Improving the Efficiency of Wireless Sensor Networks through Signal Processing Techniques

Charlie Eapen, A.K Jaiswal, Mukesh Kumar, Ravi Jon, A.Ashok

Abstract*—- *The minimization of energy consumption in modern technology has become a crucial element of research in engineering it is not only advantageous to realizing versatile, robust designs, but also the demand of an environmentally-awakened society. In the case of wireless networking, discovering energy-efficient solutions is just as important to the practicality and success of the technology as it is to commercialization and public reception. In this paper we show that a large portion of the beamforming gains can be realized even with imperfect synchronization corresponding to phase errors with reasonably large variance. We present a master-slave architecture where a designated master transmitter coordinates the synchronization of other (slave) transmitters for beamforming. We observe that the transmitters can achieve distributed beamforming with minimal coordination with the Base Station using channel reciprocity. Thus, inexpensive local coordination with a master transmitter makes the expensive communication with a distant Base Station receiver more efficient.

Keywords- Wireless Sensor Network (WSN), Master-Slave Architecture, Signal Processing.

I. INTRODUCTION

Energy efficient wireless communication network design is an important and challenging problem. It is important because mobile units operate on batteries with energy supply. It is challenging because there are many different issues that must be dealt with when designing a low energy wireless communication system (such as amplifier design, coding, and modulation design), and these issues are coupled with one another. Furthermore, the design and operation of each component of a wireless communication system present trade-offs between performance and energy consumption. Therefore, the challenge is to exploit the coupling among the various components of a wireless communication system, and understand trade-offs between performance and energy consumption in each individual component, in order to come up with an overall integrated system design that has optimal performance and achieves low energy (power). The key observation is that constraining the energy of a node imposes a coupling among the design layers that cannot be ignored in performing system optimization. In addition, the coupling between layers requires simulation in order to accurately determine the performance. The purpose of this power is to present a methodology for the design, simulation and optimization of wireless communication networks for maximum performance with an energy constraint.

One method of improving wireless communication efficiency is through a technique called beamforming. Beamforming is the method of synchronizing a group of mobiles' transmissions to a distant common sink or base station. By keeping the transmissions on a shared frequency and in phase, significant signal to noise gains can be achieved. This technique could be particularly useful in sensor networks, in which many remote devices have limited battery life and must relay information for as long as possible without maintenance. Beamforming could be extended to other networks as well. Consider the case of a vehicular ad hoc network transmitting information about an imminent or already occurring accident – through the use of beamforming between the ad hoc users, a reliable signal could be sent to distant locations for the purpose of reporting the occurrence and requesting help.

In this paper we have presented on the improving the efficiency of the sensor through beamforming, it was shown that a significant, worthwhile amount of SNR gains can be achieved, even with imperfect synchronization afflicted with phase errors of high variance. It was also shown that by using a master-slave hierarchy within the transmitter nodes, the cost of coordinating the beam can be reduced, making the overall energy-expensive transmission to the base station more efficient. Finally, the limitations of the technique, which primarily include the synchronization overhead vs SNR gain trade off, are presented. It must also be acknowledged that such a technique would be truly advantageous in the case of transmission between node and base station consuming significantly more power than transmission between cooperative nodes. Figure 1[1] portrays the typical scenario in which a group of cooperative transmitters attempt to relay a common message to their base station. Given that a single transmitter of power P_t can achieve SNR gains of η_1, it can be estimated that an array of N transmitters would yield SNR gains of $N\eta_1$, while still only consuming power P_t [each transmitter in the N-array requires only P_t/N power]. Although synchronization (phase and frequency) may be a difficult task between transmitters operating on varying (high

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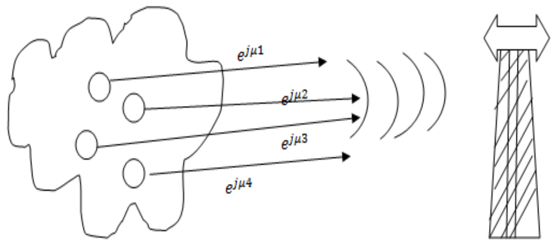


