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Procedia Computer Science 176 (2020) 2414–2422

Procedia
Computer Science

www.elsevier.com/locate/procedia

24th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems

A Framework of Optimizing the Deployment of IoT for Precision Agriculture Industry

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Abstract

The massive growth of wireless communications in recent years is mostly due to new connectivity demands and advances in technology development of low power) transceivers. An example of the unique demands is the increasing exchange of data in Internet services, which has led to wireless network deployment for data transmissions. The coordination of the IoT devices, smart systems, and agriculture can contribute directly to the development of the farmer's practices by building their farm more intelligent and digital. However, enhancing farming practices requires inspecting farm equipment and farmer's experiences, which can be analyzed through the interconnectedness of IoT objects to collect farm data over the Internet to launch smart digital agriculture. It is challenging to control all farming processes (especially in real-time), this remaining as the main limitation of traditional farming. In this work, we focus on how wireless sensors can play a vital role in smart farm systems and allow processing the large amount of data generated in batches or real-time to analyze it, retrieve insights from it, and create a Smart Digital Farm. This paper proposes hierarchical-logic mapping and deployment algorithms to tackle the problem of poor network connectivity and sensing coverage in random IoT deployment.

Keywords: IoT, Wireless Sensor Networks, Agriculture Industry, Efficient deployment, Optimization

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10.1016/j.procs.2020.09.312

1. Introduction

An IoT (or wireless sensor networks WSN) consists of a set of embedded processing units, called sensors, communicating via wireless links. Its primary function is the collection of parameters related to the surrounding environment, such as temperature, pressure, or the presence/motion of objects.

They generally comprise a large number of sensors that communicate via radio links for information sharing and cooperative processing. In this type of system, the sensors exchange information on the environment to build a global view of the controlled region, which is made accessible to the external user by one or more nodes. The data collected by these sensors is routed directly or via a multi-hop path formed by other sensors to a collection point, called base station (or SINK). The latter can be connected to a powerful machine via the Internet or satellite [1]-[2].

The number of connected devices is growing at a seemingly exponential pace -- and even modest estimates point to tens of billions of connected devices within the next two years [3].

The applications for wireless sensor networks are numerous, and as the technology evolves, these applications will multiply. In [4]-[5], wireless sensor networks are used to monitor underground mines to guarantee the safety of mineworkers.

There is also considerable interest in the production of IoT devices in rural areas. For example, in a smart agriculture scenario. Energy harvesting IoT devices would provide the means through mesh M2M networks for highly fault-tolerant, unattended long-term solutions that require only minimal human intervention.

IoT may aid farmers in gathering information about soil moisture, temperature, received sunshine, and other related parameters. Vineyards are one of the first targeted markets for these kinds of applications. Environmental sensing may be achieved with ultra-low-power WSNs providing information about atmosphere contaminants, noise pollution, and so on [6].

In this new age of agriculture changed our frame of thinking. Instead of engineering the food we eat, we're engineering the environment it grows in. The third agricultural revolution, also called the "Green Revolution" (the 1970s and 1980's) marked the introduction of genetic engineering of crops and genetically modified organisms (GMO's). Yet again, the yield was increased [7].

The technology tools using artificial intelligence will improve farmers' competitiveness and working conditions; They are already calculating crop yield forecasts for farmers. Robots could assist them in milking or automated weeding: connected farm equipment, so-called intelligent IoT sensors. Tractor guidance by GPS (no driver required), drones, robots, chips, access to databases are also considered [8].

The forces of digital will be enjoyed right across entire food networks. This includes: (1) IoT-enabled on-farm machinery that delivers inputs efficiently, (2) SMART farm management that tracks production in real-time, and (3) Artificial Intelligence that calculates optimal harvest times and informs intermediaries of yield, data will provide revolutionary insights on how best to manage food production.

