Power distribution to reduce interruption distortion and Diversity Order Analysis in wireless sensor networks

Abstract

In recent years, there has been rapid and clear development in wireless sensor networks (WSN) technology due to the urgent and increasing need for it in many fields such as automatic monitoring and control. The importance of WSN is evident in its use in many applications in various areas of life and developing and improving these networks occupies a necessary and important area of interest for research centers and many specialized scientific institutes. The main benefits of using WSN technology include low cost, self-organizing operation of the sensor network, and low power consumption. However, there are still many challenges remaining in practical deployments. Paying attention to the structures of these networks as a gateway to improving their performance is considered one of the most important techniques and methods that have given good results in this field. The cluster structure is also considered one of the most important structures that has received increasing attention over recent years. This research aims to provide insight into power distribution to reduce interruption distortion and analyze diversity ranking in wireless sensor networks. The results obtained from previous studies indicate a significant improvement in terms of reducing energy consumption and thus increasing the life time of the network that is, ensuring that the network operates for additional longer periods, compared to the traditional cluster tree. But this was at the expense of slightly lower transmission rates and delivery rates in these networks. Therefore, balancing the energy consumed between nodes within networks is the purpose of energy-efficient routing protocols. These protocols need to maximize the lifetime of the wireless network. There are many algorithms to try like the A-star algorithm or use a mathematical formulation by changing the permittivity factor to a better value where we have high remaining energy within the network and setting it to a lower value for the nodes that do not have much energy left.

Key words: Power distribution, interruption distortion, sensor networks, diversity order, power allocation, wireless sensor networks.

1. Introduction

In recent years, there has been an increasingly urgent need for communication between distributed devices used for real-time remote monitoring and control. Therefore, Wireless Sensor Network (WSN) technology developed as a result of this requirement and need [1]. WSN is a collection of distributed computing, embedded system technologies, and wireless communications, such as sensors. Through their collaborative efforts, sensor nodes can sense, analyze and then transmit all the data, so they are very important and allow monitoring of phenomena of interest in real time, in addition to controlling motors across a wide area and in different places. Low cost, self-organized operation, low power consumption, and cooperative effort are among the most important characteristics of sensor networks [2]. Due to these capabilities and characteristics, sensor nodes can be placed in many hard-to-reach places, while continuing to operate for long periods thanks to the use of batteries and solar panels as primary sources of energy. Many applications and fields that require low power consumption and low data rates can greatly benefit from sensor networks [3].

In view of the importance of these networks and their many applications, it was necessary to pay attention to performance, and the performance of the network is its work and the accomplishment of its tasks in delivering data to the required destination in the best ways, and knowing the factors affecting performance to work on improving them and then improving the performance and the work required to be accomplished by the network. The most important of these factors is the method of data transmission between the nodes that make up the network, the method of placing those components, as well as the amount of energy consumption by the sensors, as reducing the amount of energy expended will ensure that the network operates for longer periods of time, by prolonging the life time of the sensitive nodes, without the need to replenish the energy source inside the sensor. Many studies have focused on the performance of the wireless sensor network, in general, and the problem of node life time and increasing the delivery rate in particular [4].

There are many research [5], [6] focused on organizing the nodes that make up the network into clusters, as it was proven that the life time of a network with clusters is greater than in the case of a cluster network [7]. Each cluster has a head (CH) (head cluster) responsible for it, which receives the packets from all the nodes in his cluster are collected and sent to the BS (Station Base) located outside the monitoring area. The research [8] showed that the head acts as a central controller, but it suffers from a severe lack of energy as a result of its dealing with the heads of other clusters in multiple hops. Thus, the rate of energy consumption in the vertex is greater than that of any other node, and in order for communication with the entire network to remain alive as long as possible; the BS (Station Base) (BS) remains alive as long as possible. Therefore, the number of nodes in the clusters closest to the station is smaller than in the farthest clusters [4].

