Fusion Performance in Wireless DS-CDMA Sensor Networks with Analog Relay Local Processing Scheme

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Abstract

The performance of decentralized detection in power constrained wireless sensor network is analyzed. By using the distributed processing schemes with the analog relay amplifier local processing, this system is proposed to be subjected to a total power constrains. And, the distributed nodes are assumed to perform analog relay amplifier local processing. Under such conditions the effect of the sensor to fusion communication by making use of the DS-CDMA concept. It evolves the fusion performance by using non-orthogonal sensor-to-fusion center communication, as opposed to the orthogonal communication. Also, to quantify the performance a circulant matrix theory is used to derive closed form asymptotic expressions. The presented results show the effect of each parameter on the total system performance.

Keywords: *Wireless Sensors, DS-CDMA, fusion performance*

1. Introduction

Wireless Sensor Networks (WSNs) can be defined as a network of devices, denoted as nodes, which can sense the environment and communicate the information gathered from the monitored field (e.g., an area or volume) through wireless links [1]. Wireless Sensor Networks have been widely considered as one of the most important technologies for the twenty - first century, enabled by recent advances in microelectronic mechanical systems (MEMS) and wireless communication technologies, tiny, cheap, and smart sensors deployed in a physical area and networked through wireless links and the Internet provide unprecedented opportunities for a variety of civilian and military applications, for example, environmental monitoring, battle field surveillance, and industry process control [2].

WSNs have unique characteristics, for example, denser level of node deployment, higher unreliability of sensor nodes, and severe energy, computation, and storage constraints. A wireless sensor network (WSN) typically consists of a large number of low - cost, low - power, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size but are equipped with radio transceivers and embedded microprocessors. They have not only sensing, but also data processing and communicating capabilities. They communicate over short distance via a wireless medium and collaborate to accomplish a common task, such as, environment monitoring, military surveillance, and industrial process control [3].

In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful preplanning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. In particular, sensor nodes are typically battery - powered and should operate without attendance for a relatively long period of time. In most cases, it is very difficult and even impossible to change or recharge batteries for the sensor nodes [4].

WSNs enable new applications and thus new possible markets; on the other hand, the design is affected by several constraints that call for new paradigms. In fact, the activity of sensing, processing, and communication under limited amount of energy, ignites a cross-layer design approach typically requiring the joint consideration of distributed signal/data processing, medium access control, and communication protocols, Wireless Sensor Networks (WSN) are a new class of networking technology that is increasingly becoming popular today [5]. Huge strides taken in sensing technology, low-power microcontrollers and communication radio have spurred the mass production of relatively inexpensive sensor nodes. Such large scale sensor networks far outweigh use of conventional networks in situations where terrain, climate and other environmental constraints hinder the deployment and setting up of regular networks. Because of the tremendous scale at which such nodes can be deployed, they are extremely robust in terms of individual node failures which make them all the more adorable in such extreme situations. There has been an explosion in the use of sensor networks for environmental measurement and study. Also, the speed with which a sensor network can be set up renders them very useful in military applications such as monitoring and tracking, Nodes of the sensor networks communicate with each other through wireless media [6].

The multiple accesses is a serious problem due to high node density, so, the code division multiple access CDMA mechanism has recently been practical to wireless sensor networks to advocate enforcement with high bandwidth and strict latency requirements [7, 8].

In [9] this type of local processing has a reasonable performance when the sensor observations are corrupted by additive noise. Analog relay local processing has improvement in field of saving individual node power due to the minimum amount of processing involved. To provide a reliable communications in this method the delays should be small. And, needed high communication bandwidth, when ensure the reliable communication the analog relay local processing can be attractive solution especially if the node power is limited.