The most promising opportunity for agriculture to face challenges like climate change yields production, water sustainability, managing the water system smartly [9]-[11]. Is to work towards improving the farming process, by integrating smart systems and IoT devices to gather and process the informative farm data in an effective manner [12]. Smart farming based on Internet of Things (IoT) technologies enables crop farmers to collect real-time data related to irrigation and plant protection processes, aiming to increase production volume [13]-[15].

The smart system should consist of a few stages comprising:

1- Data generation: from harvesting equipment, weather, water system machines, etc.

2- Data collection: IoT devices and especially sensors, which can collect in real-time or small batches the data generated (temperature, equipment vibration, equipment tension, amount of water on the land, etc.).

3- Aggregation: of data collected in a target database;

4- Filtration: of data stored. In this phase algorithms can be launched to clean and accurate the data;

5- Classification: of data based on its field of use;

6- Computing: in this phase calculations will be done (e.g., amount of water to pump) on the classified data;

7- Decision-making: form the predictions made and visualize the data in the form of reports or dashboards.

The farm data can be collected in different ways: through human interaction on smartphone tools or paper, captured by phone application (e.g., SMS, voice-based use, USSD, etc.); or automatic capture based on technologies like drones for mapping and analyzing fields & Internet of things and sensors [16].

In this paper, we thoroughly investigated the challenges associated with the general deployment problem of IoT that are not readily addressed in numerous well-defined solutions for IoT.

This paper is organized as follows: Section 2 briefs on the importance of IoT and wireless sensors. Section 3 briefs on how Sensors can be applicable in Smart Farming. Section 4 describes the IoT deployment in underground soil. Simulation is given in Section 5. Finally, the paper will be concluded in Section 6.

2. IoT and Wireless Sensors

Wireless sensor networks that employ ad hoc networking have become an area of intense research activity. This is due to the availability of inexpensive sensors for sensing and control and technical advances in sensors, wireless communications and networking, and signal processing.

Smart Agriculture should also take advantage of new technologies, especially IoT and wireless sensors which meets extensive application to increase agricultural productivity. Nowadays, the Internet of Things is a surface paradigm, where the Internet and things merge. We can say that today's accessible enabling technology is the Internet of Things [17].

We can define the word "things" in numerous ways since the meaning changes with time, and those "things" progress with internet connectivity, and they are getting smarter and more intelligent. It was expected that in 2020 there would be around 24 billion devices [18]-[19]. Countless "things" are devised to meet agriculture requirements. These things support the wireless network (or Wi-Fi, WSN, 3G, Wi-Max, 4G-LTE, ZigBee).

Sensor devices are a noteworthy example of IoT, especially in the agriculture field, from which we can cite wearable sensing devices, actuators, smart sensors, etc. That can be served from an intelligent farming perspective. These sensors can generate a massive amount of farm data from which we can get precious and critical information, on which analysis, forecasting, and intervention (for maintenance perspective) can be based [20]-[21].

One critical goal of a sensor network is to forward the sensed data to a sink node. Routing the message created by a sensor node to a sink node may have multiple paths due to the large scale of a sensor network. Therefore, data routing is a fundamental issue in wireless sensor networking. Flooding and gossiping are two conventional routing protocols.

The sensor data are collected, aggregated, filtered, and classified, can be applied in machine learning algorithms to predict (e.g., whether a machine will fall or not), detect (e.g., anomalies, water leaks, etc.) and analysis perspective.

Heterogeneous objects from diverse parts in the smart farm will be connected through IoT technologies, from which we can cite communication protocols:

- Bluetooth;
- Z-wave;
- LTE-Advanced;
- IEEE 802.15.4.

The primary purpose of the IEEE Std 802.15.4 is to provide ultra-low complexity, ultra low cost, ultra-low power consumption, and low data rate wireless connectivity among inexpensive devices, with maximum and minimum raw data rates of 250 Kbps and 20 Kbps respectively. A more detailed description of this standard and its implementation in Zigbee are presented in the Zigbee Basics section of this chapter. Note that IEEE Std 802.15.4 does not standardize the higher communication protocol layers, including the Network (NWK) and Application (APP) layers. The Zigbee alliance provides the standard for these layers.

