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# Water quality monitoring in smart city: A pilot project

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A B S T R A C T

A smart city is an urban development vision to integrate multiple information and communication technology (ICT), "Big Data" and Internet of Things (IoT) solutions in a secure fashion to manage a city's assets for sustainability, resilience and liveability. Meanwhile, water quality monitoring has been evolving to the latest wireless sensor network (WSN) based solutions in recent decades. This paper presents a multi-parameter water quality monitoring system of Bristol Floating Harbour which has successfully demonstrated the feasibility of collecting real-time high-frequency water quality data and displayed the real-time data online. The smart city infrastructure – Bristol Is Open was utilised to provide a plug & play platform for the monitoring system. This new system demonstrates how a future smart city can build the environment monitoring system benefited by the wireless network covering the urban area. The system can be further integrated in the urban water management system to achieve improved efficiency.

## 1. Introduction

Water covers 71% of the Earth's surface. It is one of the vital resources for all known forms of life on the Earth to survive. However, only 2.5% of this water is freshwater, and even less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere. Water system is an essential component in a smart city for its sustainability and resilience. As we are entering a data-rich era, the amount of data being collected by human beings is accelerating with the popularity of Internet. In terms of data related to water, many data sources (smart meters, smart sensors and smart services, remote sensing, earth observation systems, model outputs, etc.) have been continuously accumulating significant amount of data [1]. For example, the Next Generation Weather Radar (NEXRAD), the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement Mission (GPM) have collected tens of terabyte of data [2–4]. The significant amount of the rainfall observation data is due to the high spatial and temporal coverage and resolution and its dimensions, e.g., 2-D in space and 1-D in time. The large amount of remote sensing precipitation data, though with considerable uncertainty, could counter the uncertainty in the hydrological model resulting better performance than gauge-based data [5]. However, the measurement of water quality is usually based on single spot with no spatial coverage. Also, the manual lab-based monitoring approach has its inherited disadvantage of low sampling frequency. The manual in-situ monitoring approach and the modern WSN-based solutions make use of the electronic sensors to measure water quality, which can provide data in high frequency to overcome the shortage of the traditional approach. A real estimates of water quality of lakes or rivers from remote sensing images is another approach to monitor water quality because every substance gives off a unique spectral signature. The relationship between the percentage of reflectance and the wave-length when a substance is exposed to electromagnetic spectrum is known as spectral signature which is unique for every substance [6]. Thus, the amount of substance in water can be estimated by the intensity of the reflectance at different wavelengths through building empirical statistical regression between them [7–11]. It is foreseeable that the water quality data will grow in a fast speed with the advancement in the monitoring techniques.

However, the remote sensing estimation of water quality suffers from the relative low spatial resolution which makes it difficult to monitor water quality for freshwater such as rivers, channels, ponds in urban area. Owing to the advance in smart city and Internet of Things, the network infrastructure in the urban area, both wired and wireless, is developing rapidly, and new network protocols have been developed such as ZigBee, Z-WAVE, INSTEON, WAVENIS, LoWPAN, NB-IoT, LoRaWAN, etc. Environment monitoring is without doubt one of the key applications of Internet of Things [12]. Bristol Is Open (BIO) is a joint venture between the University of Bristol and Bristol City Council, with collaborators from industry, local institutions, communities, and local authorities. BIO provides an open programmable Information and Communications Technology (ICT) infrastructure, offering 'City Experimentation as a Service (CEaaS)', for researchers to conduct user-defined experiments in the heart of Bristol city. The harbourside is a focal area of Bristol with new buildings and features redeveloped in the

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last ten years, attracting numerous visitors by the diversity of attractions and beautiful views. The urban surface water quality has a significant impact on the property values regardless of whether they are waterfront properties or not. Keeping the water quality in good condition would please people as well as benefit the aquatic ecosystems [13,14]. So, there is a timely opportunity to explore the new water quality monitoring approach with the help of the cutting-edge ICT technology.

This paper provides a timely review of a state-of-the-art wireless protocols developed for IoT to point out the new opportunities for the WSN-based solution for water quality monitoring for the future. It then describes the BIO pilot project multi-sensor and camera monitoring of Bristol Floating Harbour to prove the concept of Wi-Fi based wireless sensor network solution for water quality monitoring in smart city. The water quality monitoring system developed in this project utilised the Bristol Is Open (BIO) infrastructure for wireless communication and data processing, storage and redistribution. This is the first attempt to collect water quality data in real time and high frequency in the Bristol urban area with the Wi-Fi network provided by BIO. The system consists of the entire procedures from data acquisition, data transmission, data storage and data visualisation with the help of cloud computing, software defined network and open source platforms developed in IoT era. A few selections of results are presented afterwards together with the discussion of the potential value of the system.

