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Deliverable Summary

Water is an essential resource for the economy and life. Currently, changes in water availability, the frequency of floods and droughts due to climate and other environmental changes, pollution trends, increased competition in water use including for industry, energy, agriculture and food production, land-use changes and increasing urbanisation all require the development and implementation of robust, smart, effective and tailored water management systems. Water distribution systems are seeing the increased deployment of new technologies that use Internet of Things (IoT) and (big) data analytics to gather, analyze and extract useful information from data to develop Smart Water Networks (SWN) , which have a huge potential to enable more efficient water resources management. Heterogeneous devices/technologies from different vendors are usually employed in SWN but no sufficient attention is paid to any interoperability and standardisation considerations. The absence of standardization among Information Communication Technology (ICT) equipment creates difficulties for building appropriate monitoring and control systems which, in turn, leads to low efficiency in water distribution system operation and maintenance. The IoT technology and developed frameworks help to link the physical and digital world to ensure water

smart soultuion and help to resolve the problem of the interoperablity and standardization in IOT environment.This document firstly provides an overview of the IoT architecture and its components, emerging sensor and advanced communication technologies for developing smart water system, specially focusing on the first two layers of the SWN architecture (i.e. Sensing and Control, and Collection and Communication). The document describes the emerging technologies and their applications in IoT enabled SWNs. Secondly, the recent research work have been reviewed focussing on intelligent sensing, sensor connectivity and dynamic communication coverage in IoT enabled SWN. Finally, the challenges of using IoT in SWN are summarized and the research gaps for achieving a context-aware IoT framework for SWN are highlighted with specific regard to the first two layers of the SWN architecture.

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List of Acronyms

AI: Artificial Intelligence

AMI: Advanced Metering Infrastructure

AMR: Automated Meter Reading

CRUD: Create Read Update Delete

D2D: Device to Device

DDS: Data Distribution Service

DMA: District Metered Area

DTLS: Datagram Transport Layer Security

ERS: Event Recognition System

HTTP: Hypertext Transfer Protocol

IaaS: Infrastructure as a Service

ICT: Information Communication Technology

IoT: Internet of Things

M2M: Machine to Machine

MQTT: Message Queueing Telemetry Transport

PaaS: Platform as a Service

SaaS: Software as a Service

SAW: Surface Acoustic Wave

SSL: Secure Socket Layer

SVM: Support Vector Machine

SWM: Smart Water Management

SWN: Smart Water Network

TLS: Transport Layer Security

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1. Introduction

Human society has traditionally benefitted from the availability of large amounts of natural resources. Nowadays, however, numerous natural resources are depleted. It is everybody’s responsibility to preserve these precious natural resources. Freshwater is the most essential need for each form of life on earth. Because of pollution and other human activities, however, only a limited amount of freshwater resources is available. Therefore, it is vital to manage water use in an effective and efficient manner and avoid wastage. Information and Communication Technology (ICT) can play a fundamental role in this regard by providing tools such as Smart Water Management (SWM) solutions (Intosh, 2014); (Hussain and Wu, 2017).

SWM encompass all aspects of the water cycle; from sourcing to treatment, to transfer, to delivery, to consumption, and to recovery (Farah et al., 2017). SWM can be defined as a group of new technology solutions which support more efficient water management (Mauree, 2010). These solutions utilise state-of-the-art software and hardware to give water utilities enhanced levels of system visibility and automatic control, operational efficiency and customer services (Mudumbe and Abu-Mahfouz, 2015). SWM is enabled by near real-time measurements that allow, inter alia, continuous monitoring of water/other-relevant parameters, enhancements in modelling and problem diagnosis and, subsequently, appropriate maintenance and optimization of all parts of a water system (Mauree, 2010); (Wu et al., 2012). Examples of SWM technologies for urban water systems are: smart meters, smart pipes, sensor networks, Geographical Information Systems (GISs), cloud computing for data processing and storage, radio transmitters WIFI, and modelling and decision support systems (Saravanan et al., 2017). In this context, the application of SWM solutions to urban water systems makes it possible to introduce the concept of Smart Water Networks - SWNs (Di Nardo et al., 2014).

