Wireless Sensor Networks: Architecture, Applications, and Challenges

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Abstract

Wireless Sensor Network (WSN) is a state-of-the-art system that uses electronic sensors to monitor a particular phenomenon. This paper focuses on providing a short review of existing literature on WSN technology. It highlights the existing architectures, applications, challenges and possible solutions.

Keywords
Wireless Sensor Network; IoT; Architecture; Sensors.

1. Introduction

Wireless sensor network is a network of special system comprising of individual sensors that collect information about a given phenomenon without human interference and transmit the collected data wirelessly to a station for processing. It comprises of sensor nodes placed at strategic locations. A node is made up of several physical components which include: sensing unit (sensors), processing unit (microcontroller), communication unit and power unit, depending on the application (Mainwaring, Culler, Polastre, Szewczyk, & Anderson, 2002; Sangare, Xiao, Niyato, & Han, 2017). A State-of-the-art design has seen the application of WSN increase, with Wireless World Research Forum (WWRF) projecting an increase in services of WSN to over seven billion people by the tear 2020. WSNs are utilized in measuring different phenomenon in real-time with the deployment of either moveable or immoveable sensor nodes. Sensor nodes are often times embedded with other devices to provide additional functionalities such as memory storage, GPS and power supply.

In this paper, we provide an overview of the existing trends, applications and challenges of wireless sensor network. The remainder of the paper is organized as follows: In section 2, we present some WSN architecture that has been employed. In section 3, we present some applications of wireless sensor network. In section 4, we provide the challenges facing wireless sensor network and proffer some solutions. The paper is concluded in section 5.

2. Architecture

The flexibility of WSN allows it to be deployed in different ways, although traditional architectures exist. According to Daiya, Ebenezer, Madhusoodanan, SatyaMurty, and Rao (2016), WSN comprises of three architectures which cannot be altered after deployment. A Flat architecture type whereby the whole network sends all their packets to a single sink node. The Hierarchical architecture where the network comprises of various clusters and the packets of each cluster is sent to a cluster head. The third architecture called Hybrid is a combination of the previous two. Daiya et al. (2016) created a system with the ability to switch the roles even after deployment, thereby removing the limitations of the nodes.

Keshavamurthy, Narasimha, Ahmad, and Poornima (2016) perceived a gap in literature of a completely developed sensor network for an industrial environment and came up with an architecture which comprises of a Delta-Sigma analogue to digital converter, a serial peripheral interface bus (SPI) system which serves a controller and an OFDM transceiver. The system employs a controller with SPI interfaces, a subsystem which allows different sensors to be monitored and an OFDM baseband as a transceiver unit.

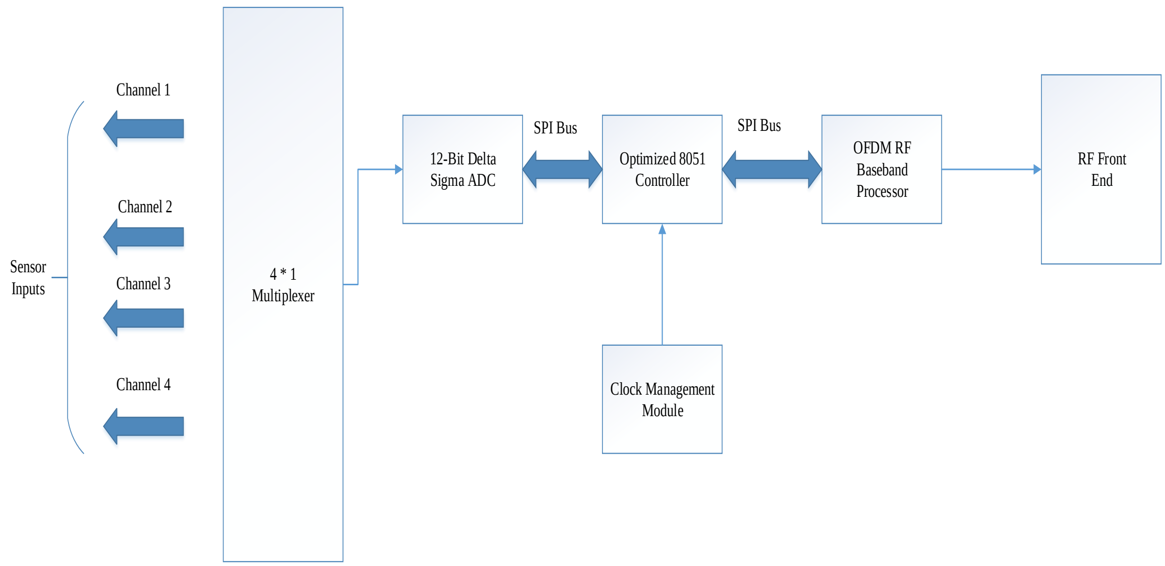

Figure 1. Proposed Architecture (Keshavamurthy et al., 2016)

