the idea that the object having a sparse representation in must be spread out in required domain [2].

II. RELATED WORK

Compressive sensing is a novel sensing/ sampling paradigm for data acquisition in wireless sensor networks as well as in Internet of Things also which asserts that original signal can be recovered from far fewer samples or measurements. Compressed sensing exploits the fact that many natural signals or measurements are sparse or compressible in the sense that they have concise representation when expressed in the proper basis [3].

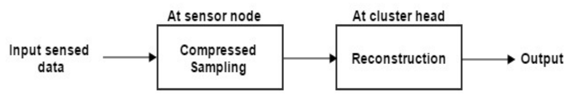


Fig. 2 Block diagram of data sampling

Compressive sensing (CS) gives new approach for data gathering in wireless sensor network. In a typical CS based data gathering scheme, data acquisition and data compression process takes place simultaneously. Compressive sensing takes place in three main steps i.e.

- Sparse representation of an original signal x.
- Generation of measurement matrix Φ to acquire measurement value y.
- Reconstruction of original signal.

In [2] author have discussed detail mathematical module of a compressive sensing theory along with CS framework. Compressive Sensing which is also known as compressed sensing is used over a traditional Nyquist-Shannon sampling theorem to reduce the energy consumption of wireless sensor network.

In [3] authors have provided detail survey on the theory of compressive sensing which gives a novel In [3] authors have provided detail survey on the theory of compressive sensing which gives a novel approach in data acquisition as per Sub-Nyquist theorem over a traditional Nyquist-Shannon sampling theorem. Compressive sensing relies on sparsity and incoherence principle by which one can recover original signal from few non-zero samples or measurements. However, in our work we are going to apply CS on real-valued physical signal at sensor node.

In [4] authors have reviewed sampling strategies which are trying to reduce the ADC rate below traditional Nyquist rate. The overall model of Sub-Nyquist sampling theorem has been discussed.

In [8] authors have studied required capacity and delay for data gathering with compressive sensing in wireless sensor networks of randomly deployed sensor nodes. For a single sink, they present a scheduling and routing scheme based on CS algorithm for data gathering and observed capacity and delay for data gathering. Also, for a multi-sink network, multi-session data gathering scheme with CS is used. However in this paper, we are going to focus on real-valued data gathering by changing sampling rate using CS and going to analyze capacity and delay for data gathering.

In [9] authors have studied how compressed sensing can be combined with routing design for energy efficient data gathering in sensor network. Authors have studied the relationship between routing paths on which data is coming to the base station and the projections of measurement matrix.

III. MATHEMATICS OF COMPRESSIVE SENSING

The theory of compressive sensing states that one can recover original signal or image from far fewer samples or measurements. CS theory involves following three main steps.

A. *Sparse representation of a signal*

Let us consider x be the real-valued discrete time signal, with a finite-length *N*, given as $x=[x(1), x(2),\ldots, x(N)]^T$ as composed vector. Any *N* dimensional vector can be represented as N×1 orthonormal basis as $\{\Psi_i\}_{i=1}^{N}$ where $\Psi= [\Psi_1,\Psi_2,\ldots\ldots\Psi_N]$.

$$X= \sum_{i=0}^{N} \alpha_i \ \Psi = \Psi \alpha \qquad (1)$$

B. *Sampling and sensing matrix*

The vector x is *K*-sparse if there are only *K* non-zero entries in vector $\Psi= [\Psi_1,\Psi_2,\ldots\ldots\Psi_N]$, the random values of x can be expressed as,

$$y = \Phi x = \Phi \Psi \alpha = \Theta \alpha \qquad (2)$$

where y is an $N\times 1$ column vector and Φ is an $K\times N$ matrix that is fixed and independent of the signal x. Since $K<<N$, generally recovering x from y is an ill-posed problem. However, within the framework of CS theory, due to the fact that x is *K*-sparse, signal recovery can actually be made possible when the matrix $\Theta = \Phi \Psi$ obeys the rule of restricted isometry property (RIP) or the sensing matrix is in incoherence with the basis Ψ. The smaller the coherence, the fewer samples are needed.

