Implementing a reliable, fault tolerance and secure framework in the wireless sensor-actuator networks for events reporting

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Abstract

The emergence of embedded systems, mobile, and the presence of sensors in all areas of human life without the presence of humans, makes it easy to do things, and to reduce the computational complexity. Wireless sensor networks are one of the types of distributed systems in recent years has been of interest to many researchers and have been used in many places, such as the military areas, banks, airports and other places, for use in protection systems. Wireless sensor networks consisting of tens, hundreds or even thousands of self-directed sensors that are wirelessly at a distance from each other and embedded in the environment, so that are associated with each other and perform the task of finding events and gather information from the environment and transmits the information to a monitoring center. Wireless sensor networks with the introduction of powerful or even mobile actuators have improved their existing wireless sensor networks. An actuator interacts with the environment according to information received from the sensors and processing information. In order to have reliable operation for the activation, it looks critical to design a reliable, secure, and fault tolerance report for sensors to alert activation of peripheral events. In this paper, we use machine learning techniques such as clustering and Bayesian rules to represent a reliable, fault tolerance and secure framework to report events in the wireless sensor-actuator networks, which are enable to optimal collect data received from the environment and report it to the actuators.
Keywords: Wireless sensor network, Wireless sensor-actuator network, Reliability, Fault tolerance, Clustering, Bayesian rules.

