Available online at www.sciencedirect.com
Journal of Applied Research and Technology
Journal of Applied Research and Technology xxx (2017) xxx–xxx
www.jart.ccadet.unam.mx
CCADET CENTRO DE CIENCIAS APLICADAS Y DESARROLLO TECNOLÓGICO

Original

Wireless sensor networks: A survey on monitoring water quality

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Received 28 April 2016; accepted 16 July 2017

Abstract

Diseases related to poor water and sanitation conditions have over 200 million cases reported annually, causing 5–10 million deaths world-wide. Water quality monitoring has thus become essential to the supply of clean and safe water. Conventional monitoring processes involve manual collection of samples from various points in the distribution network, followed by laboratory testing and analysis. This process has proved to be ineffective since it is laborious, time consuming and lacks real-time results to promote proactive response to water contamination. Wireless sensor networks (WSN) have since been considered a promising alternative to complement conventional monitoring processes. These networks are relatively affordable and allow measurements to be taken remotely, in real-time and with minimal human intervention. This work surveys the application of WSN in environmental monitoring, with particular emphasis on water quality. Various WSN based water quality monitoring methods suggested by other authors are studied and analyzed, taking into account their coverage, energy and security concerns. The work also compares and evaluates sensor node architectures proposed the various authors in terms of monitored parameters, microcontroller/microprocessor units (MCU) and wireless communication standards adopted, localization, data security implementation, power supply architectures, autonomy and potential application scenarios.

Keywords: Real-time; Remote; Water quality monitoring; Wireless sensor networks

1. Introduction

Wireless sensor networks (WSNs) have gained popularity within research community because they provide a promising infrastructure for numerous control and monitoring applications. These simple low-cost networks allow monitoring processes to be conducted remotely, in real-time and with minimal human intervention. A typical WSN network consists of two main components namely node and base-station, as shown in Figure 1. A node is a device that is normally equipped with sensing, processing and communication capabilities, and is responsible for measuring the parameters associated with a particular application. A base station is responsible for capturing and providing access to all measurement data from the nodes, and can sometimes provide gateway services to allow the data to be managed remotely (Bhende, Wagh, & Utpat, 2014).

WSNs normally employ Wireless Personal Area Network (WPAN) or Low Power Wide Area Network (LPWAN) standards, to relay measurement data to the base station. These standards include IEEE 802.15.4, ZigBee and Bluetooth. There is no single connectivity solution considered suitable for all WSNs, and the choice of standard entirely depends on communication requirements and resource constraints of a particular application. Typical considerations for selecting a wireless connectivity solution are specified in Table 1.

1.1. WSN communication standards

1.1.1. ZigBee

ZigBee is a WPAN standard that has been layered on top of the IEEE 802.15.4 specification to include the networking and application layers. ZigBee devices are capable of creating star, cluster tree and mesh network topologies and can communicate

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

https://doi.org/10.1016/j.jart.2017.07.004
1665-6423/

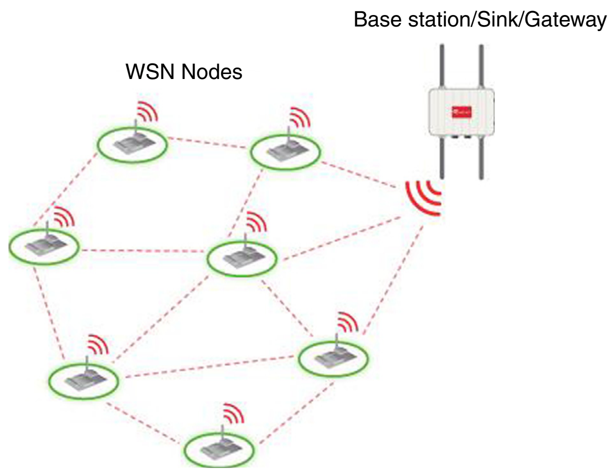

Fig. 1. A typical WSN (Libelium, 2016).