da Costa and Kleinschmidt (2016) proposed an architecture for WSN as a result of internet protocols for enclosed devices not being convenient for the internet of things. The architecture makes use of standard internet of things protocols such as Constrained Application Protocol (CoAP). The setup comprises of a border gateway, autonomous sensors, and a client. The gateway employs 6LoWPAN and RPL IoT protocols for network addressing and routing respectively. The computer on the client side reverts back to IPv6 address and standard Internet protocols.

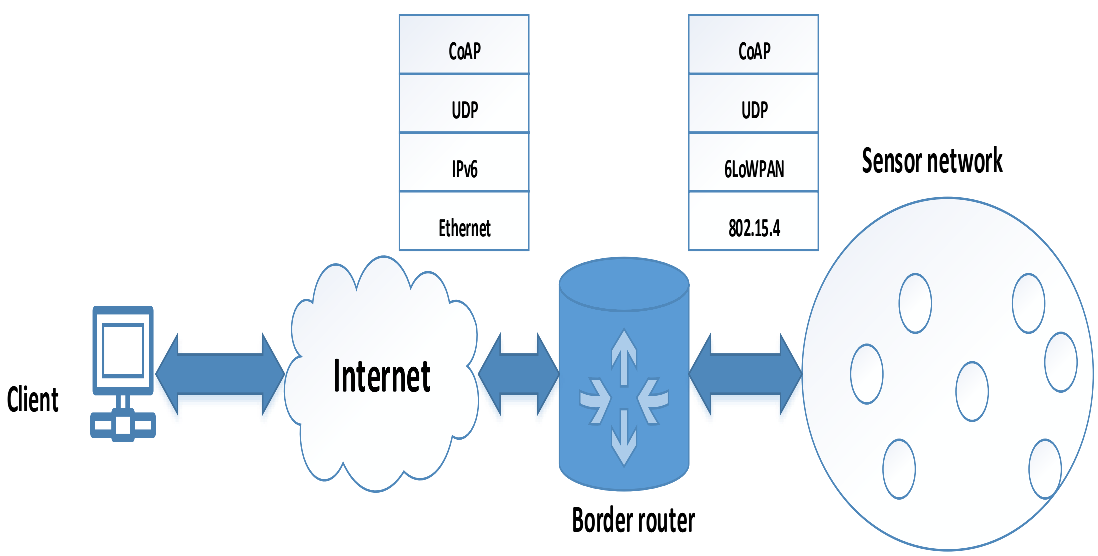

Figure 2. Proposed architecture (da Costa & Kleinschmidt, 2016)

According to Dave (2016), there are three architectural levels in WSN. The first level comprising of cluster nodes and cluster head, second level comprising of actor nodes and lastly the third level, which is the sink node. These levels fit into the traditional flat, cluster and hybrid architecture. This architecture places management functions on all the levels leading to increased overhead. As a result, an extra level was proposed which handles the responsibility of management including security. The effect of the additional level on the network includes: reduced overload on existing levels; reduced storage on network nodes; improved network span and; security.

3. Areas of Applications

3.1. Agriculture

In a survey conducted in 2014-2015, Jannat and Islam (2017) realized that a lot of crops were destroyed either through poor storage facilities or unpredicted weather conditions. It was also seen that crops perished because of waterlogging, irregular water supply and poor farm maintenance. Traditional farming methods have also been upgraded to the 21st-century technology which involves the internet of things (IoT). The IoT is the recent technology that can provide solution to the problems of present-day farming. This can be used to process information regarding soil moisture, humidity, and other environmental conditions. Farmers rely on information about soil properties and environmental conditions to carry out irrigation practices. The introduction of Wireless Sensing Network allows sensors to carry out such analysis effectively in order to have better irrigation and proper utilization of water. Khan, Ali, Suryani, Ahmad, and Zakarya (2013) discussed about an effective irrigation management system for container grown crops. Wireless sensor network is utilized to get information about the soil content and environmental conditions. This data will allow for effective planning of the irrigation practices because of the sensor nodes which are deployed on various part of the farmland. A text message is sent over LAN to the farmer to alert him about water deficient areas on the farmland.