A SWN is a group of data-driven “components” that help to operate the data-less physical layer of reservoirs, valves, pumps and pipes, among the others. Collecting and using comprehensive data on the operation of the water network provides the promise of better operation using better knowledge and optimal control over the extensive and complex network assets. Data technologies can be applied in water cycle, including transmission and distribution, water sources and production, end-points of consumption and internal pipelines (Miller and Leinmiller, 2014). SWN solutions enhance the longevity, efficiency, and reliability of the physical water networks’ layer. They also hold the promise to enable water utilities to adopt a more preventative and proactive approach to network operation and management. The recent rise of easy-to-use and low cost sensing devices and Internet of Things (IoT) technologies means that SWNs may benefit from massive increases in the density of sensor deployments. Recent advances in data analytics then play a key role in enabling efficient SWN operations (Cominola et al., 2015) (Mohammed Ibrahim et al., 2015).

The document is organised as follows. Section 2 provides an overview of the elements that make up a SWN focussing on the first two layers of the SWN architecture (i.e. Sensing and Control, and Collection and Communication). Section 3 describes the emerging technologies in IoT enabled SWNs. Section 4 presents a review of the recent literature focussing on the techniques and the strategies of sensors deployment and connectivity. In Section 5, the challenges of using IoT in SWN are summarized and the research gaps for achieving a context-aware IoT framework for SWN (with specific regard to the first two layers of the SWN architecture) are highlighted. Finally, section 6 presents the conclusion.

2. Smart Water Networks Architecture

A SWN can be divided into several layers as shown in Figure 1. These layers are: Sensing and Control, Collection and Communication, Data Management and Display and Data Fusion and Analysis.

Data needs to be collected from different sources. Data sources can be physical sources (like a sensor) or virtual sources (like software). The Collection and Communication layer is responsible for transmitting data from the field to a central point for processing (which could be in the local gateway, remotely in the water utility or in the cloud, among others). The Data Management and Display layer is responsible, inter alia, for managing the data (e.g. storing) and for presenting data to the end users in different ways. Finally, the Data Fusion and Analysis layer is responsible for tasks such as data processing (often using different data sources) aiming at, for example, issue recommendations or notifications to the end users.

Because of their relevance for the work presented in this document, further details of the first two layers of the SWN architecture are provided in the following two sub-sections.

***Figure 1**. Smart Water Network Architecture*

2.1 Sensing and Control Layer

This layer comprises the sensing and control devices. Sensors measure some water parameters such as pressure and flow from a District Metered Area (DMA) and water level in tanks. Actuators enable to automatically control elements such as pumps and valves. These devices typically have limited resources in terms of processing power and power supply. Therefore, an interesting research objective is to find ways to cope with such limitations.

2.1.1 Sensing Devices Examples

Smart sensors enable monitoring the condition of physical objects, collect important data and transfer this data to a central point in the cloud or on utility premises over a wireless network for analysis. Smart sensors can perform distinct tasks such as collecting data, data processing and transferring data. Sensors used in SWN can monitor a specific parameter or a set of parameters such as pressure, water flow and pH, among many others (Tang et al., 2017).

Smart meters represent a well-known example of smart sensors currently widely used in SWN. Based on the way that data is collected from these devices, a distinction between Automated Meter Reading (AMR) and Advanced Metering Infrastructure (AMI) can be made. As shown in Figure 2 (Hsia et al., 2012), AMR (top part of Figure 2) refers to any framework that permits computerized gathering of meter data (for the most part by radio transmission and walk-by/drive-by data collection), without the requirement for physical inspection of the meters. The AMI framework (bottom part of Figure 2), on the other hand, involves a fixed communications network and enables two-way communications with a water meter. That is to say, water consumption data is transmitted to utilities, while utilities can issue commands to the water meters to perform specific actions. In the last decade, most water utilities around the globe have started to make use of AMR frameworks. However, because of the extra perceived benefits, the industry is beginning to move towards AMI frameworks and ‘smart grid’ deployment (Mohassel et al., 2014). Regardless of the framework used, smart meters offer many potential advantages over traditional, “dumb” meters. To mention just a few, advantages include:

- Reduced meter reading costs;
- Early visibility of customer leak losses;
- Reduction in security and safety issues by removing the need for onsite meter reads at dangerous or inaccessible locations.