Some research has resorted to putting the node into a sleep phase when it is not needed, in which most of its radio circuits are closed, meaning energy is saved, and then it returns to work and enters the active phase [9], [10], [11]. Other research has also shown that Performance can be improved by reducing energy consumption by reducing the size of the packet sent by each node of the head [12]. This is done by performing a compression process at the sending end, then a decompression process at the receiving end. This method has proven effective when transmitted by each node individually to the destination required, but there is difficulty in applying this method when transmission is done through several successive nodes, while other research has resorted to this by developing new protocols to save energy during data collection and processing operations [13]. Other research has deduced algorithms to improve network performance [14], [to reduce It reduces energy consumption and increases the network's life time as the cluster heads are chosen dynamically, but the negative of these algorithms appears when the cluster heads are forced to broadcast messages to all neighboring nodes with additional, excessive energy consumption.

1.1 Problem statement

WSN is distinct from many networks in that it is set up wirelessly without using infrastructure [15]. Sensors are typically mass-produced, low-cost, battery-powered sensors with limited, simple power, communication, and processing capabilities. It is expected that as technology evolves, sensors will become smaller [16], which indicates how small a sensor node actually is compared to its large effectiveness and high efficiency. Because sensors are intended for single use only and may be placed in hazardous or difficult-to-access environments, battery replacement is usually expensive and unnecessary. The three operating modes that WSNs (and ad hoc networks in general) use to operate are transmit, receive, and "listen" mode. Each operating mode uses power differently [17].

Furthermore, power is typically used for transmission as well as circuit performance such as digital-to-analog converters. Obviously, transmission power is more important for long-range applications than circuit power, and transmission power is similar for short-range applications [18]. For wireless sensor networks in particular, effective management of the power/energy consumption of sensors is important and vital because ad hoc networks (WSNs) depend significantly and obviously on the rate of energy consumption in various domains. In WSNs, power distribution control is a technique used to regulate the transmission power of sensors in different places. Within WSNs, power control may be distributed, centralized, or a combination of the two. When using centralized power control, each network parameter must be collected by a central processing unit, which calculates the power allocation and sends the result back to each sensor. Therefore, increased communication burdens are necessary for centralized power control.

The UCS (unequal size clustering) algorithm worked to achieve a balance in energy consumption by controlling the cluster size through the distance between the cluster head and the station, as well as controlling the cluster angle, which led to an increase in the network's life time [19]. It also determined an ideal size for the cluster to prolong the life of the network [20], [but with the increase in the number of dead nodes in the network, it was difficult to control the cluster size and the distribution of clusters in practice. Some research with special applications added new units to the sensitive node, such as: a location determination unit, a power generator unit [21] to improve the performance of the node and then the network. However, such studies remain difficult to implement due to the lack of the necessary requirements and capabilities. The study [22] was to achieve the desired goals of multi-use sensor networks, without causing any interference, and to solve the problem of narrow frequency spectrum where there was no any previous protocols for spectrum management, and suggested finding new designs that would guarantee the assignment of different frequencies to different nodes, at different times and in different locations. The SAS layer (service spectrum adaptive-self management) was proposed above the physical layer, to achieve better service in spectrum management. Practical investigation of such studies remains difficult due to the lack of the necessary capabilities and the development of additional satellites in the upper classes [4].

When it comes to regulating power distribution and analyzing diversity, sensors often have the ability to calculate power based on many local data, including data collected from sensors close to them. A little data is sent between the sensors and the CPU in partially centralized/distributed power distribution ways, and the computation is done at both ends [23]. The issue of power consumption, power distribution to reduce interruption distortion, and diversity ranking analysis in WSNs is of great importance and benefit for the future; this motivates the author to conduct research to study power distribution to reduce interruption distortion and analyze diversity ranking in WSNs.

2. Literature review

2.1 Wireless Sensor Networks

A wireless sensor network (WSN) is defined as a network consisting of a group of sensitive nodes, spread out in a medium that senses the environment in which it is located through information collected via a wireless connection, and the data is transmitted in packets across the network, through hops that pass through gateways. Crossing, or communicating with other networks such as the Internet. This network is used to monitor or transmit a physical or chemical phenomenon (such as humidity and temperature). After that, all information is transmitted wirelessly to the data processing center to obtain the result without the need for a human being in the place where the phenomenon occurs, whether chemical or physical [3].