C. *Recovery of original signal*

If the restricted isometry property (RIP) or Φ is incoherent to Ψ, the signal can be recovered by l_1- *norm* minimization, namely:

$$min\|\alpha\|_{l_1} \text{ subject to } \quad y = \Phi\,\Psi \qquad (3)$$

For l_1, the restricted isometry constant satisfies $\delta_k < 1$, which guarantees the reconstruction algorithm. The l_1 norm is a convex optimization problem which can exactly recover the sparse or compressible signal with high probability.

IV. Proposed Model

A. *Conventional Data Gathering*

Fig. 2 is used to illustrate the idea of conventional data aggregation technique in wireless sensor network. Let *l* be the data gather by each sensor node S. Let l_1 be the data sensed by sensing node S_1, l_2 be the data sensed by sensing node S_2 and so on. As shown in fig.2 in conventional (plane) compressive sensing sensor node will transmit sensed data to the sink node on a predefine path.

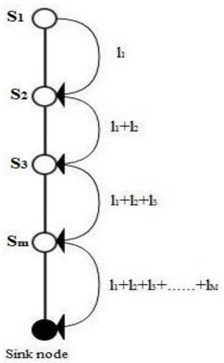


Fig. 3 Conventional data gathering model.

B. *Compressive sensing based data gathering*

Compressive sensing based data gathering network operation differs a lot from conventional data gathering network. In the proposed network compressive sensing is applied at sensing node hence instead of receiving individual sensor readings, the sink will be sent a few weighted sums of all the readings from which to restore the original data. Fig. 3 illustrates the idea of compressive sensing based data gathering.

As shown in figure 5.4 using CS, the sink needs to receive K packets instead of M. To transmit the i^{th} sum to the sink, sensing node S_1 will multiplies its reading l_1 with a random coefficient Φ_1 and sends the product to S_2. After receiving this message, sensor node S_2 will multiplies its reading l_2 with a random coefficient Φ_2 and then sends the sum $l_1\Phi_1+l_2\Phi_2$ to S_3. Similarly, each node will sends own sensed data multiplied by a random coefficient and with the addition of relayed information to the sink till the end of route.

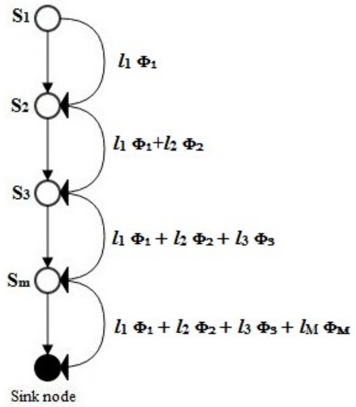


Fig. 4 Compressive sensing based data gathering.

C. *Hybrid Compressive Sensing*

In CS-based operation it is observed that more work/load for the nodes away from the sink and less work/load for the nodes close to the sink. Hence for less energy consumption load balancing is very clear in a large scale WSN. Therefore to design an energy-efficient WSN with less energy consumption and to increase the lifetime of a network, partition the wireless sensor network into sub-nets and perform the CS operation independently in each sub-net. Fig. 4 is the proposed model with partition of WSN in sub-net and with proposed three tier model. It illustrate the idea of CS in a large scale WSN with less energy consumption and significant load balancing which increases networks lifetime. In the proposed model hexagonal monitoring field is divided into three tier structure i.e. tier1 tier2 and tier3. It is assume that sink node is at center of the cluster.

