A Real-Time Groundwater Level Monitoring System Based on WSN, Taiz, Yemen

نظام مراقبة مستوى المياه الجوفية في الوقت الحقيقي على أساس (الشبكة اللاسلكية للاستشعار عن بعد WSN) تعز ، اليمن

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Abstract. Rise in the population, climate instability, and unregulated groundwater mining threaten the preservation of aquifers worldwide. Effective and data-driven control of groundwater supply is essential for sustaining critical water-dependent functions. Recently, the water crisis in Yemen has become a problem threatening the lives of many residents. This is due to the manager's lack of cost-effective, scalable, and reliable groundwater monitoring systems needed to gather vital groundwater data. In this study, we developed a fully automated real-time groundwater level system for data collection and visualization based on wireless sensor network (WSN). The study was applied in Taiz City, Yemen. The steps used to develop the system, including dividing the study area into different zones, and each zone uses a local base-station to collect the data from the sensors deployed in the same zone. All local base-station send the data to the master base station located remotely. The master bases station collects the data and sends it to the web-servers that are used to save and visualize the data permanently. The proposed system was designed and evaluated using the Castalia Omnet++ simulator and the system performance investigated based on network bandwidth (number of packets sent) and the sensors' power consumption. As expected, the results show that using local base station reduces the number of packets sent to the remote master station, this help extending the life of the water level sensors used.

الملخص

يهدد الارتفاع في عدد السكان وعدم الاستقرار المناخي والتعدين غير المنظم للمياه الجوفية الحفاظ على طبقات المياه الجوفية في جميع أنحاء العالم. يعد التحكم الفعال والقائم على البيانات في إمدادات المياه الجوفية ضروريًا للحفاظ على الوظائف الحرجة المعتمدة على المياه. في الآونة الأخيرة ، أصبحت أزمة المياه في اليمن مشكلة تهدد حياة العديد من السكان. ويرجع ذلك إلى افتقار إدارة المياه لأنظمة مراقبة المياه الجوفية الفعالة من حيث التكلفة والقابلة للتطوير والموثوقية اللازمة لجمع بيانات المياه الجوفية الحيوية. في هذه الدراسة ، قمنا بتطوير نظام مؤتمت بالكامل لمستوى المياه الجوفية في الوقت الفعلي لجمع البيانات والتصور بناءً على شبكة الاستشعار اللاسلكية (WSN). تم تطبيق الدراسة في مدينة تعز اليمنية. الخطوات المستخدمة لتطوير النظام ، بما في ذلك تقسيم منطقة الدراسة إلى مناطق مختلفة ، وتستخدم كل منطقة محطة قاعدة محلية لجمع البيانات من أجهزة الاستشعار المنتشرة في نفس المنطقة. ترسل جميع محطات القاعدة المحلية البيانات إلى المحطة الرئيسية الرئيسية الموجودة عن بُعد. تجمع محطة القواعد الرئيسية البيانات وترسلها إلى خوادم الويب المستخدمة لحفظ البيانات وتصورها بشكل دائم. تم تصميم النظام المقترح وتقييمه باستخدام محاكي Omnet Castalia ++ وتم فحص أداء النظام بناءً على عرض النطاق الترددي للشبكة (عدد الحزم المرسلة) واستهلاك طاقة أجهزة الاستشعار. كما هو متوقع ، تظهر النتائج أن استخدام المحطة الأساسية المحلية يقلل من عدد الحزم المرسلة إلى المحطة الرئيسية البعيدة ، وهذا يساعد على إطالة عمر أجهزة استشعار مستوى المياه المستخدمة.

Keywords: Groundwater wells, WSN, water level, Taiz, Castalia Omnet++.

1 Introduction

Groundwater is the primary source of water for 80% of the population in Yemen, and it is the second source of water after surface water resources [1]. In recent times, the drought problem threatens the economic and agricultural lives of many of the society's residents. In coinciding with the scarcity of rainwater, the dramatic increase in population, and random urbanization, in addition to the complete absence of water management, groundwater consumption has become five times the annual recharge rate [2]. There is a complete absence in how to manage and allocate the use of groundwater, as it is used by 90% in the agricultural aspect. Groundwater management suffers from many difficulties, and the most notable of these is the access of work teams to well sites. Since they use traditional methods to collect data manually, the accuracy of measuring groundwater levels is inaccurate. Therefore, monitoring systems lose their functions and do not perform well. In addition to that, the expansion of drilling wells and the use of large depths reduce the quality of the groundwater and increase the cost required for pumping [3]. Using an automatic monitoring system for groundwater fields is the most important effective solution [4]; this was the motivation for designing a wireless remote sensing system to monitor these fields. It provides full knowledge of decision-making systems for making future strategic decisions and plans, such as laying pipes for drought-affected areas and the development of policies that organize groundwater management operations and reduces these crises [5].