1. Introduction

Although the first computer systems were in large-scale, the performance was very low, therefore, people need for computing devices with less size, weight and cost and greater speed and efficiency, improved computing systems and computer. Insofar as very large systems weighing several tons are replaced with small desktop personal computers, which not only easily portable by humans, but the speed and efficiency are very high [12]. These personal computers (PCs) had evolution, Insofar as at first, these were uni-core systems, but increase of efficiency and productivity was the factor for computer systems to have advances as multi-core and multi-processor computer systems. But despite this increase of speed, efficiency and productivity and reduce the size of their computer systems, there is also a challenge for users so that exchange and transfer of information between different computer systems was not possible and there was no possibility of sharing resources, therefore, systems were led to the network and distributed systems. A network is displayed as a $G = (V, E)$ weighted graph where $V$ represents a set of nodes and $E$ represents the set of edges between any two nodes. Computer networks can be classified in different ways. For example, in terms of geographical diversity of the area networks can be classified in various categories such as personal area network (PAN), local area network (LAN), metropolitan area network (MAN) and wide area network (WAN), or in terms of communication channel they can be classified into two categories: wired networks and wireless networks. From one aspect you can define network and distributed systems as any two sets of independent and autonomous nodes while these nodes are connected to each other for information transfer, and from a user perspective it looks like a unified system. The only difference between a network and a distributed system is in the homogeneity of nodes, i.e. in a distributed system nodes are homogeneous with each other, while nodes in a network may not be homogeneous. For example a computer network may consists of a number of computers, switches, routers, hubs, etc., which are heterogeneous, but a distributed system consists of a number of homogeneous nodes such as wireless sensor networks that is made of a number of sensors in a distributed environment [3,6,13]. Distributed systems to have attracted the attention of many researchers and are classified into three sub-categories of wireless sensor networks [4,9], pervasive computing [1,2,11], and grid network [3]. Development of technology and its role in modern life and recent advances in the field of electronics and telecommunication, with uses and advantages of wireless sensor networks and the role of sensors in everyday life made us to perform an overview of wireless sensor networks. Wireless sensor networks is one the sciences in recent years has been interested to many researchers and has been used in many places, such as the military areas, banks, airports and other places, for use in protection systems. Wireless sensor networks consisting of tens, hundreds or even thousands of self-directed sensors that are wirelessly at a distance from each other and embedded in the environment, so that are associated with each other and perform the task of finding events and gather information from the environment and transmits the information to a monitoring center. In fact, the tasks of sensors is to collecting data points at regular intervals and converting it into an electronic signal, and provide signal propagation to sink nodes or base stations through reliable wireless communications media. Sensors are equipped with processors and communication facilities and are used in a variety of environmental conditions such as temperature, pressure, light, humidity, noise, vibration, motion, pollutants emission and etc. Sensors had initially military applications and were used in military areas to monitor the battlefield, but over time their use were developed. The main reason for the development of wireless network was continuous monitoring of environments where permanent presence of human in them is difficult or impossible. Some of these applications include monitoring of erupting volcanoes, impossible regions, and disaster locations, monitoring the strength of dam, bridges and roads, monitoring battlefield, military critical areas, the use in practical programs such as safety care, target tracking and medicine software. Working areas of sensor networks are increasing and soon it will become a part of daily life. But today, wireless sensor network is one of the active subjects to research for computer science, communications, industry, and many non-military purposes. Some of its applications include monitoring and controlling industrial processes, health monitoring of devices, monitoring the environment of firms and houses, smart houses, traffic control and etc. [5,6,8,9,13]. In recent years, wireless networks due to their potential in a wide range of practical applications have attracted interests of researchers. Secure data transfer is one of the most important requirements in wireless sensor
Wireless sensor–actuator networks (WSANs) greatly enhance the existing wireless sensor network architecture by introducing powerful and possibly even mobile actuators. The actuators work with the sensor nodes, but can perform much richer application-specific actions. To act responsively and accurately, an efficient and reliable reporting scheme is crucial for the sensors to inform the actuators about the environmental events. Wireless sensor networks (WSNs), constructed by a group of sensors, have been suggested for numerous novel applications, such as monitoring for harsh environments and protecting national borders [8]. Researches in various fields of wireless sensor networks are done in several ways and each one focus on a certain case. In various researches and studies, in order to transfer data and information from source to detonation we need to consider several objectives include reliability, fault tolerant, increased longevity, cost reduction, delay reduction, rout traffic reduction and etc. thus finding an optimal data transmission rout in a wireless sensor network is difficult or almost impossible and is considered as a NP problem (NP-complete) [7,14]. One of the most important disadvantages in wireless sensor network is limited battery power, while excessive consumption of energy causes problem such as malicious attacks, hardware failure and sensor nodes failure [4]. Power of sensor nodes is another important factor in wireless sensor networks that is provided by batteries with limited energy source, therefore, limited energy of broken nodes is a challenging problem, and then, introducing an effective protocol to reduce energy consumption is necessary in order to maximize network lifetime. To achieve these goals, packets should be transferred by a rout with minimum energy consumption [14]. Actuators for rapid response to environmental events require accurate, fresh and updated data and information, therefore a reliable protocol to communicate actuators and sensors is critical. In this paper, we use machine learning techniques to represent a reliable, fault tolerance and secure framework to report events in the wireless sensor-actuator networks, which are enable to optimal collect data received from the environment and report it to the actuators. The remainder of this paper is organized as follows: In section 2 and 3, artificial intelligence and machine learning techniques such as clustering and Bayesian theory will be examined. In Section 4, with the idea of clustering techniques and Bayesian theory we introduce a proposed framework for collecting and reporting events in WSANs that is to improve reliability, safety, and fault tolerance and decrease cost and traffic. Finally, we conclude the paper in Section 5.

2. Clustering

Clustering is a form of unsupervised learning, so that places the data with same features in a group and place samples with different characteristics in different categories or clusters. There are several methods for clustering, including Hierarchical clustering, K-means clustering and C-means clustering, and we continue to investigate the k-means clustering algorithm [10]:

2.1 K-means clustering algorithm:

1. The idea of the algorithm is to definition of K points (centers) that determine the number of clusters, so that the center of each cluster is unique. These centers should be chosen carefully because different centers create different results. The best choice is to place centers at the maximum distances from each other.

2. Next, we calculate the distances of all points to all centers and any point or pattern will be assigned to the nearest center. When all the points were allocated to existing centers, the first phase has been completed and a basic grouping is done.

3. After the initial clustering, at this stage we need to determine new centers for clusters. The new center of each cluster is the average of all samples of that cluster. After determining K new centers, again data will be allocated to appropriate (nearest) centers.