The wireless sensor network has recently appeared significantly, as the wireless sensor network in the twenty-first century began to develop at an accelerated pace as one of the best emerging technologies in the past ten years. In recent years, a lot of research and scientific papers have been conducted on the wireless sensor network to improve and develop it in all aspects and fields, including its construction, routing protocols, node operating systems, data collection and integration, and time synchronization. Moreover, large numbers of applications have emerged and been deployed in various geographical areas such as scientific exploration, traffic monitoring, military surveillance, environmental protection, tracking of many objects and fields, and others. In the recent period, with the conveniences provided by the wireless sensor network, life has been noticeably affected and changed a lot in many ways. However, there are still many problems plaguing the wireless sensor network. Some of these problems include failure of wireless communication systems nodes, limited power available in some places, unreliability of wireless communication systems, etc. [3].

Wireless sensor network is an important way to study and interact with the physical world. A sensor network usually consists of a large number of small sensor nodes. Each sensor node has one or more sensing components to sense ambient conditions (e.g. temperature, humidity, pressure) and a processing and communication component to perform some simple operations on the data and communicate with its neighboring nodes. Sensor nodes are usually deployed densely over a large scale and communicate with each other via wireless links. Control nodes process data collected from sensor nodes, collect control commands from sensor nodes, and connect the network to a traditional wired network. Sensor nodes are usually spread out randomly, and then form a sensor network designed to perform specific tasks. There is usually no infrastructure support for sensor networks [23].

2.2 Power Management Approaches

Power efficiency is a major concern in WSNs, because using a tethered power supply is usually not cost-effective in outdoor applications. The difficulty of achieving sustainable operations of sensor nodes has been widely explored in the scientific community [24] since batteries contain a limited amount of energy. The solutions fall into two basic categories: environmental energy harvesting and energy saving technologies.

1) Energy-Efficient Approaches

In energy-efficient approaches, enhancing the basic functions of sensor nodes and their communication methods leads to improving and enhancing energy efficiency in many areas. In wireless communications, data transmission uses much more energy than other sensor node operations such as data processing and sensing. Energy consumption can be significantly reduced by using energy-efficient routing techniques [25]. By using energy metrics to determine the best paths based on the remaining energy of sensor nodes, the routing algorithms in [26] successfully balance the energy distribution of all sensor nodes in the network. [27]. Several variations of the clustering hierarchy described in [28] significantly reduce energy use in WSNs by selecting appropriate cluster heads to minimize transmission and data aggregation distances. Mostly, the MAC layer is responsible for implementing another suitable power management technology. The MAC protocols in [29] allow the duty cycle to be changed based on a spreadsheet by specifying time parameters within a special window in a synchronous manner, greatly reducing the amount of time spent in idle listening. In a cluster-based network architecture, there are generally two ways to achieve energy savings: task migration and remote processing, which can be compared to data aggregation. The decision-based randomization method shifts tasks from sensor nodes to the server using an energy-efficient strategy, thus reducing overall energy usage [30].

2) Energy Harvesting

It can be seen that energy-efficient methods suitable for managing and reducing energy consumption are well designed based on the considerations of optimizing and enhancing the residual energy utilization of sensor nodes. Furthermore the sensor nodes may be powered by a range of potential ambient energy sources. The primary sources – solar energy, human movement, vibrations, and thermal gradients were obtained by the authors in [31]. It has been shown that solar energy harvesting methods can significantly increase the lifetime of WSNs [32]. For WSNs containing battery- and solar-powered sensor nodes, [33] presents solar-aware routing algorithms. For energy harvesting WSNs, a variety of adaptive service cycling techniques for energy harvesting have been proposed in [34]. The goal is to maximize the use of the harvested energy and achieve an energy neutral process. Several analytical models are presented in these works to identify and predict energy harvesting sources, their availability, and appropriate task allocation [35]. The goals of duty cycle conscious harvesting technology are to achieve energy neutral operation, increase work performance, and reduce duty cycle fluctuations. Furthermore, Raghunathan et al. presented a system architecture analysis of solar-powered sensor nodes, including design concerns and the harvesting module. Jiang et al. [36] also developed a suitable design using a multi-stage power transmission system for solar-powered WSNs, which mainly uses a battery and a capacitor to store energy and reduce its consumption. Many strategies have been proposed in the field of energy harvesting to increase environmental energy efficiency. A model that predicts harvested solar energy over long timescales has been proposed by Krüger et al. [37]. This model takes into account several important aspects that affect energy harvesting. References provide empirical research on solar energy harvesting systems [38].