Figure: 1 Model for a cooperative transmission of data in sensor network

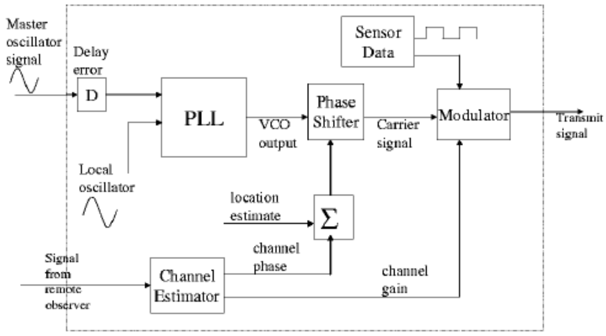
frequency) carrier signals (something often supplied by a local oscillator value, which would vary from node to node), it can be shown that even out-of-synch beams could yield beneficial gains. Here we have assumed that the local communication among the cooperative transmitter (sensors) is cheap in comparison to transmitting to the Base Station (BS). Consider the simple example of two equal amplitude signals from two transmitters combining at the BS with relative phase error of μ. The resulting signal amplitude is given by

$$\left|1+e^{j\mu}\right| = 2\cos\frac{\mu}{2}$$

Even a significant phase error of μ = 30° gives a signal amplitude of 1.93, which is 96% of the maximum possible amplitude of 2.0 corresponding to the zero phase error case. The feasibility of distributed beamforming then depends on being able to keep the synchronization errors sufficiently small. We examine the different possible sources of phase error in detail. We observe that phase noise in practical oscillators causes them to drift out of synchronization; therefore, it is necessary for the master sensor to resynchronize the slaves periodically. We develop and analyze space-time coded cooperative diversity protocol for combating multipath fading across multiple protocol layers in a wireless network. The protocol exploits spatial diversity available among a collection of distributed terminals that relay messages for one mother in such a manner that the destination terminal can average the fading, even though it is unknown a *priori* which terminals.

II. METHODOLOGY

The key concept for achieving the synchronization required for distributed beamforming using a cluster of nodes is to have one node in the cluster serve as a master node, broadcasting both a carrier and timing signals. Figure 2 shows the functionality of a sensor node in block diagram form.



SENSOR NODE

Figure 2: Block Diagram of Sensor Node functioning

Assuming that the slave nodes in the cluster know their distance relative to the master node, they can lock up to the carrier and timing signals sent by the master, and compensate for the delay with which the master signal arrives, thereby achieving frequency, phase and timing synchronization. The precision with which this synchronization is achieved depends both on the signal-to-noise ratios for the synchronization circuits employed, and on the accuracy of the estimates of the delay between the master and slave nodes. Before discussing implementation of this general concept, we consider a special scenario in which the `implementation is particularly simple.

Suppose that the master and slaves are arranged in a star topology, with the master at the center. That is, the master is at approximately equal distance from each slave. This topology could be achieved either by initial placement of the nodes, or, for mobile nodes, by suitable control algorithms that place the slave nodes at a desired distance from the master.

Master-Slave Architecture

We consider the communication system illustrated in Figure. 3. Where a cluster of energy-constrained wireless transmitter nodes communicating with a distant receiver. The main assumption is that local communication among the cooperating transmitters is inexpensive compared to transmitting to the receiver. In a traditional (centralized) multi-antenna transmitter, one way to perform beamforming is by exploiting reciprocity to estimate the complex channel gains to each antenna element. These channel gains are computed in a centralized manner with reference to a RF carrier signal supplied by a local oscillator. However, in a distributed setting, each transmitter has separate RF carrier signals supplied by separate local oscillator circuits. These carrier signals are not synchronized a priori. In the absence of carrier synchronization, it is not possible to estimate and pre-compensate the channel phase responses so as to assure phase coherence of all signals at the receiver. Accordingly, we consider master-slave architecture [10], where a designated master transmitter coordinates the calibration and synchronization 20 of the carrier signals of the other slave transmitters, so that reciprocity can be used to estimate the channel gains to the receiver.

In this way, the transmitters use cheap local communication between the master and the slave transmitters to emulate a centralized antenna array, and to avoid the need for coordinating with the distant receiver .We observe that phase noise in practical oscillators causes them to drift out of synchronization, therefore, it is necessary for the master transmitter to resynchronize the slaves periodically. This, combined with the duplexing constraints of the wireless channel (i.e. it is not possible to transmit and receive on the same frequency simultaneously), reveals a fundamental tradeoff between synchronization overhead and beamforming gain. We quantify this tradeoff using a stochastic model for the internal phase noise of oscillators.