Recently, Wireless sensor networks are widely used in all aspects of environmental monitoring applications, and environmental conditions variation as pressure, weather condition, temperature [6]. WSNs support the lowest duty cycle monitoring application [7] [8]. WSN consist of connected small electronic devices (sensors) uses to collect precision and real-time data at a different location [9]. The environment of water is considered as a factor that effects on the WSN to monitor and get the efficient points [10]. 6LoWPAN (IPV6-based low-power personal Area Network) is low-cost, reduced energy consumption defined by Internet Engineering Task Force (IETF) to enhance the WSN by adding TCP/IP implementation [11]. 6LoWPAN allows many wireless networks to connect with each other via the internet and offer IP communication by implementing a new layer. This layer is adaptation layer which implemented by routers at the edge of 6LoWPAN regions to represent the physical and MAC layer of this protocol to make compatibility the ipv6 packet with IEEE802.15.4 link [12][13].

This paper aims to design a real-time groundwater monitoring framework to help manage and reduce the loss of groundwater. The proposed framework uses a web site to visualize the collected.

The rest of the paper is organized as follows: Section 2 selective review of most recent papers are presented. Section 3 describes the proposed framework and the study area used in this study. Section 4 presents the results and discussions. Finally, section 5 concludes the work.

2 Literature Work

The development of groundwater monitoring systems took the interest of many researchers and conducted many studies. In [14], the system has been proposed to manage the changes in the water resources over time and offer long term groundwater level data. They used a data logger as a component to measure the water level and stored recorded data in the database. The system uses GIS to manage the data of water level and visualize the information to the user to understand the relation between borehole's location and topographic. J. Wang et al. [15] proposed a water monitoring system based on WSN with ZigBee protocol. ZigBee node uses GPRS/CDMA techniques to forward data to the base station. A set of fixed sensors were deployed in the study area to monitor a different kind of water parameters. In [16] they developed a system that depends on the context of electrical conductivity of water to measure the water level using water level sensor and Microcontroller, water level indicator. The water level was implemented on the tank to determine the state of the tank (i.e., empty or full) to control the pump operation. The main finding of this study is to investigate the idea of water management.
Another study in [17] implemented the cluster structure of wireless sensor networks in the department of the kingdom of Saudi Arabia to monitor the water quality of water resources. A vast number of sensors were deployed to collect the data, and the controller used to forward the data to the central unit. Real-time wireless monitoring and control of the water system using ZigBee 802.15.4 in [18] designed to monitor flood areas, reservoirs, rivers, and automated the operation of the pump. They use PH sensors, oxygen dissolved sensors to monitor water quality—the data sent from e node to the coordinator by the router through wireless technology. Many emerging technologies are used in this study such as: ZigBee, GSM and 74HC14 Hex Inverting Schmitt Trigger. In which the Schmitt used to reduce the cost of the system. GSM technology has been used to send data to user's phones from the flood area. This system implemented a testbed on water tanks. The proposed structure designed to automated the well's operation and monitor essential parameters of water quality, water level and EC by using WSN based on IEEE 802.15.4. It uses wireless sensors deployed at twenty-four wells of the agricultural area of Karbala, Iraq. The data movement in the network is controlled by the PAN coordinator. The operation of the pump is automatically controlled by the PAN coordinator decision. Collected data will be relayed to the main base station wirelessly. However, this system does not offer remote control [19]. Real-time groundwater level observation (GWO) application depends on WSN, programing language(R language), and an open-source framework in the South American Sub-basin of California. They found pressure transducers sensor is more suitable for giving groundwater level time series data than manual water level meter measurement [20].

3 The Proposed Groundwater Framework

3.1 Case Study

This study was applied based on the Aldhabab field that represents the most important area on the eastern side of the city of Taiz, Yemen. It represents the main water field to cover the drinking water needs of the city's residents. The water utility in this city showed that the number of water points in this field is 300 points, where the hand wells constitute the largest percentage. This is due to the random drilling works of wells, especially since the field is within a water stone area, and the number of artesian wells reached 26 wells. Fig. 1 show the distribution of Wells in the study area.