Choi, Chimeddorj, Altankhuyag, and Dunkhorol (2016) developed a WSN for obtaining the location of livestock herd. The system utilizes XBee communication protocol and employs a GPS enabled mobile sink architecture, with sensor nodes sending updates regularly. The GPS keeps track of the herd's location constantly and can be monitored by an end user using Google map API. This resolves the issues associated with open grazing and improves livestock management. The system was designed using an Arduino. In India, the agricultural sector has experienced a downside over the years which reduces the production rates. There is a need to apply new techniques to restore the liveliness of the sector and return it to higher production rates. Awal (2012) explained the need for e-Agricultural applications based on KM- knowledge and monitoring modules. This consists of a data flow model encompassing different information about market prices, current production levels and other useful statistics. A prototype of this module was built using a TI CC3200 Launchpad interconnected sensors modules with other needed electronic devices. An analytic study of both the existing and the new technology was done and the new technique seemed to cover loopholes in the traditional methods. The Introduction of Information and Communication Technology into the agricultural sector has been able to reduce cost and utilizing energy for greater yields.

Inadequate amount of fresh water supply is threatening food production. As a result, irrigation is employed to combat the unavailability of water for crop production. Irrigation is defined as the application of controlled amounts of water to soil at intervals (Gutiérrez, Villa-Medina, Nieto-Garibay, & Porta-Gándara, 2014). Bangare, Patil, Khatib, Kadu, and Mangalgiri (2016) proposed a system for controlled irrigation using wireless sensor network. The objectives are to provide both manual and automatic modes of drip irrigation, thereby conserving water. Drip irrigation involves applying water directly to plant roots. This system employs moisture and temperature sensors, Arduino microcontroller, wireless transceiver and a cloud database. The sensor values are sent to the cloud database in real time, and when a set threshold is reached, the irrigation system is automatically turned on. The design provides an extra feature, providing the user with the ability to turn off and on the irrigation system via an Android device. To optimize water usage, Gutiérrez et al. (2014) designed an automatic irrigation system using wireless sensor network. The system employed moisture, temperature and water level sensors which communicate with the microcontroller via ZigBee communication protocol. The sensor data is processed by a gateway and when particular threshold limits are reached, the system triggers the actuators. A software application which receives information via a GSM module is used to monitor the entire system. Angel and Asha (2015) proposed a system for smart irrigation in agriculture using wireless sensor network. The system employs sensor nodes with sensors such as moisture, temperature, humidity, and pH embedded within the nodes and tries to maximize cost and energy usage. The system also employs an automatic water pump system in which the water tank meant for irrigation is monitored by a water level sensor. If the water level drops below a set limit, a motor is turned on which pumps water from a well. The entire system has an hourly interval, and when the sensor nodes communicate values below a given threshold, the system opens up valves in the pipes for a duration of three seconds. The end user is made aware of the entire process via SMS notifications.

In today’s world, web-based applications are being implemented in all sectors of life for faster and more efficient end results. This application is extended towards automatic irrigation control whereby productivity of farmers is increased. The benefit of the system designed by Raigonda and Valsang (2016) provides the farmer the advantage of not having to be physically present in order to irrigate the farmland, and also the system provides the farmer with important environmental conditions. When a farmland is over-irrigated or under irrigated, the production capacity of the yield is tainted and reduced; sometimes the crops even die out. This virtual sensor module gives the farmer appropriate information about the conditions of the farmland such as humidity, temperature and other parameters needed by the farmer. This module resolves the problem highlighted above. This system proves to be highly cost-effective which is greatly appreciated in today’s world.