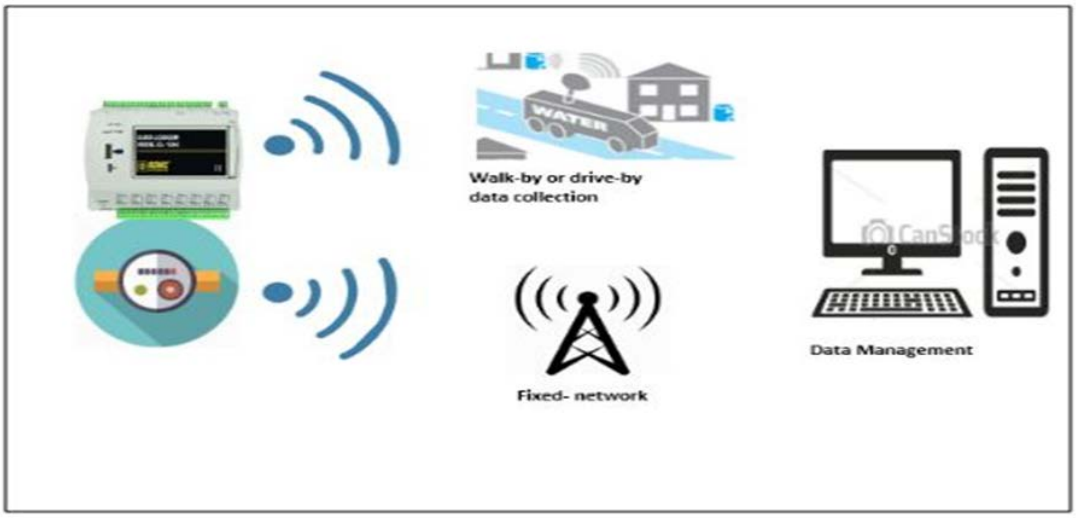

***Figure 2**. Automated Meter Reading and Advanced Metering Infrastructure*

Another example of novel sensing devices are smart pipes. Just to mention one player in this space CIPPS WX100 (datatecnics, 2016). CIPPS is a smart pipe that makes use of novel materials and creative nanosensors to monitor pipeline integrity on a real-time basis (see figure 3). Various parameters such as stress, flow and viscosity can be collected and communicated to the operator's servers for real-time processing. This type of technology has the potential to transform standard pipelines into intelligent self-reporting and self-analyzing device. A few of the potential benefits of smart pipes are as follow:

- Full integration of the sensing elements into the pipes
- Automated failures detection;
- Enhanced understanding of pipeline integrity to support asset management decisions.

Figure 3. *Smart Pipeline (datatecnics, 2016)*

2.1.2 Considerations for Sensors Deployments and Power Management

The deployment of sensors is a critical phase that significantly affects the performance of a sensors network (Abdollahzadeh and Navimipour, 2016). A few factors that need to be taken into account while deploying sensors are as follows (Mnasri et al., 2014):

- Coverage maximization;
- Cost of deployment;
- Fault tolerance and load balancing;
- Optimization of power consumption.

With specific regard to the optimization of power consumption, it is important to address on issue of the power supply of some smart water sensors (e.g. sensors used in remote areas) and, hence, self-powered smart devices become a challenge. This said, managing power is a broad topic that spans software and hardware. In detail, the following factors are critical for successful smart sensors deployments:

- Active sensor power;
- Frequency of data collection;
- Wireless (radio) communication strength and power;
- Frequency of communication;
- Microprocessor or microcontroller power as a function of core frequency;
- Passive component power;
- Energy loss from leakage or power supply inefficiency;
- Power reserve for actuators and motors.

2.2 Collection and Communication Layer

This layer is responsible for connecting the various smart sensors/actuators to a gateway (sink node). The gateway is the core of the communication infrastructure as it provides data exchange between the smart sensors/actuators and the utility. The gateway can make use of different technologies. For example, ZigBee IEEE802.15.4 can be used for local communications between the smart sensors and between the smart sensors and the local gateway; Wi-Fi IEEE802.11 can be used for the long-range communications between the gateway and the utility. Moreover, a gateway can provide other functions such as converting IPv6 packets used by some smart sensors to full IPv6 or IPv4 used to communicate with outer networks. Although other ways IoT protocols can be used to satisfy this function (Mudumbe and Abu-Mahfouz, 2015); (Radhakrishnan and Wu, 2018).

2.2.1 Communication Technologies

Communication technology types can be summarised as follows (see also Figure 4):

- Direct communication: between the sensors in a single area (cluster).