Also, there were a considerable work have been done by other researchers, in decentralized detection and fusion center,: K. Premkumar and J. Kuri [10] considered the problem of event detection in wireless sensor networks (WSNs) that are large in sense and event affects the statistics of the observations of a small number of sensors in the vicinity of its occurrence. H. Pai, J. Deng b, Y. S. Han in [11] considered wireless sensor networks; the data fusion is often performed in order to reduce the overall message transmission from the sensors toward the base station. We investigate the problem of data fusion assurance in multi-level data fusion or transmission. Proposed scheme uses the time-slotted voting technique. In this scheme, each fusion node broadcasts its fusion data or ‘‘vote” during its randomly assigned time slot. Only the fusion result with enough number of votes will be accepted. V. W. Cheng and T. Wang In [12] developed a multilevel censoring scheme to achieve energy-efficient decentralized detection and examined its performance under various environments in WSN systems. In the traditional censoring scheme, the sensor transmits data to the fusion center (FC) only when the reliability is beyond a specified threshold, and hereby, energy saving is achieved. To further exploit the energy efficiency capability of the censoring decision scheme, proposes a new multilevel sensor-censoring scheme. As opposed to our earlier proposed three-region censoring scheme, the number of censoring levels in the proposed scheme is not restricted.

In [13] T. Wang, C. Yu, and C. Tai, proposed a distributed sampling design for the signal detection application in the cluster-based wireless sensor networks (WSNs). Considering the energy saving requirement in the cluster-based WSNs, a linear weighting data fusion Scheme for data reduction at the cluster head is also developed. The objective functions are derived in a closed form and two numerical examples are presented to illustrate our distributed sampling design and data reduction scheme. Numerical results show that our sampling design outperforms the uniform sampling and is insensitive to the sampling jitter. The proposed schemes are very suitable for the detection applications in battery-powered WSNs.

In [19] using the total power constrains and with the assumption of analog relay local processing, the performance of decentralized detection in wireless sensor networks was investigated, assuming the orthogonal sensor to fusion communication is optimal for such model. This paper presented evolutions for the performance with the same assumptions, i.e., the channel can be accessed to each sensor and varying the code cross-correlation. This corresponds to non-orthogonal communication. The performance with non-orthogonal communication Assuming uncorrelated observation, and using large matrix theory was analyzed in [14]. In this paper assuming correlated observation.

1.2 Decentralized Detection and Data Fusion

In a decentralized sensor networks each distributed node obtains a partial data about its area and send the summary to the fusion center. The fusion center makes a decision, according to a possible set of hypotheses. The problem in consideration in this paper is to characterize the fusion decision rule that leads to the optimal fusion performance. The distributed sensor nodes perform analog relay amplifier signal processing with power constrained. Distributed nodes in a wireless sensor network (WSN) are battery powered and the whole network has access to only a finite portion of the spectrum. This leads to both power and bandwidth constrained wireless communication between sensing nodes and the fusion nodes [15, 16].

Gathering and processing of information through a large number of networked sensors has potential applications in a number of areas, including environmental monitoring (e.g., traffic, habitat, security), industrial sensing (e.g., nuclear power plants), infrastructure integrity monitoring (e.g., health monitoring of bridges, power grid), homeland security (e.g., remote surveillance of ports and airports), and military applications (e.g., target tracking) Availability of micro-sensors with miniature batteries, processors with built-in computation, and wireless connectivity capabilities has made such a paradigm a reality. Sensor nodes (because a sensor has computation and communication capabilities apart from sensing, it is termed a sensor node) can be deployed almost anywhere: on the ground and in the air, inside buildings, on vehicles, and under water. In some applications, they can even be worn by humans. Realizing the full potential of sensor networks, however, presents a number of challenges, including the limitations posed by finite battery life, limited processing capability due to power constraints, and limitations posed by unreliable wireless link quality [17].

Each individual distributed node in a wireless sensor network (WSN) can sense in multiple modalities, but has limited communication and computation capabilities. There are two issues related to reliable information gathering: (1) efficient methods for exchanging information between nodes and (2) collaborative processing of useful information about the environment being monitored. A successful design of a sensor network involves addressing layers of design issues: computational capability of a sensor node, network architecture, and routing of information between nodes. All these issues must be resolved so that reliable information is gathered in an efficient and affordable manner while extending the whole network lifetime, in a wireless sensor network, the communication between two nodes is typically unreliable due to channel fading/shadowing, transmission bandwidth limitations, and transmitter and receiver processing power constraints. The quality of sensed data, the quality of processed data at a node, and the quality of information passed between nodes all play important roles in the overall performance of a sensor network [18].