In the quest for better irrigation in combination with sensor modules for improved and efficient results, Gutiérrez et al. (2014) devised a sophisticated module of soil moisture and temperature sensors which are transmitted to a web application for better analysis. Threshold values were programmed to an algorithm to determine temperature and moisture content connected to a microcontroller to regulate water quantity. The module is powered by photovoltaic panels and there exist a duplex communication link which runs on a cellular-Internet interface which allows the farmer anal size data for scheduling of irrigation via a web page. This module was put to test over 136 days and it showed to have water savings of up to 90% compared with traditional irrigation methods. Kim, Evans, and Iversen (2008) illustrated a wireless sensor network system for real-time monitoring and control of a flexible irrigation system. The system is comprised of five monitoring stations, a control and a base station. Farm values such as soil moisture and temperature were compiled by the monitoring terminals and communicated to the base station at intervals. The base station bears the responsibility of processing sensor values and feeds them to the control station which in turn activates individual sprinklers via GPS coordinates to apply a controlled amount of water. Kumar and Ravi (2016) developed a wireless sensor network that employs both temperature and moisture sensors at a farm in order to provide automated irrigation system. The design comprises of the monitoring station and a base station. The former is equipped with ARM microcontroller which processes sensor values and transmits them via ZigBee to the base station. The base station is equipped with a ZigBee module, microcontroller and a wireless module. The ZigBee module receives values sent from the monitoring station and the values are uploaded online via the wireless module. Sahu and Behera (2015) developed a wireless sensor network prototype to address issues of irrigation. Moisture sensors and wireless modules are embedded in an Arduino microcontroller and placed at several locations on the farm. Sensor values are processed by the Arduino and transmitted wirelessly to a Raspberry pi microcontroller. The raspberry pi’s function is for internet connectivity which sends periodic updates as emails to the farm owner. The Raspberry Pi also has on-screen feature for monitoring current events locally.

3.2. Environment

Originally, methods employed in collecting temperature and pH values in an industrial plant came with a lot of drawbacks. One of the methods involves stopping the process to manually test a sample inside the operating plant, exposing the operator to severe heat. Another involves attaching temperature sensors to data recorders and analyzing the data when the process is completed. Although more convenient than the previous, it had a drawback of records not compiled in real time. Leone, Murdoch, and Mazzara (2010) developed a model based on IEEE 802.15.4 with TinyOS 2.1 software embedded in the nodes and base station which was capable of adapting the industrial environment to a Wireless sensor network.

At summer time, Quito the capital city of Ecuador is plagued annually by forest fires with extreme temperature aiding in the propagation. Cantuña, Bastidas, Solórzano, and Clairand (2017) addressed the challenge by developing a WSN built with XCTU software which is capable of detecting fire incidents in the forest in real-time and notifying the subscribers. Muheden, Erdem, and Vançin (2016) designed a wireless sensor network with the ability to detect fire incidents using an Arduino microprocessor and a WIFI shield. Flame and gas sensors were vital in monitoring and detecting threshold values. When the given threshold is exceeded, the user is alerted via a trigger which is sent wirelessly. A collection point was established for all data collected which could be accessed remotely by any internet enabled device. The software was set up in Android studio using Java programming language. United States Geological Survey (USGS) defines a landslide as “mass wasting” of the earth which denotes any downslope movement of soil and rock under the direct movement of gravity. It is a common natural occurrence if which left unchecked, poses a great risk to communities. Fosalau, Zet, and Petrisor (2016) developed a wireless sensor network system aimed at monitoring in real time the displacement of soil layers. The sensors which are also capable of predicting the degree of glide are positioned in areas prone to landslide and communicate wirelessly, conveying data to a monitoring and processing hub.

Farm theft is a frequent practice in India. Farm owners find it difficult to maximize their yields either as a result of unauthorized human entries resulting in the theft of farm produce, or unauthorized animal entry leading to consumption or damage of yields. Barricading the entire farmland is quite expensive most likely when the expanse of land is big. Also, unauthorized human entry is still not guaranteed with a barricade. As a result, it is important to properly monitor the borders of the farmland to detect any unauthorized entry. Nagpal and Manojkumar (2016) provided a system which employs wireless sensor network to curb this challenge. To detect movement around the farm borders, poles equipped with motion sensors are placed at specific locations along the farm boundaries. The sensors are placed at a low distance in order to detect both animals and human movements. When movement is detected, a trigger is activated which raises an alarm and also sends a text message to the farm owner. Radio Frequency Identification (RFID) tags are configured in order to prevent the system from raising a false alarm when authorized persons enter the farm. The entire system was designed using Arduino.