2.3 Power allocation in orthogonal MAC and coherent

Wireless sensor networks are useful in a wide range of situations. An important and key issue from the perspective of minimizing energy usage in sensor networks is to determine the optimal power allocation in sensor transmitters to minimize outage under different power constraints. Within the framework of codeless transportation, several previous studies have examined the challenges of multi-sensor estimation and identified the most prominent concerns related to power/energy efficiency [39]. Energy efficiency in wireless sensor networks has also been studied in the context of power optimization problems, where results show that sensor networks with orthogonal MAC [39] and coherent MAC [40] provide optimal power allocations (minimizing total power subject to distortion constraints or minimizing distortion subject to for the total energy constraints). However, these ideal power distribution schemes rely on fixed channels and do not specifically consider fading channels, which may not always be able to meet strict distortion constraints.

In distributed estimation, sensors collect information and data about a particular physical phenomenon on their own and send it directly to the central processing unit, also known as a fusion center, which typically uses sensor measurements to try to reconstruct the physical quantity. Many recent researches [41] have shown that in a Gaussian sensor network, it is always preferable to forward the unencoded analog data by several sensors asymptotically in order to decouple the source channel coding of the transmission. Another research [41] also showed that transmission using uncoded analog forwarding of readouts by multiple sensors is completely optimal in a Gaussian sensor network. Since then, a number of studies have investigated power allocation issues in multi-sensor estimation using the analog transport model. In [40], the authors used analog and forward amplification with a coherent MAC to determine the best power allocation for a heterogeneous Gaussian wireless sensor network while adhering to the distortion constraint (a performance parameter determined by the variance of the reconstructed source). In [39] found a solution to the problems of power minimization under distortion constraints and distortion minimization under power constraints in an amplification and forward scenario using an orthogonal MAC. In [39] for coherent MAC and [42] for orthogonal MAC, energy allocation with correlation in sensor data, and energy allocation in distributed source vector estimation are also explored.

Finally, the diversity estimation achieved by wireless sensor networks was studied for the first time in [39] to equally allocate power in multiple orthogonal access channels with Rayleigh fading. They demonstrated that a network of this type may achieve an estimated diversity proportional to the total number of sensors within the network. When compared to an ideal channel setting, it has been shown that the diversity gain remains constant when the channel estimation error is included [43]. A broad class of fading distributions has been studied with respect to discontinuity and diversity scaling laws for distributed discretization over multiple orthogonal access channels [44]. They show that for constant energy per sensor, the outage probability decays more slowly than $\exp(-K \log K)$, where K is the number of sensors, and exponentially faster than the number of sensors.

2.4 Power Allocation for Distortion Minimization in Distributed Estimation

Recently, several previous studies and literature have examined cross-layer optimization to increase the lifetime of energy-constrained wireless sensor networks and wireless networks in general [45]. Through this kind of collaborative adaptation, they developed an online heuristic that can save a significant amount of energy. The issue of energy-efficient transmission scheduling for wireless networks with delay constraints—both deadline and average delay constraints—has been studied in work. They also investigated how to save more energy and manage it better by using channel coding and electrochemical processes that allow batteries to recover full energy when not in use [46]. The authors propose joint optimization for energy and bio impact management, as well as joint optimization for congestion control and media access control, using a cross-layer optimization approach on wireless biosensor networks in interference-limited wireless sensor networks in [47]. Many researchers have investigated the cross-layer optimization problem that determines the best transmission powers, rates, and link scheduling to improve network lifetime [48]. The results indicated that the lifespan of power-limited networks can be extended through the use of several transmission techniques such as interference mitigation and load balancing [49].