This paper presents performance of the decentralized detection in a resource constrained WSN using non-orthogonal sensor-to-fusion communication, with analog relay local processing at the sensors level. Found the performance by deriving fusion for large sensor networks.

The rest of the paper is arranged as follows; Section 2 presents the system model. In Section 3 the achieved result and analyses are given. Then, the main conclusions are summarized in Section 4.

2. System Model

We consider a binary hypothesis testing problem, in an N-node distributed sensor system. The K-th sensor observation, under each of the two hypotheses is given by [19, 20, 21]:

$$\left.\begin{array}{l} B_0: y_k = x_{0,k} + v_k \\ B_1: y_k = x_{1,k} + v_k \end{array}\right\} \qquad (1)$$

In vector notation, Eq. (1) can be rewritten as:

$$\mathrm{Y} = x + v \qquad (2)$$

where v is a zero mean Gaussian N-vector of noise samples with covariance matrix $\sum_v$. Supposing the sensors are placed on a straight line and are separated by an equal distance d and the fusion of a deterministic signal, so that $x_{0,k}$ = - m for B_0 and $x_{1,k}$= m for B_1, when k= 1, 2, ….N, each node applies analog relay amplifier local processing to its observation by multiplying it by an amplification factor g, and a signaling waveform v_k is assigned for each sensor, which corresponds to discrete sequence code division multiple access (DS-CDMA).

The cross-correlation between codes used in this model to represent the non-orthogonal sensor-to-fusion communication.

For total power constrains P, the individual sensor nodes amplification factor g is given by

$$g = \sqrt{\frac{P}{\mathrm{N}(m^2 + \sigma_v^2)}} \qquad (3)$$

In the following, first consider the case of R = I, which represents orthogonal communication, followed by the general non-orthogonal communication. We aim to explore the effect of sensor-to-fusion communication on the fusion performance, and to figure how its contribute in the effective fusion SNR. Using the idea of DS-CDMA helps to explore that effect by varying the correlation values between the sensor codes. So our main objective is to explore the effect of non-orthogonal sensor-to-fusion center communication on the fusion performance. So, for simplicity we first assume the case of independent observation, and consider the general correlated observation case next section. This may be achieved by deriving performance asymptotic equations.

2.1 Orthogonal Codes and Independent Observation Noise at the Sensors

Consider the case of R = I and $\sum_v = \sigma_v^2$ I, that represent the case at which the sensors use orthogonal codes, with independent observations. This case was presented in [20], but with different approach. The effective SNR at the fusion center for this case is

$$SNR_f = \sqrt{q_0 e^T \left(I + \frac{\sigma_w^2}{g^2\sigma_v^2} R^{-1}\right)^{-1} e} \qquad (4)$$

where we have substituted, $qc = \frac{m^2}{\sigma_v^2}$ and $q_o = \frac{p}{\sigma_w^2}$, which represent the observation and channel SNR, respectively. For the case of R=I and $\sum_v = \sigma_v^2$ I, we have:

$$SNR_f = \sqrt{\frac{N\, q_c\, q_o}{q_c + N(1+q_o)}} \qquad (5)$$

2.2 Non-Orthogonal Codes and Independent Observation Noise at the Sensors

Suppose that the code cross-correlation matrix R and that $\sum_v = \sigma_v^2$ I, then the fusion center effective SNR can be shown to be given by

$$SNR_f = \mathrm{mg}\sqrt{e^T (g^2\sigma_v^2 I + \sigma_w^2 R^{-1})^{-1} e} \qquad (6)$$