4. We repeat these steps until K cluster center are fixed, that means centers are convergent [10,11]. This procedure is shown in algorithm 1:
Initialize $m_i=1,...,k$, for example, to k random $x^i$. Repeat
For all $x^i \in X$

$$b_i^i \leftarrow \begin{cases} 1 & \text{if } \|x^i-m_i\| = \min_j \|x^i-m_j\| \\ 0 & \text{otherwise} \end{cases}$$

For all $m_i=1,...,k$

$$m_i \leftarrow b_i^i x^i / \sum_i b_i^i$$

until $m_i$ converge

Algorithm 1. K-means Clustering.

3. Bayesian decision-making theory:

Bayes' rule is one of the artificial intelligence and machine learning techniques which its framework is based on probability theory and is used to make decision in places or situations where there is no certainty. Since the future may be somewhat similar to the past, therefore, we can predict the future from the past, but this is not entirely true. This is basis of the Bayes' rule, so that on the basis of facts and events occurred in the past it predicts the future. This rule can be expressed mathematically by the equation [10]:

$$p(C \mid x) = \frac{P(C) \cdot P(x \mid C)}{P(x)}$$

4. Proposed model based on intelligent techniques:

What we present in this paper is based on the activities mentioned above. To better understand the proposed structure we the following scenario: suppose we get our hands on fire, sensors that have been placed in our hands, feel a burning sensation are notice an incident. The incident should be reported to the brain, and then by event processing brain concludes the results and make us to have a reaction. It is important to know that the faster reporting of the incident, the sooner our reactions (such as hand pulling on fire, cooling hand in liquids, and etc.) is done. Given the scenario above, we move to the proposed framework. Here we encounter various questions which we can mention them in the following questions:

- What is the best method of ordering sensors in the environment?
- What is the most appropriate method of data collection by sensors?
- What is the best and the most logical method to transfer data collected by sensors to the actuators? Which means which route is the best, most trusted, most reliable, least-cost, least-traffic and most tolerant route for data and information transmission from sensors to actuators? Is this a unique route or not?
- If several events occur in the environment, which event is priority?
- What strategies is there for increasing the reliability and safety and route traffic reduce?

Sensor information from the environment is very important; any information obtained from sensors can help actuators in automatic and optimal decision-making. Some of the goals in routing include: reliability, Quality of Services (QOS), the success rate of sending packets, minimizing delay time and maximizing rate of packets transmission from source to destination. Since our goal is to increasing the reliability and security in wireless sensor-actuator networks, to achieve this goal there must be redundancies in the system. In this part of our work, we present a reliable and secure framework in wireless sensor-actuator network by use of machine learning techniques, while
sensors collect environmental data and report it to actuators in the best way. Actuators for rapid response to environmental events require accurate, fresh and updated data and information, therefore a reliable protocol to communicate actuators and sensors is critical. The proposed model follows the following algorithm. This method consists of 3 steps: Ordering of the sensors in the environment, collecting information by the sensors and reducing invalid data and routing of data by the sensors to actuators.

1. The use of Bayesian theory allows us to predict the future from the events of the past. These predictions allow us to place most of sensors in places and areas where most of events have occurred. This will result in a great extent on the reliability of the system. Figure 1 shows this issue.

![Fig.1. Ordering of the sensors in the environment](image)

2. In a network with a large number of sensors, it is likely many sensors collect environmental data and events simultaneously and similarly, so it is preferred to organize data before delivering to actuators and check it for validation. It is also necessary to enhance reliability of reported data and reduce rout traffic, reduce or remove invalid or duplicate data. When many information receiving sensor nodes try to send their data and information to destination, congestion occurs. In this case, data traffic is higher than network capacity and congestion problems occur in wireless network, meanwhile nodes start to remove packed data or delay in sending them to destination. Remove packets frequently result in energy loss and reduction of reliability.

3. The use of clustering algorithm and the division of the working space to the grid cells is an effective plan to reduce redundant and invalid information. Perhaps sometimes the sensors in grid cell receive invalid and duplicated information, then reduction of invalid and duplicated data can greatly increase efficiency and decrease rout traffic and congestion. Select a smaller grid cells greatly helps to increase accuracy, while larger grid cell results in less loss of information and optimization of network performance, then cell size of the network should be balanced and optimized. Grid cell size is selected with respect to the sensors range. Figure 1 shows an example of cell division (clustering) of environment.