3.2 Methodology

The main structure of the proposed system is shown in Fig. 2 it encompasses four main parts: study area, base stations (BS), web server, and end-users. The study area is divided into four different zones, and each zone uses a local base-station to collect the data from the sensors deployed in the same zone. All local base-station send the data to the master base station located remotely.

Fig.1. Distribution of well In Aldhabab (The case study map)

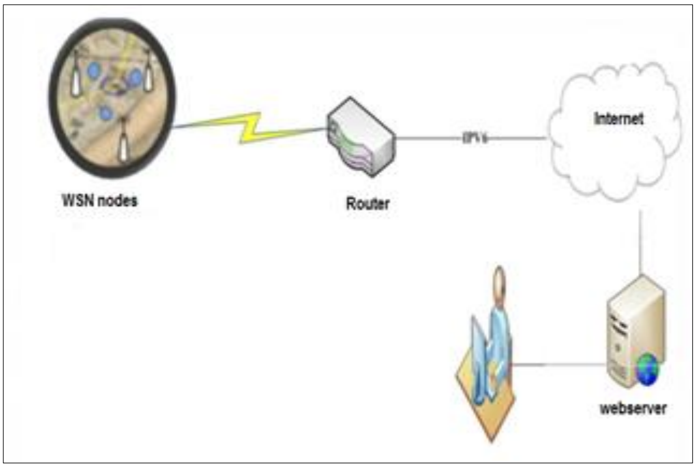

Fig.2. Groundwater Network Architecture

The master bases station collects the data and sends it to the web-servers that are used to save and visualize the data permanently. The data saved on the web-server based on a web-model developed to help reduce the traffic (see Fig.3). This model passes through three stages: safe, updating, and visualization, more details of these stages as follow:

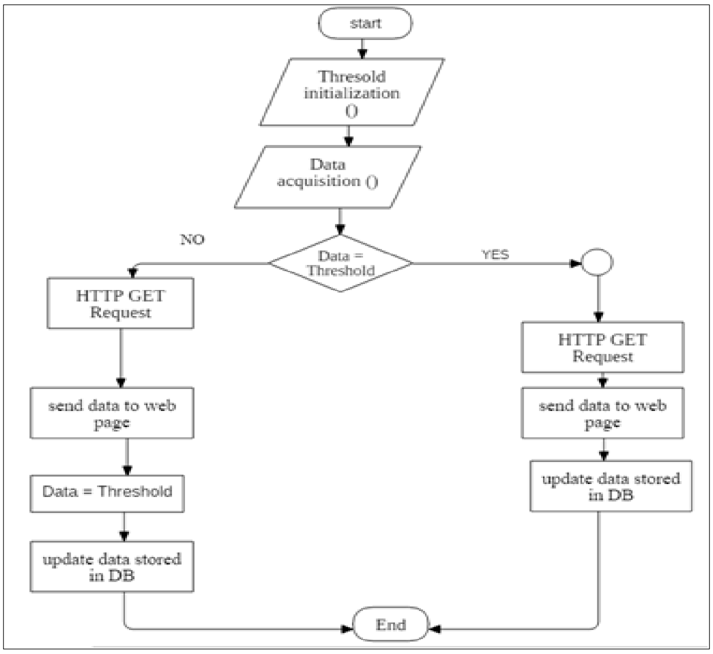

Fig. 3. Flow chart of updating DB

Data safe

All data were collected from the study area, which considered well's data are stored in the SQL Database to be safe for a long time and visualize using web-application.

Data updating

Because we are continuously collecting data in real-time, we need to keep the data updated in the databases. Fig. 3. shows the algorithm used to update the data in the database. The updating process depends on the threshold value, which is the initial data collected from the field. The backup of data was considered to avoid indirect data loss caused by any unexpected malfunction in the network and the data saved in the SQL database on the cloud.

Data visualization

Once data stored, it visualizes to the end-users by using a web application (website), which is connected directly to the SQL database. Detail information about the well's area and level of groundwater visualize to end-users in real-time. It allows the users to interact with data and manage it in an efficient way anytime from anywhere.

4 Results and Discussions

As mentioned previously, the proposed system was designed and simulated using the Castalia3.3 OMNET++ simulator. Different experiments have been applied; the first experiment is to measure and evaluate the communication between the water level sensors deployed in the study field and the local base stations in each zone. The second experiment is to measure and assess the communication between local base-stations and the master base station that use to collect all packets and forward it to the web-server. The performance matrices used to evaluate the proposed system are the number of packets and the energy consumption of each sensor. Different communication technologies have been used to manage the connection between the sensors and the local base station, and the local and master base stations.