In order to perform the effect of sensor-to-fusion communication, consider the SNR_f for the case N = 2. The term (I + $\frac{\sigma_w^2}{g^2\sigma_v^2} R^{-1}$) in (5) and $\frac{\sigma_w^2}{g^2\sigma_v^2}$ =a, then the effective SNR

$$SNR_f = \sqrt{\frac{2\, q_o}{1+\frac{a}{(1+p)}}} \qquad (7)$$

Substituting the value of a = $\frac{\sigma_w^2}{g^2\sigma_v^2}$,

$$SNR_f = \sqrt{\frac{2\, q_o}{1+\frac{2(1+q_o)}{q_c(1+p)}}} \qquad (8)$$

With increasing the code correlation p evolving the performance or using the same channel for all sensor nodes is important choice for using separate channels for each sensor, which corresponds to orthogonal communication. To view that in general considers Eq. (6) as follows:

For P = 1: this means that all sensors used the same code s, consider the k-th sensor output and denote it as l_k then

$$l_k = g_s\,(\, m_k + v_k\,) \qquad (9)$$

And the received signal at the fusion center z, leading to

$$z = \sum_{k=1}^{N} gs(mb + v_k) + w$$

$$z = N\, gmbs + gs\varphi + w \quad (10)$$

Where b= ± 1 , $\varphi = \sum_{k=1}^{N} v_k$ and the noise term $(gs\varphi + w)$ has the distribution $N(0, (N\, g^2\sigma_v^2 + \sigma_w^2)I)$. the fusion center correlates this signal with the code s, so the decision variable is

$$s^T z = N\, gmb + g\varphi + sw$$

$$s^T z = N\, gmb + \eta \quad (11)$$

Where $\eta = N(0, N\, g^2\sigma_v^2 + \sigma_w^2)$, then the SNR_f at the fusion center given by

$$SNR_f = \sqrt{N \frac{q_c q_o}{1 + q_c + q_o}} \quad (12)$$

$P = 0$: in this case a code s that is orthogonal to other sensor codes, is assigned to k-th sensors, the matched filter input at the fusion center is given by:

$$z = gmSeb + gSv + w \quad (13)$$

The matched filter correlate the input with codes matrix S, the matched filter output is given by

$$S^T z = Ngmb + \eta \quad (14)$$

This shows that the system can be improved by using full non-orthogonal sensor-to-fusion communication, by increasing the network size N. When p = 1, in the orthogonal communication the matched filter correlates the channel noise in N orthogonal direction, it correlates the channel only in one direction. From (10) find the SNR is strictly increasing with the number of the sensors N.

2.3 Asymptotic Fusion Performance

In order to analyze the asymptotic fusion performance of the system we use circulant matrix theory [21], the observation correlation matrix $\sum_v$ is a toplietz matrix and that the code cross-correlation matrix R is already a circulant matrix.

The distribution of the decision rule statistic T (u) to be Gaussian with mean and variance derived as

$$E\{T(u)|H_1\} = m^2 g^2 e^T\, RC^{-1} R_e$$

$$= m^2 g^2 e^T\, R(g^2 R \textstyle\sum_V R + \sigma_w^2 R)^{-1} Re \quad (15)$$

Applying matrix inversion lemma, is given by $(A+BCD)^{-1} = A^{-1} - A^{-1}B(C^{-1} + DA^{-1}B)^{-1}DA^{-1}$, leading to

$$E\{T(u)|H_1\} = \frac{m^2 g^2}{\sigma_w^2}\left(e^T Re - \frac{e^T}{\sigma_w^2}\left(\frac{1}{g^2}(R\sum v\, R)^{-1} + \frac{R^{-1}}{\sigma_w^2}\right)^{-1} e\right) \qquad (16)$$

Substituting (11) and $e^T Re = N(1 + P(N-1))$.