## 2. Background

### 2.1. Internet of Things

The term Internet of Things has gradually become popular in recent years after the flourishing of cloud computing, big data, and artificial intelligence. Evidence of the popularity of IoT has been found on the increasing trend of the Google search volume of the term "Internet of Things" [15]. In the foreseeable future of Internet of Things, it aims to integrate heterogeneous communication technologies, both wired and wireless, to connect trillions of devices to contribute the vision of a global infrastructure of networked physical objects [16,17]. Although there are many ways to describe an IoT, we can define it as a worldwide network of uniquely addressable interconnected objects, based on standard communication protocols [12]. The vision of a future smart environment is described by Mark Weiser as "the physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network" [18]. The idea of IoT is useful in many application scenarios such as healthcare and wellness, home and building automation, improved energy efficiency, industrial automation, smart metering and smart grid infrastructures, environmental monitoring and forecasting, asset management and logistics, vehicular automation and smart transport, precision agriculture, smart shopping, etc. [15,17,19]. The number of application is usually limited by human's creation rather than technical challenges.

The connectivity of the physical objects is the fundamental requirement of IoT. There are a variety of network protocols developed in the IoT era. They are usually different combinations of power consumption, data rates and range. Radio-frequency identification (RFID) uses electromagnetic fields to automatically identify and track tags which contain electronically stored information attached to objects [20]. RFID is now popularly used to tracking objects, people, and animals, which, to some extent, inspired the boom of IoT [21]. ZigBee is a wireless short-range (10–20 m), low-rate (20 Kbps–250 Kbps), low-cost and low-power communication protocol based on IEEE 802.15.4. ZigBee devices can easily form a mesh network to transmit data over long distances by passing data through of intermediate devices to reach more distant ones [22]. Application areas of ZigBee include Smart Home, building automation, embedded sensing, industrial control, wireless sensor networks, etc. Z-Wave is a low bandwidth wireless half duplex protocol in a low-cost control network, used to communicate short control messages in a reliable manner from a control unit to one or more nodes in the network. Z-Wave defines two types of devices: controllers and slaves. Controllers poll or send commands to the slaves, which reply to the controllers or execute the commands [23]. INSTEON is a peer-based solution for home automation developed by SmartLabs and promoted by the INSTEON Alliance. It provides a simple and cost-effective solution for devices to be networked in powerline or radio frequency, or both. No master controller or complex routing software is required as each device is designed as a peer to transmit, receive or repeat messages [24]. Wavenis is a RF based wireless protocol stack developed by Coronis Systems for control and monitoring applications in several environments, including home and building automation. It extends the industry standard Bluetooth protocol to provide secure and reliable wireless connections with long range and low power consumption [25]. People are usually more familiar with the IP-based protocols such as Bluetooth, Wi-Fi, since they are widely used in smart phones and laptops nowadays. Wi-Fi features high bandwidth, which can reach up to 7 Gbps based on the latest IEEE 802.11 ac standard with medium range, around 30 m to 100 m, but also comes with high power inefficacy [26]. 6LowPAN (IPv6 Low-power wireless Personal Area Network) is an important IP-based solution as it uses IPV6 to extend the IP addresses to approximately $5 \times 10^{28}$ addresses to provide enough addresses for every connected object based on the commonly used IPV4. The standard has the freedom of frequency band and physical layer and can also be used across multiple communications platforms, including Ethernet, Wi-Fi, 802.15.4 and sub-1GHz ISM [27]. The latest and the protocols which are gaining more and more momentum are LoRaWAN and NB-IoT. LoRaWAN is a Low Power Wide Area Network (LPWAN) that defines the communication protocol and system architecture for a Low Power Wide Area Network (LPWAN) based on the physical layer of LoRa patented by Semtech. LoRaWAN features a combination of long range, low power consumption and secure data transmission. The range of LoRa can reach up to 15 km in rural area and the data rates range from 0.3 Kbps to 50 Kbps [28,29]. NarrowBand IoT (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard developed by the 3rd Generation Partnership Project (3GPP) to enable future IoT devices to use cellular telecommunications bands. NB-IoT features wide coverage, extreme low power consumption (10-year battery life) and massive connections. The current cellular network is not the best solution for IoT for the cost of the devices, short battery life and unsuitable for occasional small data transmission. NB-IoT was designed and frozen at Release 13 to overcome these issues of current cellular network [30,31]. As new protocols are still being developed for future IoT applications, this paper cannot cover all the relevant technologies, but only a summary of some popular ones in Table 1. However, giving such many options for connectivity, it might be difficult to decide the suitable solution to use for a desired scenario. In Bristol, the Bristol Is Open platform provides common network connectivity such as RFID, Wi-Fi and mobile network for researchers to

**Table 1**
Summary of some relevant IoT communication protocols.

| Protocol | Coverage range | Data rates | Power consumption |
|---|---|---|---|
| ZigBee | Short (10–20 m) | Low (20 Kbps–250 Kbps) | Low |
| Z-Wave | Short (30 m) | Low (40 Kbps–100 Kbps) | Ultra - low |
| INSTEON | Short (50 m) | Very Low (38.4 Kbps) | Low |
| Wavenis | Long (1 km) | Low (4.8 Kbps–100 Kbps) | Low |
| Wi-Fi | Medium (30–100 m) | High (typical 100–300 Mbps, up to 7 Gbps) | High |
| 6LowPAN | N/A | N/A | Low |
| LoRaWAN | Very Long (15 km) | Very Low (0.3 Kbps–50 Kbps) | Low |
| NB-IoT | Very Long (10–15 km) | Medium (2 Mbps) | Ultra - low |