- Local communication: at the edge of each cluster, between the cluster members and the cluster head. It allows a single zone to communicate with the others using a gateway (cluster head).

- Telecommunication service provider connection: provided by a telecommunication company to connect cluster heads through the internet.

- Dedicated connection: between the cluster heads and a utility using a specified technology like Device to Device (D2D) or Machine to Machine (M2M).

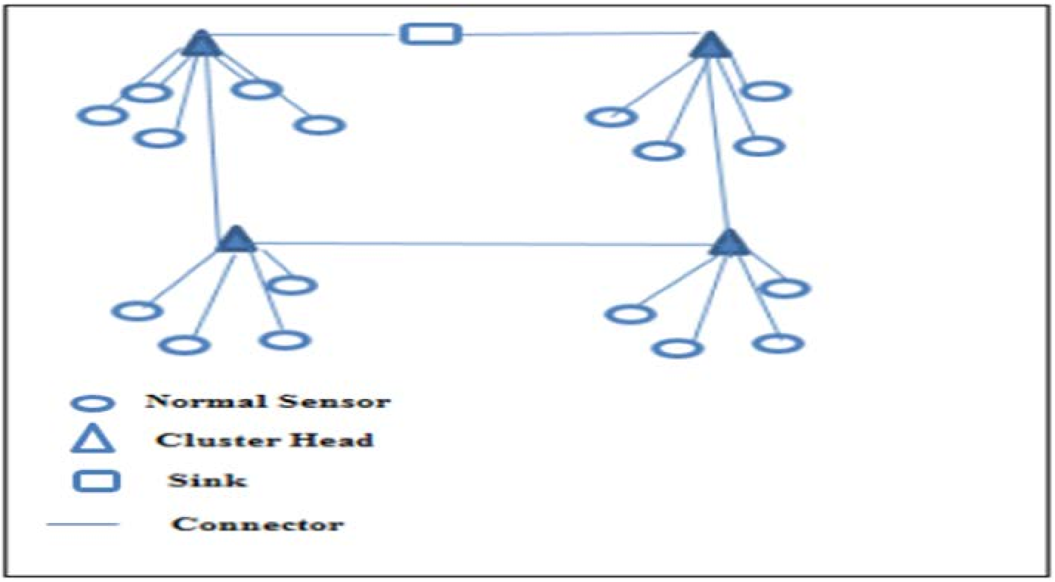

Figure 4. *Communication Types*

Communication technologies for collecting and transporting data can be wired, wireless mobile, wireless fixed network, or a combination of them (Kageyama et al., 2016). The choice of technology depends on multiple factors such as challenges of the utility, the maturity of the knowledge, deployment configuration, importance of the data, working process inside utility, and the costs (Chen and Han, 2018); (Lloret et al., 2016). Table 1 details the main characteristics of communication technologies that can be used (Hindia et al., 2015).

Table 1. *Main characteristics of different communication technologies*

Technology	Transmission Range	Data Rate	Power Consumption
Wi-Fi	50 Metres	2-600 Megabit per second	High
Wavenis	(1k Kilometres)	4.8 -100 kilobits per second	Low
INSTEON	(50 Meters)	38.4 Kilobit per second	Low
ZigBee	(10-20 Meters)	20 -50 Kilobit per second	Low
Z-Wave	(30 Meters)	40-100 Kilobit per second	Low
6lowPAN	N/A	N/A	Low
LoRaWAN	(15 Kilometres)	0.3-50 Kilobit per second	Low
NB-IoT	(10-15 Meters)	2 Megabit per second	Low

SigFox	(3-10 Meters)	0.3 Kilobit per second	Low
Bluetooth (802.15.1)	(1-100 Meter)	3 Megabit per second	Low
GPRS	(1-10 Kilometres)	75 Megabit per second	High
GSM	(3- 80 Kilometres)	9.6 Kilobit per second	High
3G	(10-50 Kilometres)	(384 Kilobit per second – 7.2 Megabit per second)	High
WiMax	(10-50 Kilometres)	(75 Megabit per second)	High
Broadband PLC	Several Kilometres	(Up to 100 Megabit per second)	High

The number of communication technologies have been highly applied in each zone. Some of them are proprietary and developed exclusively for specific applications, while others are well-known communication standards.