Flood has a negative effect on the environment, and in cities where a high number of electrical equipment such as substations are present, it is important to protect them from the impending dangers of flood. Macau in China is plagued by flood occurrences as a result of low-lying regions present in the city. Distribution substations are mostly placed at ground level, making them a major concern against flood events. Zhuang, Junior, Cheong, and Tam (2011) proposed a design using wireless sensor network to combat the challenge. The system employs sensor nodes comprising of flood detection sensors, microcontroller and Xbee communication transceiver. In the event of flooding, the system detects it and sends a warning signal via Public Switched Telephone Network (PSTN). The warning is received by a control station and appropriate measures are devised.

Flash flood is a result of low infiltration rate and heavy rainfall over a short time period. They are upstream floods with very little delay time and as a result, are the most hazardous to human lives. In many countries, flash flood has caused tremendous damage to lives and properties. In the summer of 2012, twelve lives were lost and damages amounting to about a billion dollars from flash flood within the San Antonio River Basin, Texas (Chang & Guo, 2006). Castillo-Effer, Quintela, Moreno, Jordan, and Westhoff (2004) proposed a wireless sensor network system in for Mérida city in the Andes Mountains of Venezuela. He proposed a self-adapting and self-sustaining wireless sensor network which must be void of third-party interference. Islam, Islam, Syrus, and Ahmed (2014) implemented a wireless sensor network in Bangladesh for the control of flash floods as well. The sensor node deployed consists of water level transducers, microcontroller and an Ethernet module for wireless communication. Sensor values are transmitted in real-time wirelessly to a web server for publication. Chang and Guo (2006) illustrated a modern wireless sensor network technology capable of mapping out urban flash flood occurrences. The system comprises of three key modules namely: the flood detection sensors, an embedded camera for video feed and a third module which processes the collected data from the previous modules in real time. The third module which is a server also has the capability to process Digital Elevation Model (DEM).

3.3. Health

As a result of the inadequate application of real-time location system (RTLS) in healthcare, Adame et al. (2018) developed a system called CUIDATS, a hybrid system for smart health monitoring. It employs RFID to track and monitor patients and valuable equipment within the hospital premises. In addition, the vital signs of patients such as temperature and pulse are monitored via the aid of sensors implanted in wristbands. Gateways including RFID readers are stationed at strategic locations in order to compile data for transmission to a general server. CUIDATS which is translated to "cared-for" in Catalan has recorded high success rates in real hospital scenarios.

As a result of closed and inflexible architecture, sensor networks have faced challenges in extending solutions to penetrative healthcare applications. Triantafyllidis, Koutkias, Chouvarda, and Maglaveras (2008) developed a system for health care monitoring which employs flexible and interoperable WSN with extra features focused on scalability. Two sensor nodes having communication and processing abilities were deployed for monitoring heart rate and blood glucose level. A personal digital device (PDA) was employed as a mobile gateway and the entire system was programmed using Java 2 Micro Edition.

In order to promote the integration of WSN into health application, Ashraf, Tarek, and Marwan (2006) developed and implemented a health monitoring system. Sensor nodes capable of monitoring vital signs are placed on patients while medical staffs are equipped with PDA devices or cellular phones which can be accessed both within and outside the hospital premises. An ad hoc server named ASNET bears the responsibility of monitoring patients and health staffs, making it easier in informing the right staff when a patient's bio signal exceeds the threshold. ASNET is capable of identifying periodic and critical updates from patients.

4. Challenges and solutions

Notwithstanding the numerous benefits gained from utilizing WSN, one should be aware of the limitations that arise. Communication is a vital part of WSN, and there lies a major challenge of data security as a result of the nature of their communication medium. Information sent from sensor nodes to data centers needs to be protected. Also, the data stored in data centers can mostly be accessed by anyone over the internet and this creates a great risk.

4.1. Security

The authors in developed a light encryption algorithm with faster encryption rate, thereby reducing the computing time of the network. The design utilizes the benefits of both symmetric and asymmetric cryptography creating a hybrid encryption algorithm. The algorithm keeps in check the aim of cryptography which are confidentiality, authentication and integrity. Sudarsono, Al Rasyid, and Yuliana (2016) suggested anonymous authentication using Verifier-Local Revocation (VLR) group signature. Group signature is a public encryption key with a unique digital signature. The process involves keeping data gotten from verified sensors private without disseminating the identity of the sensors. Also, only verified personnel should be able to access data centers without the risk of exposure of privacy.