The only challenge is to set up a communication protocol standard for all heterogeneous smart farm objects. Special hardware platforms can be implemented on Cloud Platforms, allowing smart farm objects to send data, which is processed in real-time to the cloud for storage and extract valuable information from the massive farm data [8]-[16].

Many design issues about sensor nodes and WSNs have been studied, including energy-efficient hardware design, data aggregation, topology control, routing protocols, and media access control (MAC) protocols, etc. One fundamental issue is how sensors are deployed in a WSN [22].

3. Smart Farming

The increasing population has contributed directly to the growth of Agriculture [9]. The critical challenge for agriculture is improving farm productivity and farming quality without constant manual monitoring to meet the fast-growing demand for food. Climate change is also a challenging criterion in agriculture [7].

As a matter of fact, it is necessary to enhance agricultural productivity to ensure farm profitability and high yield. It is predicted that in the year 2050, food production will have to increase by 70 percent so that it can meet the estimated world population above 9 billion people.

The most remarkable challenge in quality farming is weather's unpredictability (e.g., unpredictable rainfall and temperature, etc.) and the conditions of the environment (e.g., soil moisture) from which we can cite [6]:

- Humidity: It can be considered as one of the leading environmental parameters in farming because it can affect the turgor pressure of the plants, which can indicate the amount of water in plant cells. When the amount of The low is the humidity in the air, the quick transpiration occurs in plants.
- Transpiration: The higher its rate, the rapidly plants wilt, because much water has been taken off from plant cells.
- Moisture: when its amount in air is high, the transpiration reduces.
- Temperature: When it's hot with a high humidity level, the rate of transpiration will reduce, limiting the water evaporation.

Traditional agriculture, which is based only on farmers' experience, showed incapable of handling the rapidly growing agricultural requirements. Also, modern agriculture, which still relays mostly on manual human intervention, shows many limitations, especially when it comes to real-time maintenance, where a timely right interposition can save a lot of money, and timely wrong response can be costly. The continuous manual efforts proved impractical and not always possible, especially when it comes to monitoring the environmental conditions.

IoT provides services for connecting wireless sensors and multiple devices to the network. Thus, each smart farm object (e.g., temperature sensor, tension sensor) is a resource on the system. The agriculture fields nowadays can take advantage of network technologies. They are combined with the techniques of sensing to provide continuous and remote access to various smart-farm sensors-data that supports web application, which will help the agriculture sector providing a safe, healthy, and sustainable living. Also, wireless sensors are less costly for agricultural practices, easily programmable, can be based on open source sensor-based applications. The back-end data for smart farming analytics and predictive farming maintenance can be stored in the cloud environment and flexibility in providing farmers with applications to maintain their farming process through mobile phones and laptops.

Wireless sensors are now essential for smart farming to improve agricultural practices. Sensors now can intervene in almost all agricultural fields. An exciting and valuable analysis can be done based on data generated from these sensors, to adjust the farming practices and enhance farm security and stability.

Let's take an example of a farm with an extreme cold zone, extreme hot zone with crop extraction equipment. IoT is intervening to maintain the sustainability of the crop extraction system. Thermal, temperature, and vibration sensors and robots are set up next to the farm equipment center. The table below shows how sensors and IoT can guarantee the maintenance of the system.

Table 1. Table captions should be placed above the tables.

Sensor	Utility	Perspective
Thermal sensor	To sense an object in equipment center	Sensing anomalies
Temperature sensor	Returns measurements about temperature of the equipment	Having a visibility on machine's temperature
Vibration Sensor	Returns measurements about vibration of the equipment	Having a visibility on machine's vibration
Robot	To start or turn-off a machine	The generated sensors data will be collected and sent to a controller, then it will be aggregated, filtered and classified in order to apply analytics on it and instruct the robot to take action based on the result.