2.2.2. Communication IoT protocols

One of the main challenges in the collection and communication layer is to establish communication between the participating parties. The protocols that can be implemented can be divided into three categories namely: data-oriented, message-oriented and resource-oriented (Meng et al., 2017). Further details about each of these categories are provided in the following three sub-sections.

2.2.2.1. Data Oriented Communication Protocol

The most common data-oriented communication protocol is the Data Distribution Service (DDS). DDS has been characterized by the Object Management Group (OMG) to give a standard data-centric publish-subscribe programming model and specifications for the implementation of appropriate frameworks (Al-Madani and Shahra, 2018). DDS has been applied for the development of high-performance applications in the as automotive and finance domain to mention just a few. The OMG DDS does not provide an explicit method to determine the allocation and distribution of the participant to enhance the deployment setting with respect to the performance. Deployment setting is selected manually which is appropriate for small to medium scale applications, but it is not suitable for large applications. Figure 5 shows how the DDS protocol works (Tekinerdogan et al., 2018).

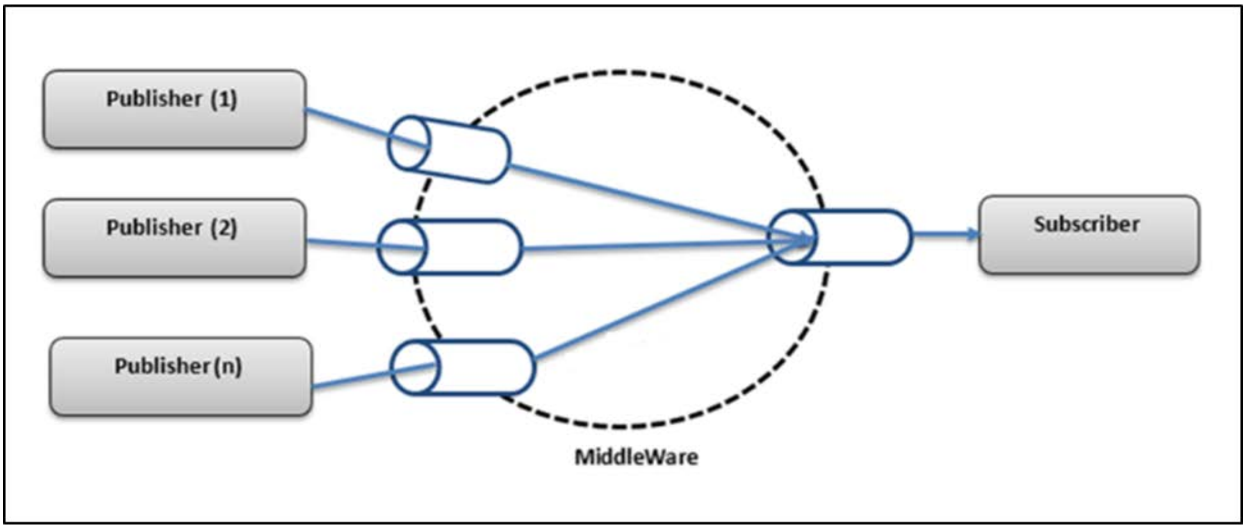

***Figure 5.** DDS Protocol*

Key features of the DDS are:

- Discovery of all communication parts at run-time.
- Support multiple Quality of Service (QoS) configuration.
- Support peer-to-peer communication between two parts with no broker.
- Support re-transmission of missed data for subscribers.

2.2.2.2. Message-Oriented Communication Protocol

The main concern of message-oriented protocols is to deliver messages from producers to consumer. The most common message-oriented communication protocol is the Message Queueing Telemetry Transport (MQTT). The communication of this protocol is established at M2M level (Zhai et al., 2018). It is a publish/subscribe-form of light-weight protocol streaming over TCP/IP with reliable bi-directional message conveyance (Light, 2017). Different consumers receive the message which is published once by the producer. A publisher sends the message on the topic and subscriber consumes a message on their registered topic of interest. MQTT broker matches publications to subscriptions. If one or more matches are found, the message is sent to the corresponding subscriber and if no matches are found the message is discarded. The MQTT (Figure 6) is intended for constrained systems (Kim et al., 2018, Fysarakis et al., 2016).