Table 1. Illustrates some parameters used in simulation operation to enhance the performance of nodes behavior.

Table 1. General parameters for simulation

Parameter	**Value**
path loss Exponent	2.4
Signal Delivery Threshold	-100
Frequency	2.4 GHz
MAC Protocol	CSMA 802.15.4
Modulation type	OQ-PSK
Sensitivity[dBm]	-105
Pwr Consumption Per Device (mW)	0.02
Analog model type	Simple path loss

Fig. 4 indicates the main structure of the proposed system that shows the communication method of communication in different layers. The first layer, the communications between the sensors and the local base-stations, uses the Zigbee that allows for the packets to be transmitted for a few meters. The second layer, the communication between local and master local base-stations, and for this long-distance communication technology such as Lora or 3G used to transfer the packets. The third layer, the communication between the master base-station and the web-servers, the 6LOWPAN communication technology used for this part.

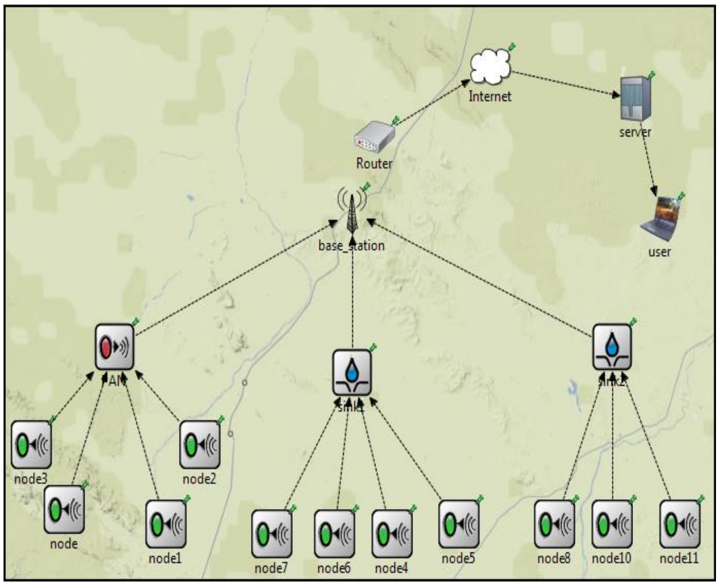

Fig.4. present a snapshot to the structure of framework designed.

Fig. 5 shows the number of packets sent from the water level sensors to the local base-station. This shows a large number of packets sent from each individual node. From Fig. 5 we can notice that number of packets sent by the nodes are almost normally distributed, and node number 6 has the high number of a packet sent (342 packets) while node 10 and 18 shows the lowest number of packets (332 packets). Since the sensors use the ZigBee (IEEE802.15.4) IEEE802.15.4 standard and carrier sense multiple access with collision avoidance (CSMA/CA) MAC protocol technology, many problems are considered such as the interference between the nodes in the same transmission range that causes loss a lot of the packets. It is necessary to concentrate on the Back-off of each node. Back-off is defined as the number of times the packets retransmitted when the transmission medium is busy. This leads to consuming a lot of sensors' energy. Fig. 6 shows the number of Back-off for each individual node.

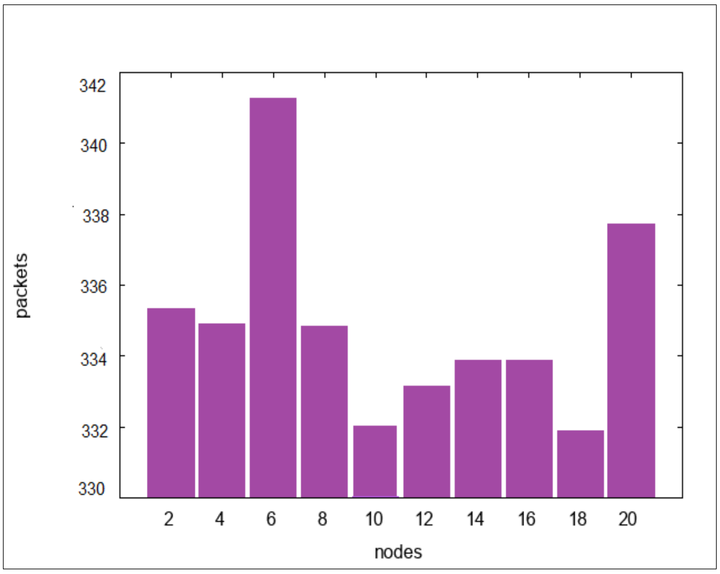

Fig.5. Number of packet sent to local station.