One of the main problems with WSNs is the limited battery life of the sensors and that changing their batteries may be expensive or even impossible. Several studies have investigated energy allocation issues for distributed estimation in wireless sensor networks [50, 51]. Some studies have provided solutions to the issues of reducing the deformation sustaining capacity and reducing the deformation sustaining capacity of multiple orthogonal access channel (MAC) [50]. The optimal power scheduling problem in a heterogeneous sensor network was studied using a deconvolved modulated quadratic transmission approach and a global decentralized quantization/estimation technique [51]. For a coherent MAC, the energy scheduling of the vector source is calculated in [52]. The broadcast nature of wireless communications has made privacy and security concerns one of the major issues facing WSNs. Moreover, data security and privacy are important and necessary in many scenarios, including security systems, smart buildings, and hospitals. However, integrating security is very difficult. This is because traditional encryption and cryptography methods require high computational power and capabilities, making them impractical for use in WSNs [53]. In fact, cryptographic systems with small key sizes may not work if the eavesdropper has access to sufficient computing power. Therefore a different approach to achieving data confidentiality is presented by Shannon's concept of perfect security [54].

Research [55], [56] worked to improve performance and prolong the network's lifespan, through what was called ideal flow control, as the congestion occurring in the link was taken into account, as well as the energy efficiency of each sensor. The peculiarity of this research is demonstrated by establishing the system model used, which relies on node diffusion algorithms, to organize movement between components. The research [57] proposed an action plan to improve network performance by increasing the life time of a linear wireless sensor network (i.e. linear placement) by reducing the volume of transmitted data and achieving a balance in the flow. The study showed that the return is maximum, that is, achieving the best possible increase in network life when work is done on Both data compression and control of its flow at the same time. The peculiarity of this study is that it is used when the sensors are placed in a linear, sequential manner, as in networks monitoring power and gas transmission lines, monitoring public roads, etc. The researchers in [58], [59], and [60] proposed applying the cluster tree to reduce energy consumption while maintaining the data transmission rate, as well as maintaining a high packet delivery rate between the terminals and the base station. Our research will focus on modifying the cluster tree algorithm to ensure lower energy consumption while not decreasing the transmission rate below the limit that ensures that WSN networks in the proposed applications work well [3].

2.5 Diversity Order Analysis in wireless sensor networks

Cooperative diversity is a set of techniques that exploit the capabilities of geographically distributed user antennas to increase communications reliability [61]. Theoretically, the use of cooperation to produce diversity in wireless networks was examined in [62], where the cooperation rate region was accessed using Markov overlay block encoding and inverse decoding, subsequently, many decoding, amplification and forwarding methods with minimal complexity have been proposed and investigated in [63]. Each node in these studies was considered to have a common transmission power. Recently, several resource allocation issues for collaborative diversity systems have been examined in [64].

The best power allocations for amplification, decoding and forwarding protocols are found in for parallel relay AWGN channels. In [65, 66], several allocation difficulties for a three-node cooperative diversity system were studied, assuming a Rayleigh fading channel where instantaneous channel state information is accessible from transmitters. It is standard practice to assume that the average channel gain is known only at the transmitters when modeling systems with very little feedback. But only a small number of studies have studied allocation based on average channel gain [67], [68]. For an amplification protocol that uses linear dispersion space-time codes, a power allocation that explicitly minimizes the pairwise error probability is defined in [67] under the assumption of identical average channel gains for all source and destination relay connections. The best allocation is determined by solving a series of nonlinear equations, which calls for the use of iterative techniques [68].