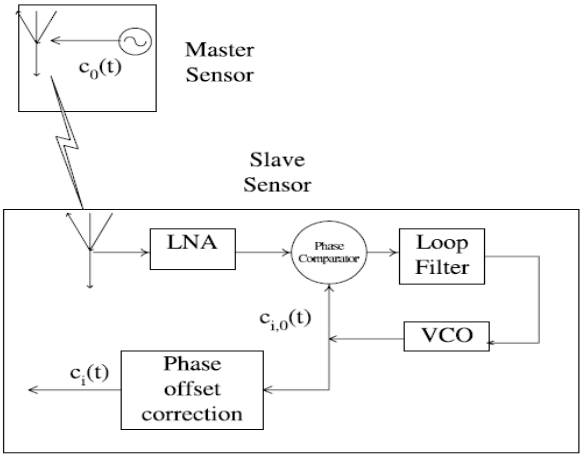


Figure 3: Master –Slave architecture for carrier synchronization.

III. RESULT AND DISCUSSION

In this section, we studied the efficiency in WSN through signal processing using Master-Slave Architecture as given below.

In this section, we measured how gain in received power scale with sensor nodes. Using a uniform distribution for the phase errors, and using Proposition 2 [1], we have

$$E[P_R] = 1 + (N + 1)(1 - \tfrac{1}{6}\tilde{\Delta}^2)^2 \qquad (1)$$

Where $\tilde{\Delta} = \pi\Delta$

Table-1 Gain in Received Power Vs Sensor Nodes

SN o	Parameters	Nominal Values
1.	**N**	**2:2:6**
2.	Δ	**0.1:0.1:0.4**
3.	π	**3.14**

The analytical results in figure 4 match well, indicating that the phased locked loop does not introduce any significant errors. We therefore present further results for the analytical model only.

Figure 4 shows the variation of average beamforming gain normalized to the maximum possible; i.e. $\frac{E[P_R]}{N}$ against the phase error parameter Δ.

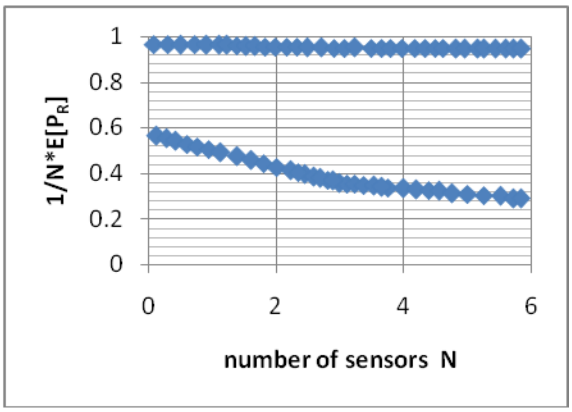


Figure 4: E[P_R] /N vs N

Figure 5 shows how E[P_R], calculated using equation (1) scales with N for discrete values of Δ at 0.1 and 0.4. The maximum slope is 1, corresponding to the case of ideal beamforming. Here, we have to note that for Δ = 0.4, at N=40, there is almost 50% loss compared to ideal this ideal beamforming. Therefore the expected received signal power P_R is still over 20 times greater than that for a single antenna transmission. Hence significant gains can still be expected for distributed beamforming.

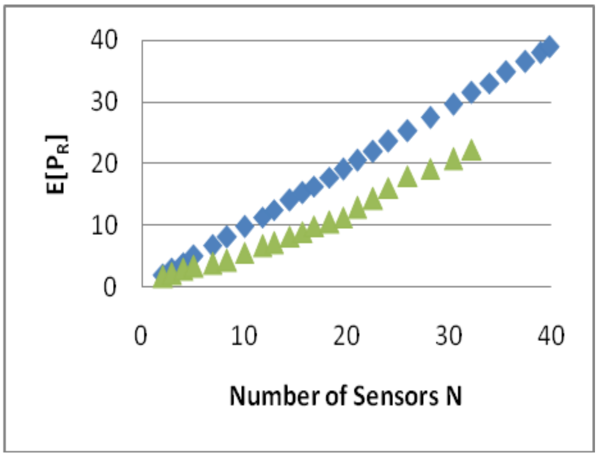


Figure 5: Received Signal Power against the number of Sensor Nodes N

IV. CONCLUSION

In this paper, we studied that we can improve the efficiency of Wireless Sensor Network through Master - Slave Architecture; with a large portion of the signal processing gains can be realized even with imperfect synchronization corresponding to phase errors with reasonably large variance. We observe that the transmitters can achieve cooperative signal processing with minimum synchronization with the Base Station through Signal Processing techniques. An important assumption in our results is that, errors between master - slaves are small in compared to the carrier wavelength. Hence, we showed that the difficulty of carrier synchronization was central to its implementation, and presented a solution based on master-slave architecture.

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