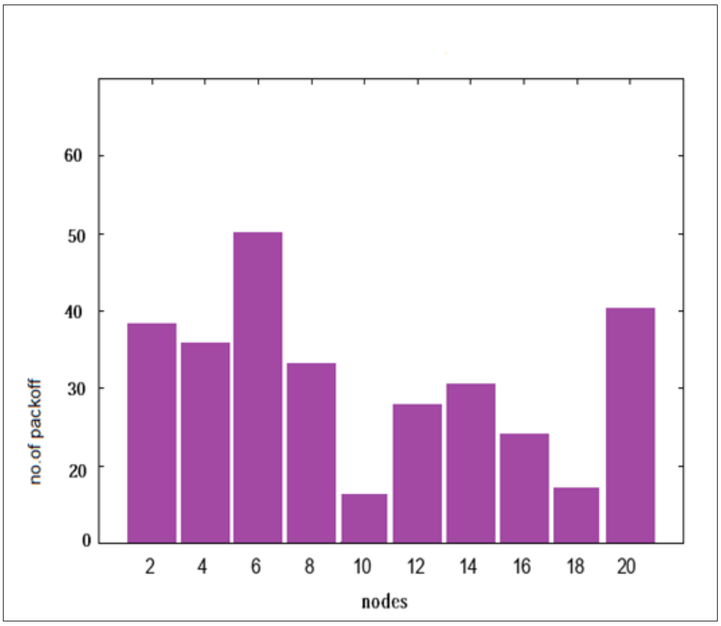

Fig. 6. The number of Back-off for each node.

Fig. 7 shows the interference between the nodes that affect the transmission of the packets. Four different modes used to check the condition of the transmitted packets: received successful, failed non-RX, failed below the threshold, failed with interference. The results show the number of successful packets received without interference is the highest while the number of packets failed with interference is the lowest.

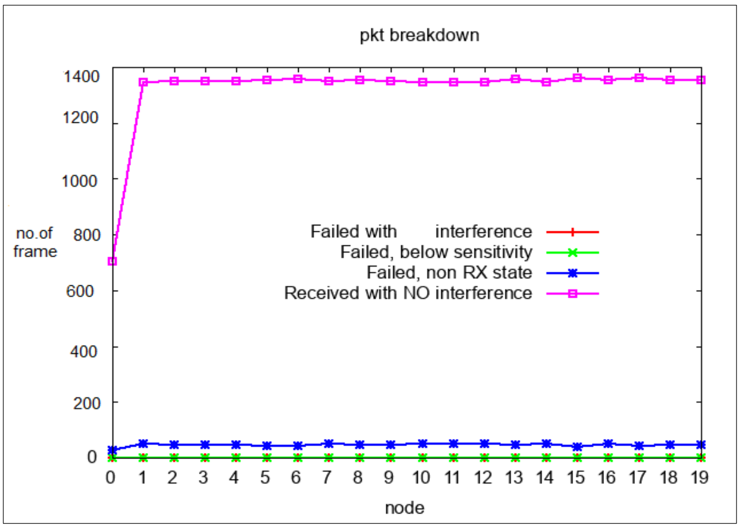

Fig.7. Interference between nodes.

Another performance metric used to evaluate the proposed system is the energy consumption for all sensors. All sensors used the same parameters of transmission range, communication models, and the protocol of accessing the medium. Therefore, the main factor that will affect energy consumption is the number of packets sent by each node. Fig. 8 shows the energy consumption of all nodes, and it is differ based on the number of packets sent. For example, node 6 shows more energy consumption than others; this obviously clear and expected as node 6 sent the largest number of packets. On the other hand, nodes 10, 18 show the low energy consumption; this is because they sent a few packets.