Then,

$$E\{T(u)|H_1\} = \frac{q_c}{1+\frac{1}{y_o}} \times \left[1 + p(N-1) - \frac{2q_c\,(1+P(N-1))^2}{N(1+q_o)(1-p_d) + 2q_c\,(1+\rho(N-1))}\right] \qquad (17\text{-a})$$

Similarly, we can show that

E {T (u)| H_0 } = -E {T(u)| H_1}

The variance of T (u) is the same under both hypothesis and is given by

$$\text{VAR}\{T(u)\} = \frac{2\,q_c}{1+\frac{1}{q_o}} \times \left[1 + \rho(N-1) - \frac{2q_c\,(1+P(N-1))^2}{N(1+q_o)(1-p_d) + 2q_c\,(1+\rho(N-1))}\right] \qquad (17\text{-b})$$

Using these results the minimum probability of error is asymptotically given by

$$p_e = Q\left[\frac{1}{\sqrt{2}}\sqrt{\frac{q_c}{1+\frac{1}{q_o}}\left[1 + \rho(N-1) - \frac{2q_c\,(1+P(N-1))^2}{N(1+q_o)(1-p_d) + 2q_c\,(1+\rho(N-1))}\right]}\right] \qquad (18)$$

3. The Results and Analyses

Figure 1 shows that the value of the SNR is almost fixed when the number of sensor nodes accessed 20 nodes. However, channel SNR (q_c) plays a considerable rule in the amount of performance.

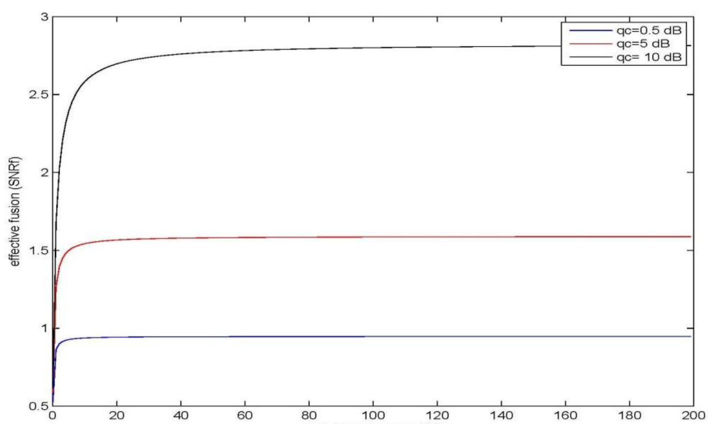

Figure1. The Effective of the SNR on the Number of Sensor

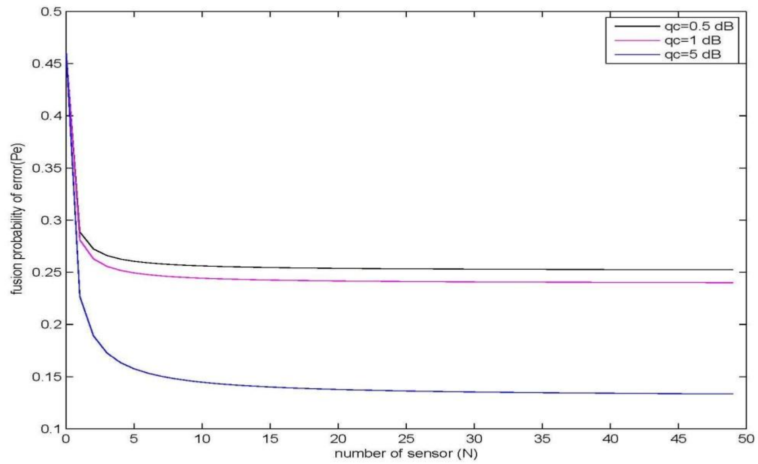

Figure 2. Fusion Error Probability as a Function of a Number of Sensor Bodes with p = 0.

Figure 2 shows that the P_e is decreasing to specific level with increasing the number of sensors (network size). The fusion probability of error P_e is decreases as the value of q_c is decreases which make the P_e dependences on q_c.