4. Deployment of IoT Network in Underground Soil

Deployment schemes are classified as either random deployment or deterministic deployment. Deterministic implementation specifies the exact positions of all nodes one by one.

To solve a deterministic deployment problem, however, we should rely on the centralized solution, which requires global information. The necessity of comprehensive information incurs much communication and latency.

Most applications for WSNs require optimal placement of the sensors in the environment beforehand. Indeed, these WSN applications require the installation of the IoT embedded devices, which allows optimal coverage of the area to be monitored. It can be predetermined when the environment is sufficiently known, in which case the sensors can be strategically hand placed.

Several techniques for the optimal placement of sensors have been proposed in the literature [23]-[27]. However, these are for some scalar and general nodes (i.e., sensors with omnidirectional transmission capabilities) and homogeneous sensors. Furthermore, the sensor networks are intrinsically heterogeneous and directional, which makes them utterly different from scalar sensors. These two characteristics (heterogeneity and directional transmission) make the placement problem more complicated than we had with scalar sensors.

Optimal placement techniques previously proposed in the literature may not be accurate. A specific scheme for the optimized placement of directional sensors according to their capacities is consequently necessary. This should allow the placing of the communicating sensors to cover a targeted area optimally.

4.1. *Coverage of WSN:* Generally, coverage can be considered to measure the quality of service of a sensor network (Fig 1). After the deployment of a WSN, sensors are expected to monitor a given area. The data reported by the sensors need to represent the whole area.

4.2. Minimizing the number of sensors needed: Statistically, we know that more sensors will lead to a better network sensing coverage given a random distribution of sensor nodes. Since there is always a cost associated with any sensor node, we cannot afford to deploy an arbitrarily large number of sensors. Minimizing the number of sensors needed for a particular application is also an essential issue in sensor networking.

4.3. Lifetime of WSN: Wireless sensor networks (WSN) operate under limited radio coverage and attempt to conserve bandwidth and battery power [27]. Network lifetime is also an essential issue in the design of a WSN. There are many different definitions of the network lifetime and have been surveyed in [28]. Some define the network lifetime as the failure time of the first sensor.

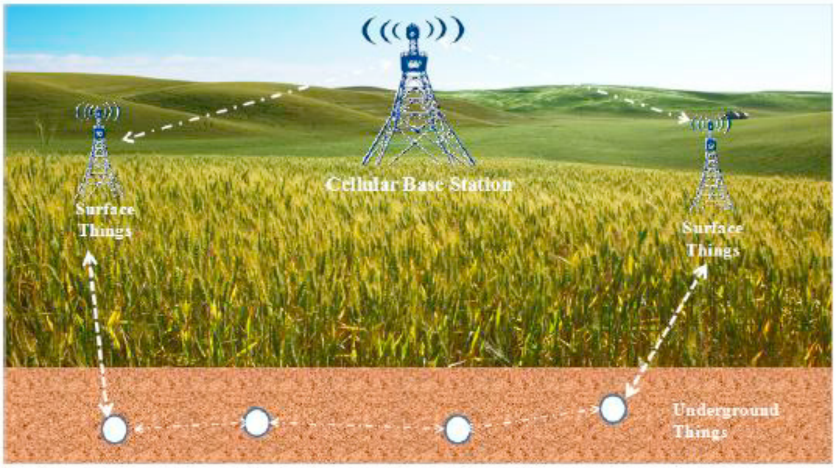

Fig. 1. Illustration of an IoT deployment in underground soil for smart farming application.

4.4. Underground Wireless Channel.

The underground communication and networking are primarily affected by the wireless channel capabilities, advanced models and techniques are necessary to characterize the underground wireless channel and lay out the foundations for efficient communication through soil have been proposed [29] – [33]. The unique characteristics of signal propagation in soil require the derivation of the path loss considering soil properties.