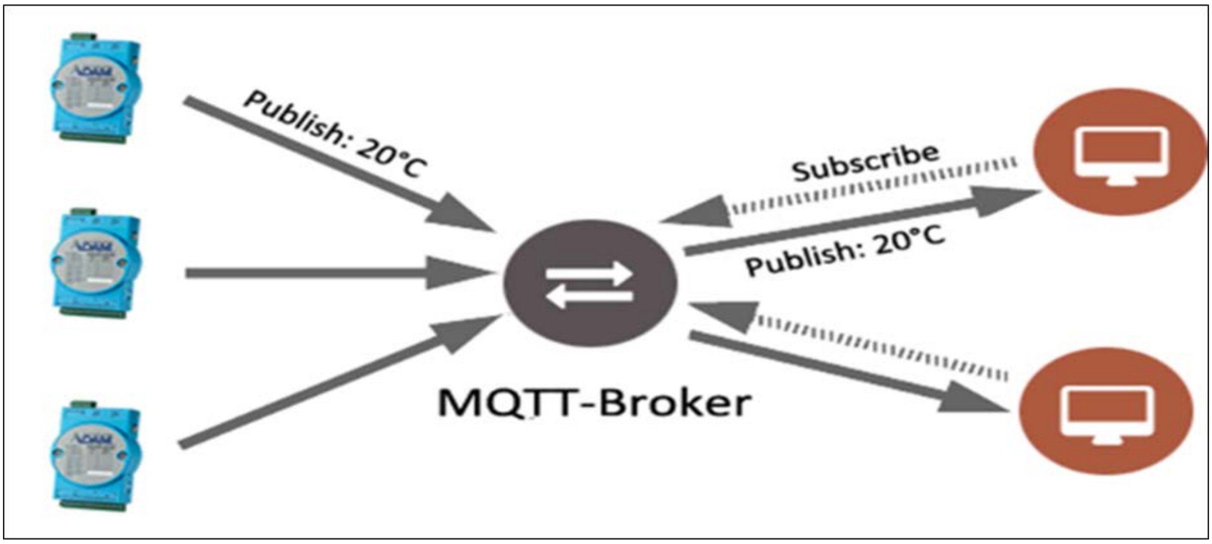

Figure 6. *MQTT Protocol*

2.2.2.3. Resource-Oriented Communication Protocol

Since sensors are resource constrained (i.e., nodes with limited processing and power), they are often connected to a computer node that is used to process the data (Sheltami et al., 2017). In some cases, the computer node is represented as a server that exposes data from sensors and processes using Representational State Transfer (REST) full web service. RESTful web services allow the requesting systems to access and manipulate textual representations of web resources by using a uniform and predefined set of stateless (i.e., communications protocol in which no information is retained by either sender or receiver) operations. In a RESTful web service, requests made to a resource's Uniform Resource Identifier (URI) will elicit a response with a payload formatted in some format such as Hypertext Markup Language (HTML) or other. The response can confirm that some alteration has been made to the stored resource, and the response can provide hypertext links to other related resources or collections of resources. When Hypertext Transfer Protocol (HTTP) is used, as is most common, the operations available are GET, POST, PUT, DELETE, and other predefined CRUD (Create Read Update Delete) HTTP methods.

Since the resources need to process the requests, they need to have some processing abilities. This provides the ability to distribute the processing load and reduce the load on backend-services. In addition, as the requests have a read-write semantic, RESTful web services allow to add infrastructure support in the form of caching and reverse proxies, thus allowing to better distribute the load and the network traffic. As a result, a resource-oriented approach seems most appropriate for connecting mobile devices clouds to sensors clouds. (Kim et al., 2018). Figure 7 shows the RESTful ways of sending and receiving the requests and replies.