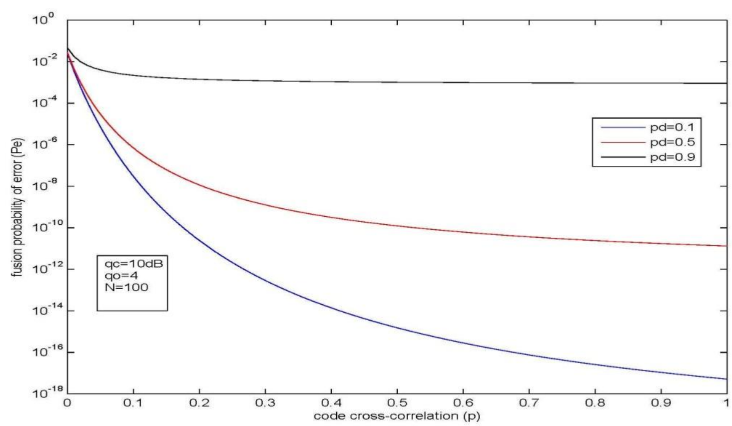

Figure 3. The Fusion Probability of Error on Signaling Waveform (code) Cross-correlation p

Figure 3 illustrates the relation between the fusion probability of error (P_e) and the code cross-correlation (p). The P_e is a decreasing function to the observation correlation (p_d) which increases the new data by using extra sensor, and the effect of the value in p_d in much important in the system performance.

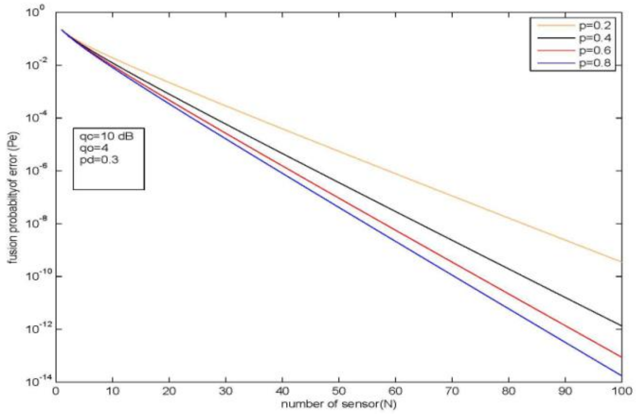

Figure 4. The Fusion Probability of Error on the Sensor Network Size N

Figure 4 shows variation the fusion probability of error to the number of sensor (network size). The fusion probability of error (P_e) decreases with decreasing the value of p which led that the P_e is dependence on the p, with different level of number of sensors.

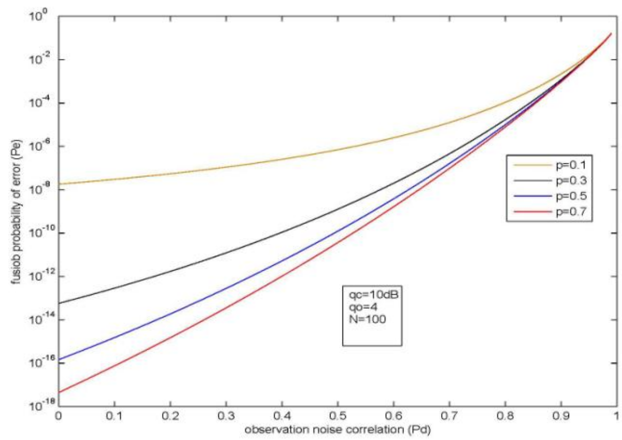

Figure 5. The Fusion Probability of Error on Local Observation Cross-correlation Parameter p_d

Figure 5 depicts the relation between the fusion probability of error (P_e) and the observation cross-correlation (p_d). The P_e increases with the p_d for different value of p. When the probability of error decreases this makes the dependence as increasing the observation noise correlation is an important parametric should be considered to improve the system.

4. Conclusions

The fusion execution in a wireless sensor network, under the assumption of analog relay amplifier local processing and total power constraints are studied in this paper. This type of processing was demonstrated to perform well when the observations are corrupted by additive Gaussian noise, analyzing the effect of the sensor to fusion communication by making use of DS-CDMA concept. The achieved results show that using the non-orthogonal communication, allows harnessing the coherent gain in the case of deterministic signal detection. Circulates matrix theory is used, to quantify the fusion performance. The use of circulated matrix theory gives an insight into the effect of each parameter on the overall fusion performance.

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