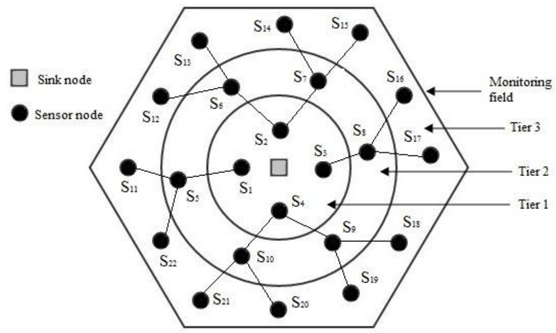


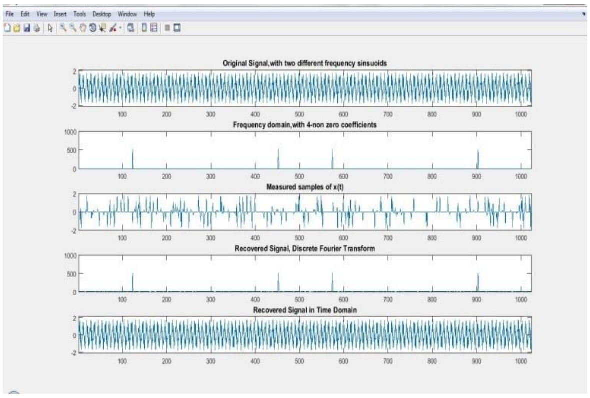
Fig. 5 Data gathering sensing network with partitions.

It is assume that sink node is at center of the cluster. The compression ratio (ρ) which decides how many sensors are participating in data aggregation is given by $\rho = \frac{N}{K}$ constant.

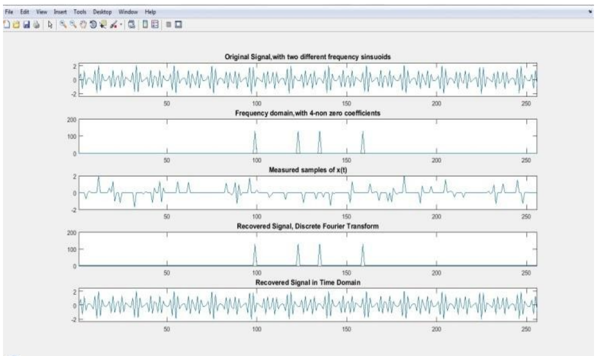
As shown in fig. 4 sensor nodes in tier 3 are far away from sink node and sensor nodes in tier 1 are comparatively close to the sink node or cluster head. In the proposed model of data aggregation in WSN sensing nodes in tier1 will work as fusion center of a sub-net to remaining sensor nodes of tier2 and tier3 will send data on a predefine route. CS theory is applied on sensing node of tier1 only, instead of applying it on each sensor node. In normal CS operation it is observed that if CS theory is applied at each sensor node it will increases number of bits on transmission path. Sensor nodes in tier1 will compress the data and will send it to sink node [9].

V. Result

Fig. 6 a) and b) shows simulation results with different sampling rate in tier 3, tier 2 and in tier 1 respectively. We have used MATLAB R2015a version for simulation. The compressed signal is obtained by applying Discrete Fourier Transform (DFT) with sample values 1024 and 256. By keeping constant sampling rate one can almost recover original signal. Fig 6 a) shows simulation result for tier 3 with data length *N*=1024 samples. Fig. 6 b) shows simulation result tier 1 with data length *N*=256 samples.



a) Number of samples *N*=1024



b) Number of samples *N*=256

Fig. 6 Simulation results with compressive sensing.

VI. Conclusion

In this paper, we have studied conventional data gathering, compressed sensing based data gathering and hybrid compressive sensng at sensor node. The effect of compressive sensing on a natural signal with different sampling rate in a proposed three-tier model for wireless sensor networks or Internet of Things. It is observed that if compressive sensing theory is applied on natural signal at sensor node less number of samples are required to transmit. This reduces the bandwidth requirement for transmission of samples. By varying sampling rate at different tier in proposed model energy-efficient data gathering is possible and also, the further computational cost can also be reduced.

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