In addition to network parameters, such as node distance and operating frequency, an essential difference in underground communication is soil properties' direct influence. Since the dielectric properties of soil change significantly based on soil composition, communication is severely affected. Figure 2 shows the path loss when the sensors are buried in underground soil. The figure shows the relationship between path loss and various parameters, such as operating frequency and internode distance.

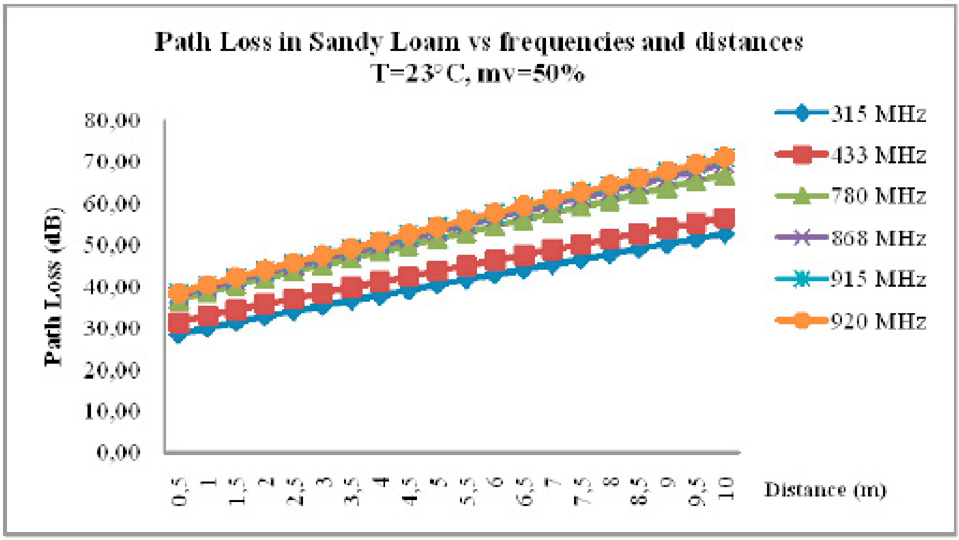

Fig. 2. Path loss versus operating frequency and internode distance.

5. Simulation

The deployment problem can be described as: Given N wireless sensors and a rural or agricultural area A to be covered. How to deploy these sensors to form a WSN that satisfies the requirements of the system, such as the network is connected, the network can sense a relevant event that happens in the area A and the network can function within a required period, etc. This problem is related to the coverage, connectivity, and life issues in a WSN.

A Poisson point process usually models randomly deployed sensor nodes with density λ. Given the number of nodes to be m, the node locations are mutually independent random variables with uniformly distributed over the area (Fig 3).

In many practical scenarios, the placement of sensors is controllable so that the node density can be modified as per variation in energy consumption. In this way, the network lifetime can be increased. For example, in a small WSN, the nodes may be placed arbitrarily. As for a large scale, WSN is concerned, it is possible to deploy more sensors in those areas where energy consumption is much larger, e.g., by merely dropping more sensors on those selected areas. Thus, it is necessary to correlate sensor density with energy consumption. The node density should correspond to the distance of sensors from the sink. Several known algorithms will be compared.

- Greedy Algorithm: is an intuitive algorithm that selects the locally optimum choice in each iterative decision step to finding the globally optimum solution.
- Greedy Heuristic Algorithm: We now detail the design of our Greedy Heuristic algorithm, where we can garner locally optimal candidate locations and expand on this approach to improve our enhanced secondary solution. The greedy heuristic algorithm's objective is to achieve complete area coverage of the regions A by determining the

candidate locations.

We assume the maximum transmitted radio range between two adjacent nodes is 5 meter—this typical value for underground IoT networks. In particular, at the operating frequency of 300–400 MHz, the communication can only be extended up to 5 m [30]. This suggests that multi-hop communication is essential in WUSNs. Consequently, in the design of WUSNs topology, multi-hop communication should be emphasized. The covered area is assumed to be square with different lengths. We assume that all nodes are located at the same depth under the ground.