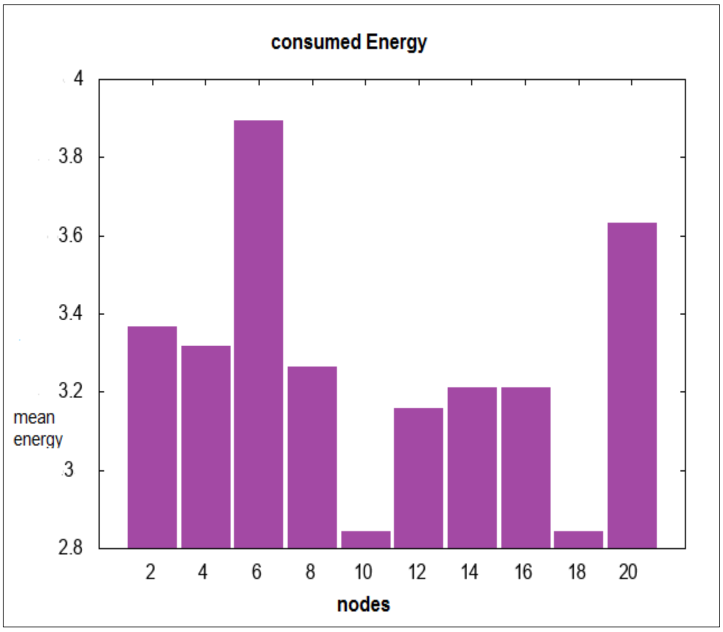

Fig. 8. Energy consumption of all nodes.

The number of packets sent from the local station to the master base station based on different rates of data shown in Fig. 9 To optimize the rate (number of packets sent per second) of the communication channel between the local base station and the master station, different rates were used and evaluated based on the number of packets. The result shows that rate 60 allows optimizing the use of the channel by sending more packets per second.

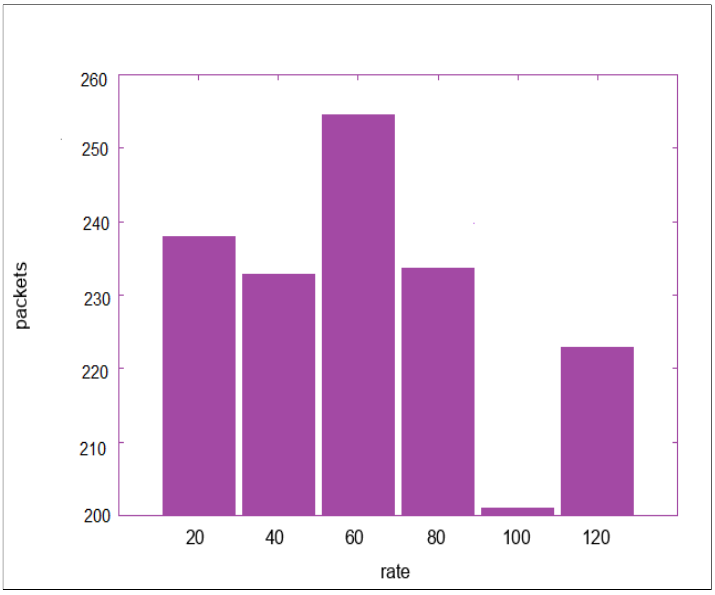

Fig.9. The number of packets sent to the master base station.

The last part, web application (website), is designed to save and visualize the data on the web-server. Fig. 8 shows such an example from the website; in this result, the data collected from the study filed are presented with a full description of the data such as location, date, depth of wells, etc.

Repoting Of State Well

Name of Directorate	Name of Isolation	Wadey	Name Holder	Depth Well	Width Well	Date Insert	State Well	Count the Water of m3	Ratio Presser	Date Reading
Mountains Habashee	Baney Jesus	Althbab	Mohamad	1000	2	2020-04-09	Work	735	44	2020-04-09
Mountains Habashee	Baney Jesus	Althbab	Saeed	1200	1	2020-04-10	Work	351	44	2020-04-09
Mountains Habashee	Baney Jesus	Althbab	Ahmed	800	1	2020-04-28	Work	561	44	2020-04-09
Mountains Habashee	Baney Jesus	Althbab	Mohamad	1000	2	2020-04-09	Work	656	44	2020-04-09
Mountains Habashee	Baney Jesus	Althbab	Saeed	1200	1	2020-04-10	Work	752	44	2020-04-09
Mountains Habashee	Baney Jesus	Althbab	Ahmed	800	1	2020-04-28	Close	960	44	2020-04-09

Fig.10. Report of well's data.

5 Conclusion

In this study, a groundwater level monitoring system is proposed based on a wireless sensor network. The sensors are deployed in the study area to monitor the water level in the individual well. The data collected and send wirelessly to be store and visualize in the cloud. Different performance metrics used to investigate and evaluate the performance of the proposed system, such as the number of packets sent in all zones, and packet breakdown probability, the energy consumption of all sensors. The results show the distribution of the packet sent and the impact of the interference for all communications. Moreover, the energy consumption of all nodes are computed and presented based on the number of packets sent by each node.

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