4. After clustering and gridding the sensors in environment, a unique node called decision making node (or cluster head) is selected in each cell of the network that manage related cell or cluster. Figure 2 shows this issue. Several parameters can be effective in cluster head node selection. Since the sensors have limited range battery power and this is one the most important challenges and problem to sensors, to solve this problem we use three factors to select the cluster head in a grid cells (clusters): first, using the equation (2), we calculate the distance between all the sensors in the cluster and consider the sensors that have normal distance to each other in the cluster, then we remove those sensors from head cluster that have too long distance with other sensors in the cluster, Then, using equation (3) calculate the amount of remaining energy of all sensors in each cell, and using equation (4) energy loss of all nodes in a cluster (cell) is calculated. A sensor is selected as cluster head in each cluster which its distance to the rest of the sensors is normal and has maximum battery power and minimum energy loss.
$$distance = ((x_2 - x_1)^2 + (y_2 - y_1)^2)^{\frac{1}{2}}$$  

(2)

$$E_s = \frac{\text{remaining (energy)}}{\text{initial (energy)}}$$  

(3)

$$E_i = \frac{\text{no of packets dropped by node i}}{\text{total no packets received by node i}}$$  

(4)

5. Security in distributed systems can be evaluated in to contexts which are security in data content and security in data transmission. So far, many solutions is presented such as encryption for data and content security. The following proposed strategy largely helps in security for content accuracy and data transmission of sensors.

6. Furthermore, we proposed a multicast protocol in order to improve security for accuracy of the content of the received information. The proposed approach is as follows: cluster head perform many tasks including, collecting and organizing information of grid cell sensors, averaging between these information, validation of sensors and detection of valid sensors from invalid ones. Cluster head or decision making node of cluster broadcast a packed as a "requesting information package" among all the sensors of its cell (as is shown in figure 3). All the sensors in this cell receive this package and provide required information, then send it back to the cluster head of the cell (See figure 4). Required information that should be sent to the cluster head by sensors in that cluster include received Information from environmental events, size of information, angle and location coordinates of their place in environment and the time of information transmission. After collecting all of the information packages of sensors in the cluster, cluster head makes decision among them. First, cluster head compare the sizes of all received information packages and among them which their sizes are not the same from source sensor and in destination sensor, are known as incomplete packages and responding information of those sensors declared invalid. It should be noted that the sensors have a small amount of battery energy can't send the required data to the cluster head, Therefore, these sensors are considered invalid. cluster head collects reliable data of sensors in grid cell and then averaging all these information. Among these sensors those which have a significant difference in reported information compared with average information of the cluster, will be considered as invalid information. Necessarily significant differences between received data by sensor and average data calculated by cluster head don't mean the failure of sensors. The cluster head also should perform the task of comparing the information of each cluster (cell) with adjacent clusters (cells). Note that with analysing time of data transmission at the source and delivers it at destination (cluster head) and by checking the angle and location coordinates of sensors, cluster head estimates the angle and distance of all sensors to cluster head.
7. Now data of all clusters (cells) are gathered in cluster head and there are still many of clusters head. Before transmitting information to actuators, we still want to reduce information so we don't face with traffic of information packages in rout. The proposed solutions are as follows: at this stage, again information of all the clusters head are compared to each other and those with significant differences will be considered as invalid and then are terminated. Among remaining clusters head in network, two clusters head with highest battery power and minimum distance to actuator, are selected and called as reducing traffic node or reporting node. These nodes can help in traffic reduction significantly. Reporting nodes R1 and R2, which are shown in figure 5, are to collect and classify the information of whole grid cells in order to gather this information and transmit them to actuators. Since our goal is to improve reliability, selecting two reporting nodes R1 and R2 makes it possible, in the event of a reporting node failure, the other reporting node transfer gathered information of all sensors to actuators.