Depicted in Figure 4 are the results of our evaluation, analyzing the impact of the region of interest (RoI). The greedy heuristic algorithm outperformed the random algorithm for each size of the region (in requiring a smaller number of sensors to cover the area), and the needed greedy heuristic fewer sensors compared to the baseline (random) and greedy approach.

6. Conclusion

Internet of Things can be applied in various other fields of Intelligent Agriculture, like monitoring soil humidity and temperature, water management, etc. The sensors are ready to capture the farm's data so that it can be processed. Its values will be transmitted to gather insights from it (e.g., getting high precision of crop control) and performing actions without any human intervention.

We can now assume that the Internet of things can be considered as a Smart Farming method to deal with different situations in the farming process. This work was aimed to represent the importance of upgrading our farming practices into smart ones, and also demonstrating the importance of IoT and sensors to do so; the research will continue to put the proposition into practices and contribute locally into the evolution of the agriculture.

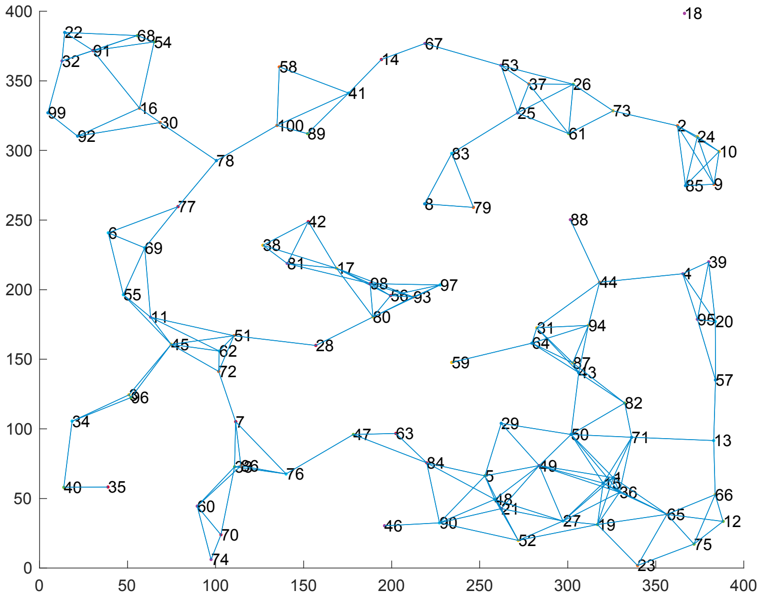

Fig. 3. Random node deployment in the square area (agricultural field).

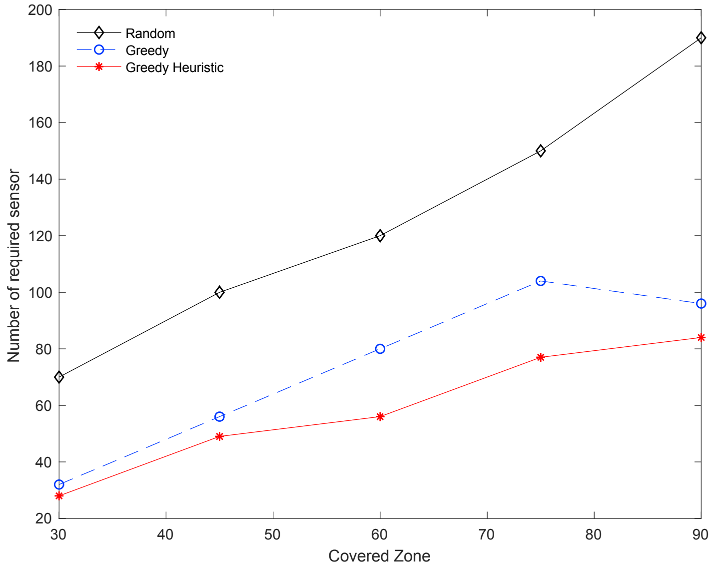

Fig. 4. Optimal node deployment in the square area (agricultural field).

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