4.2. Energy consumption

In WSN technology, energy supply is a scarce resource. Most sensor nodes are equipped with a battery source, hence with limited power, making power conservation a paramount concern. Multiple-Input Multiple-Output (MIMO) technology provides a solution in enhancing energy challenge. Săcăleanu, Perişoară, Şucu, and Stoian (2016) provided a low power WSN by employing the benefits of a virtual MIMO. It involves having multiple antennas at both transmitting and receiving stations. A spatial multiplexing technique was performed to test the advantage in a WSN communication.

4.3. Positioning

Location of sensor nodes, especially in dense situations where several nodes need to be placed at the same time might result in positioning issues as sensors may not have maximum contact on the phenomenon to be observed or measured, thereby negatively affecting computational time and accuracy of the result. Wang, Yan, Xie, and Pang (2016) proposed a novel approach of group positioning. Group partition and received signal strength indicator (RSSI) filter designs were implemented, and test result carried out verified the success of the approach.

5. Conclusion

Wireless sensor network has become a global brand with the aim of efficiently monitoring various physical conditions to improve human existence. Implementations also provide room for scalability as changes and growth are always considered. Architecture continues to change giving room for flexibility which may create new application areas in the future. Researches are ongoing to reduce the challenges involved in adopting WSN.

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References

Adame, T., Bel, A., Carreras, A., Melià-Seguí, J., Oliver, M., & Pous, R. (2018). CUIDATS: An RFID–WSN hybrid monitoring system for smart health care environments. *Future Generation Computer Systems, 78*, 602-615.

Angel, C., & Asha, S. (2015). A study on developing a smart environment in agricultural irrigation technique. *International Journal of Ambient Systems and Applications (IJASA), 3*(2), 3.

Ashraf, S. M., Tarek, R. S., & Marwan, H. A.-A. (2006). *Wireless sensor network implementation for mobile patient.* Paper presented at the GCC Conference (GCC), 2006 IEEE.

Awal, M. (2012). Ghana: Democracy, economic reform, and development, 1993-2008. *Journal of Sustainable Development in Africa, 14*(1), 97-118.

Bangare, P., Patil, R., Khatib, Z., Kadu, I., & Mangalgiri, K. (2016). Automated Drip Irrigation System Using Cloud Computing. *Imperial Journal of Interdisciplinary Research, 2*(6).

Cantuña, J. G., Bastidas, D., Solórzano, S., & Clairand, J.-M. (2017). *Design and implementation of a Wireless Sensor Network to detect forest fires.* Paper presented at the eDemocracy & eGovernment (ICEDEG), 2017 Fourth International Conference on.

Castillo-Effer, M., Quintela, D. H., Moreno, W., Jordan, R., & Westhoff, W. (2004). *Wireless sensor networks for flash-flood alerting.* Paper presented at the Devices, Circuits and Systems, 2004. Proceedings of the Fifth IEEE International Caracas Conference on.

Chang, N.-B., & Guo, D.-H. (2006). *Urban flash flood monitoring, mapping and forecasting via a tailored sensor network system.* Paper presented at the Networking, Sensing and Control, 2006. ICNSC'06. Proceedings of the 2006 IEEE International Conference on.

Choi, S.-G., Chimeddorj, G., Altankhuyag, B., & Dunkhorol, S. (2016). *Design and implementation of a GPS-enabled mobile wireless sensor network for livestock herd tracking in mongolian nomadic herding.* Paper presented at the Strategic Technology (IFOST), 2016 11th International Forum on.

da Costa, G. A., & Kleinschmidt, J. H. (2016). *Implementation of a wireless sensor network using standardized IoT protocols.* Paper presented at the Consumer Electronics (ISCE), 2016 IEEE International Symposium on.

Daiya, V., Ebenezer, J., Madhusoodanan, K., SatyaMurty, S., & Rao, B. (2016). *Dynamic architecture for Wireless Sensor Network-implementation & analysis.* Paper presented at the Wireless Communications, Signal Processing and Networking (WiSPNET), International Conference on.

Dave, M. (2016). *Four-tier network architecture for wireless sensor and actor networks.* Paper presented at the Computing for Sustainable Global Development (INDIACom), 2016 3rd International Conference on.

Fosalau, C., Zet, C., & Petrisor, D. (2016). *Implementation of a landslide monitoring system as a wireless sensor network.* Paper presented at the Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), IEEE Annual.