Table 1
Considerations in the selection of a WSN connectivity standard.

Item	Description
Frequency	WSNs often employ unlicensed ISM frequency bands for low cost implementation. Some of these bands are vulnerable to channel blocking and signal interference which is not suitable for critical application scenarios.
Range	In some WSN applications, nodes are deployed in remote rural areas which require connectivity solutions with good range capabilities. Selecting the right solution requires pre-assessment of network coverage requirements.
Data Rate	The type and size of data to be sent across a WSN plays a significant role in the choice of connectivity method. Image and video signals require high data rate solutions as compared to other data signals.
Power	Energy is a limited resource for all WSNs, but different applications require different levels of autonomy and hence the selected connectivity standard must satisfy the associated power requirements.
Security	WSN connectivity standards offer different levels of security. Sensors supporting mission critical applications would require a careful consideration of this aspect.

over hundreds of meters with a maximum data rate of 250 kbps (Gungor, Hancke, & Member, 2009; Lee, Su, & Shen, 2007).

1.1.2. Bluetooth low energy (BLE)

BLE is an ultra-low power version of the Bluetooth specification which allows data rates of up to 1 Mbps in the 30–80 m range context (Gungor et al., 2009; Lee et al., 2007).

1.1.3. Long range wide area network (LoRaWAN)

LoRaWAN is a technology that has been designed for applications that need to send small amounts of data over long distances a few times per day. Its low power features offers the capability to achieve autonomy of up to 10 years (LoRa Alliance & Machina Research, 2015; LoRa Alliance & Technical Marketing Workgroup, 2015; LoRa Alliance, 2015a, 2015b).

1.1.4. SigFox

SigFox is the world's first cellular network dedicated to low bandwidth Machine-to-Machine and Internet of Things applications. Its patented Ultra Narrow Band (UNB) technology utilizes unlicensed frequency bands to transmit data over a very narrow spectrum. Sigfox has a range capability of up to 40 km in open space (SigFox, n.d.).

Table 2 provides a technical comparison of the commonly employed WSN standards.

2. Applications of WSN

WSNs have numerous applications ranging from military surveillance, industrial monitoring, medical telemetry and environmental monitoring. These applications have different operational requirements, which is why they tend to adopt different WSN architectures. For military surveillance, the most important requirements include high bandwidth, high security and good coverage. Industrial monitoring applications require secure, reliable, robust and real-time WSN solutions. Medical applications often put more emphasis on security and network reliability, and environmental monitoring usually requires robust, energy efficient and autonomous nodes (Bhende et al., 2014; Buratti, Conti, Dardari, & Verdone, 2009; Girão, Postolache, & Pereira, 2014; Zhao, 2011).

2.1. Environmental monitoring

The development of human society has come with major impacts on the environment, and all efforts to improve its conservation have been aggressively sought. Environmental monitoring is one such significant effort, which has allowed various physical parameters to be monitored in order to control or limit further progression of environmental degradation. Conventional monitoring techniques required manual collection of environmental data, but were later considered inefficient since they are labor intensive and lack early warning capability to issues of environmental contamination. Some years ago, digital data loggers were introduced to help improve the spatial and temporal resolution of environmental monitoring, but still lacked real-time data analytics. With the advent of micro-electro-mechanical-systems (MEMS), low power WSN technologies were developed, and environmental monitoring could be conducted remotely and in real-time (Oliveira & Rodrigues, 2011). This approach has since promoted pro-active response to environmental contamination.

2.1.1. Air quality monitoring

Han and Cui (Zhi-gang & Cai-hui, 2009) reviewed the application of ZigBee based WSN in monitoring air pollution. The proposed system employed GPS enabled sensor nodes to monitor air quality parameters and transmit them to a sink node linked to a computer network. GIS analysis was suggested to simulate spatial and temporal distribution of air pollution in a given area. However, the proposed schema was only developed for a small area, which implies additional networking