In many modern communications disciplines, scheduling approaches to reduce co-channel interference have been documented and the diversity advantage in a multi-user environment has been widely investigated. However, there are not many researches that examined multi-user scheduling and communication performance in the context of WPSNs in the literature, such as [70], [71], [72]. Two scheduling strategies have been developed by the authors in [70] to enhance the secrecy performance in WPSNs, where the secrecy outage probability is used to measure the system performance. In addition, a joint selection technique is provided by works in [71] to select a friendly jammer and transmitter node for WPSN when passive eavesdropping is present. While the end-to-end SNR-based selection strategy provides adequate and improved outage performance in different system situations, a general selection mechanism for WPSN is proposed in [73], which is compatible with many diverse channel state information needs and implementation-related challenges [74].

Many advantages of using receive diversity are described in [75] for Wireless Sensor Network (WSN) applications that require high data accuracy and resolution at the moment of event triggering in many fields. The collaborative diversity method with similar sensors randomly spread across an area with large was presented in [76]; it improves and enhances connection reliability and increases network longevity. These nodes collect a joint message and then send it to the Unarmed Aerial Vehicle (UAV) fusion center. In practice, these situations present an access problem since the nodes are not powerful enough to send data directly to the remote receiver due to the low-power transmitter design [77]. In [78], a distributed method is provided that can compute linear signal expansions for a sensor broadcast protocol where all sensors collect associated samples, broadcast to all other sensors an encoding bounded by their sampling rate, and generate an estimate from the whole field.

Sensors simply need access to samples from a small number of surrounding sensors in order to uncorrelate. Applications such as collecting data from a remote location are common. In [79], a distributed diversity strategy that uses geographical dispersion of sensor nodes was investigated and developed. However, in order to ensure increased network performance, optimal assumptions such as cooperation and concurrency are included.

Furthermore, the use of diversity methods in the receiver may significantly reduce power consumption, which directly affects and leads to a reduction in battery consumption and thus an increase in network life, in addition to ensuring that data is received correctly in the remote receiver and thus leads to improved performance in specific field. Taking advantage of the variation in WSNs, several new relay mechanisms based directly on Luby switch codes have been presented in [80]. It is accepted that diversity is implemented at the sender end, which then leads to a relatively low level of decoding complexity at the receiver. Although decoding and encryption operations need more energy, a group-based cooperative strategy for multi-hop WSN is also presented in [82] which may obviously reduce the energy consumption of sensor nodes. In addition, two distinct group-based models were used to study the energy efficiency of a cooperative multi-input, single-output (MISO) system for a multi-hop WSN in [82]. The data was encrypted using space-time block cryptography (STBC), which requires additional energy from the cooperating nodes to complete the encryption process. The performance of cluster-based WSN via the GBSBE model is shown in [83], depending on the number of receiving antennas and broadcast power [75].

3. Conclusion

This paper presented energy-efficient power allocation algorithms for wireless sensor networks used in distributed estimation and diversity ranking analysis in wireless sensor networks. In this paper, problems that require reducing the probability of distortion discontinuity are mentioned. Through previous studies, three power allocation algorithms based on full CSI were proposed and a theoretical analysis of the diversity order of discrimination discontinuity of each scheme was presented. It is shown that the EPA scheme and the total power constraint distortion minimization power allocation scheme (ST-OPA) achieve the same diversity ranking, which shows that the spatial diversity in EPA can overcome fading equally well as well as the full CSI knowledge in ST-OPA for a large number of sensors. On the other hand, LTOPA (minimizing outage probability subject to long-term aggregate power constraints) analysis showed that we can push the outage probability to zero by using a limited amount of long-term aggregate power for networks with two or more sensors. A wireless sensor network has also been studied, where sensors transmit their signals to the fusion center via an orthogonal MAC.

In conclusion, the uses of WSN are an inspiration for many future ideas in many fields. Even with the development of many MAC and routing protocols and methods, there are still many problems and difficulties that require further investigation in many areas. This paper reveals that routing is a very challenging problem in WSNs due to the large number of threats and risks associated with transmission. It means that two major considerations - safe method and optimal path - must be taken into account while creating a routing system in many areas. As a result, it is highly recommended to use protocols that may extend the network lifetime and are clearly reliable and energy efficient.

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