Gutiérrez, J., Villa-Medina, J. F., Nieto-Garibay, A., & Porta-Gándara, M. Á. (2014). Automated irrigation system using a wireless sensor network and GPRS module. *IEEE transactions on instrumentation and measurement, 63*(1), 166-176.

Islam, M. A., Islam, T., Syrus, M. A., & Ahmed, N. (2014). *Implementation of flash flood monitoring system based on wireless sensor network in Bangladesh.* Paper presented at the Informatics, Electronics & Vision (ICIEV), 2014 International Conference on.

Jannat, K. S., & Islam, M. S. (2017). *Development of the Pre Seeding Decision Support System Based on IOT in Agriculture.* East West University.

Keshavamurthy, B., Narasimha, A., Ahmad, A. A., & Poornima, G. (2016). *VLSI implementation of a novel sensor architecture for industrial wireless sensor networks.* Paper presented at the Computational Intelligence and Computing Research (ICCIC), 2016 IEEE International Conference on.

Khan, R., Ali, I., Suryani, M. A., Ahmad, M., & Zakarya, M. (2013). Wireless sensor network based irrigation management system for container grown crops in Pakistan. *World Applied Sciences Journal, 24*(8), 1111-1118.

Kim, Y., Evans, R. G., & Iversen, W. M. (2008). Remote sensing and control of an irrigation system using a distributed wireless sensor network. *IEEE transactions on instrumentation and measurement, 57*(7), 1379-1387.

Kumar, M. K., & Ravi, K. S. (2016). Automation of irrigation system based on Wi-Fi technology and IOT. *Indian Journal of Science and Technology, 9*(17).

Leone, N., Murdoch, M., & Mazzara, P. (2010). *A wireless sensor network implementation for an industrial environment.* Paper presented at the Argentine School of Micro-Nanoelectronics Technology and Applications (EAMTA), 2010.

Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R., & Anderson, J. (2002). *Wireless sensor networks for habitat monitoring.* Paper presented at the Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications.

Muheden, K., Erdem, E., & Vançin, S. (2016). *Design and implementation of the mobile fire alarm system using wireless sensor networks.* Paper presented at the Computational Intelligence and Informatics (CINTI), 2016 IEEE 17th International Symposium on.

Nagpal, S. K., & Manojkumar, P. (2016). *Hardware implementation of intruder recognition in a farm through wireless sensor network.* Paper presented at the Emerging Trends in Engineering, Technology and Science (ICETETS), International Conference on.

Raigonda, M., & Valsang, V. S. V. M. S. (2016). An IOT Based Framework for Group Monitoring and Irrigation Control. *International Journal Of Engineering And Computer Science, 5*(9).

Săcăleanu, D. I., Perişoară, L. A., Şucu, L., & Stoian, R. (2016). *Practical implementation of a Wireless Sensor Network for a Virtual-MIMO transmission scenario.* Paper presented at the Communications (COMM), 2016 International Conference on.

Sahu, C. K., & Behera, P. (2015). *A low cost smart irrigation control system.* Paper presented at the Electronics and Communication Systems (ICECS), 2015 2nd International Conference on.

Sangare, F., Xiao, Y., Niyato, D., & Han, Z. (2017). Mobile charging in wireless-powered sensor networks: optimal scheduling and experimental implementation. *IEEE transactions on Vehicular Technology, 66*(8), 7400-7410.

Sudarsono, A., Al Rasyid, M. U. H., & Yuliana, M. (2016). *An implementation of anonymous authentication system in wireless sensor network using vlr group signature.* Paper presented at the Electronics Symposium (IES), 2016 International.

Triantafyllidis, A., Koutkias, V., Chouvarda, I., & Maglaveras, N. (2008). *An open and reconfigurable wireless sensor network for pervasive health monitoring.* Paper presented at the Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on.

Wang, J., Yan, H., Xie, Y., & Pang, Z. (2016). *Research and implementation of groups positioning method for wireless sensor networking.* Paper presented at the Industrial Electronics (ISIE), 2016 IEEE 25th International Symposium on.

Zhuang, W.-Y., Junior, M. C., Cheong, P., & Tam, K.-W. (2011). *Flood monitoring of distribution substation in low-lying areas using wireless sensor network.* Paper presented at the System Science and Engineering (ICSSE), 2011 International Conference on.

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