8. Now, after the integration of information of all sensors in two reporting nodes, it's time to transfer this information to actuators so they can react as required in order to neutralization of environmental events. Mechanism of reliable transmission in order to reach a high rate of delivery in wireless sensor network is important, because inappropriate environment tends to lose a lot of packed data during data transmission. The main goal of transfer
protocol in a wireless sensor network is to achieve a secure data transfer and controlling the process and congestion with minimum use of energy. The performance transfer protocol in a wireless sensor network is evaluated using criteria such as reliability, congestion and energy efficiency. In this routing we tried not to use invalid sensors or routes that damage information or those which are too far from each other or the responding time of data transfer is too long for them. The proposed method to find secure and reliable rout and to maintain it for data transmission from reporting nodes to actuators is as follow: nodes in this rout should be selected among sensors so that reliability and fault tolerant of network are increased, and rout traffic and loss packed data is decreased. For this purpose, the following protocol has been proposed: two reporting nodes check all of whole sensors in terms of battery power, distance, healthy or fault percentage of node in the past and node angle with respect to actuator and score them. Two sensors with highest score will be selected as next two next nodes. The requested information package is transmitted from reporting nodes to these two selected sensors. This information package as shown in figure 6, in addition to data bits, has another segment in right side that contains information volume. Next, two packed data receiving sensors must confirm data receive by a reply to source sensor. Note that reply package contains another segment called number of received bits in addition to confirmation segment. This is illustrated in figure 7. The node that replies faster and with the volume of information received is equal to the volume of packages sent from the source (request) is considered as main node for transferring data, then the other node is terminated so rout traffic will not increase. Now, the previous procedure is repeated with the exception that the node which receives information of reporting node should check whole nodes in 4 terms (battery power, distance, healthy or fault percentage of node in the past and node angle with respect to actuator) and select two of best nodes for transferring data to actuator. It should be mentioned that at each data transfer, two nodes with highest score of these four parameters are selected as next rout nodes, because in the case of one node failure, another node is to transfer data, so rout reliability and fault tolerance of system are increased. Also each node examined by reply-request method, among these two selected nodes, the node with faster confirmation (in terms of content and volume) is chosen as main node in routing of packages. This procedure continues until data packages are delivered to actuators. Figure 8 shows some examples of routing and data transmission from reporting nodes to actuators.

<table>
<thead>
<tr>
<th>Node’s data</th>
<th>volume of Data (Information)</th>
</tr>
</thead>
</table>

Fig. 6. The data packet from the reporting node to chosen sensors (Request).

<table>
<thead>
<tr>
<th>Consirm information</th>
<th>The number of received bits</th>
</tr>
</thead>
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Fig. 7. Reply from destination sensor to origin (source) sensor.

Fig. 8. Routing and data transmission from reporting nodes to actuators.
9. Choose a few (at least 2) actuators in environment lead to increase in work reliability, because in the event of failure of one of the actuator, other actuators response to reported event. Note that the arrangement of actuators in environment is based on the past events and forecasts. The gridded environment and actuators are placed on locations with respect to number of events in the past and based on forecasts some actuators are arranged in environment with a high probability of event occurrence.

10. In the case of multiple different events we use priority queue and events with higher priority are addressing first. Events with the same priority are reported randomly.

5. Conclusion and recommendations:

Wireless sensor networks are one of the types of distributed systems in recent years has been of interest to many researchers and have been used in many places, such as the military areas, banks, airports and other places, for use in protection systems. Wireless sensor networks consisting of tens, hundreds or even thousands of self directed sensors that are wirelessly at a distance from each other and embedded in the environment, so that are associated with each other and perform the task of finding events and gather information from the environment and transmits the information to a monitoring center. Wireless sensor networks with the introduction of powerful or even mobile actuators have improved their existing wireless sensor networks. An actuator interacts with the environment according to information received from the sensors and processing information. In order to have reliable operation for the actuator, it looks critical to design a reliable, secure, and fault tolerance report for sensors to alert actuator of peripheral events. In this paper, we use machine learning techniques such as clustering and Bayesian rules to represent a reliable, fault tolerance and secure framework to report on events in the wireless sensor-actuator networks, which are enable to optimal collect data received from the environment and report it to the actuators. Performing other intelligent algorithms such as particle swarm optimization (PSO) algorithm, ant colony optimization (ACO) algorithm, meta-search algorithm, fuzzy theory and etc. is recommended for further researches.

References


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