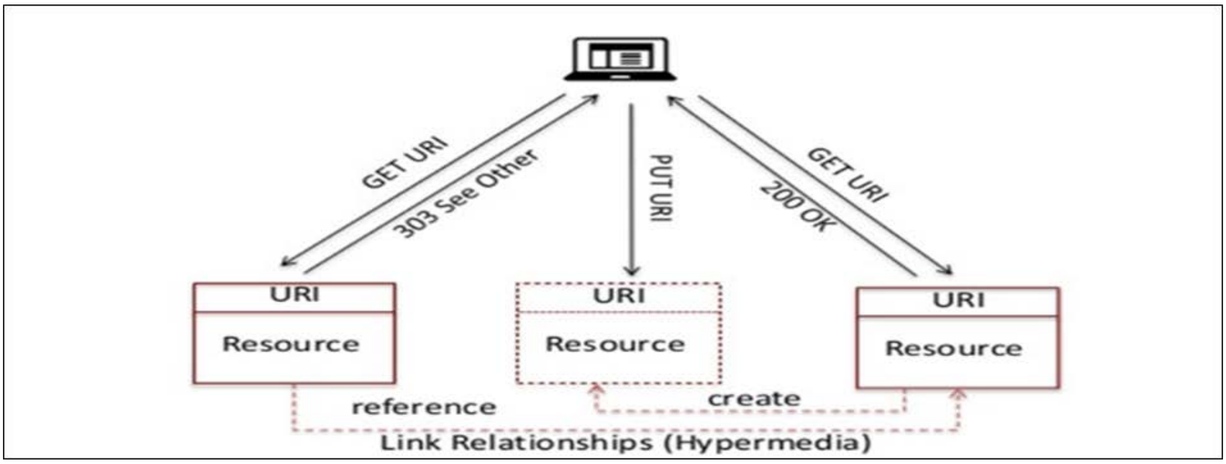

Figure 7. *RESTful Protocol*

2.2.2.4. Comparison of DDS, MQTT and RESTful Communication Protocols

Currently, the promising communication protocols are DDS, MQTT and RESTful. The main features of the DDS, MQTT and RESTful communication protocol are compared and shown in Table 2. Regarding the QoS, MQTT and DDS provide different QoS while the RESTful does not provide any QoS. MQTT provides only three QoS for message deliveries, which are as follows:

- At most once: the message is delivered at most once, or it is not delivered at all. Its delivery across the network is not acknowledged.
- At least once: the messages are assured to arrive, but duplicates can occur;
- Exactly once: messages are assured to arrive exactly once. This level could be used, for example, with billing systems where duplicate or lost message could lead to incorrect charges applied.

DDS provides a rich set of QoS providing control on the followings:

- Data availability: reliability and availability of published data.
- Resource usage: memory and bandwidth utilisation.
- Timeliness: data prioritisation and end-to-end traffic differentiation,

Based on the QoS only, DDS is the best protocol because it provides many QoS. While the RESTful is the worst because it does not provide any QoS.

Table 2. *DDS, MQTT and RESTful communication protocols comparison*

Protocol	Method	Standard	Transport	QoS	Security
DDS	Publish-Subscribe	OMG	TCP/UDP	Extensive	TLS/DTLS
MQTT	Publish-Subscribe	OASIS	TCP/IP	3 levels	TLS/SSL

RESTful	Request-Response	IETF	TCP/IP	N/A	TLS/SSL

Regarding security, the DDS protocol supports Transport Layer Security (TLS) and Datagram Transport Layer Security (DTLS) - in which TLS uses reliable connection (TCP) and DTLS use connectionless (UDP). DTLS provides two more functions to solve the problems of packet lost and reordering. On the other hand, the MQTT and RESTful protocols support the same security protocols, which are TLS and Secure Socket Layers (SSL). SSL is a security protocol for establishing encrypted connection between the two parties, and it ensures that all data are encrypted during transmission. Therefore, MQTT and RESTful outperform the DDS in term of security because they provide both reliable and encrypted protocols.

3. The Emerging Technologies in IoT Enabled SWNs

At the present, various business sectors all over the world have access to many sensors with increasing high-accuracy, reliability and suitable costs. Additionally, the latest developments in internet technology are enabling sending and receiving information at unprecedented speed and volumes (Petäjäjärvi et al., 2017). Furthermore, cloud storage technologies are removing the need for extensive local data storage systems while fog computing introduced as new distributed architecture that bring the core functions such as storage, control, computing and communication to be closer to the data origin. In view of all this and many other technology developments, IoT technologies have a key role to play. IoT technologies provide both software and hardware to support computerized and data-driven decision making (Rathore et al., 2016). Using these technologies give the ability to enable developing SWN, for example, leak detection and localization, pumping, and contamination detection.

3.1 IoT Architecture

The IoT architecture may be treated as a system with four different stages. First stage consists of physical things such as sensors and actuator while the second stage includes the communication protocols and sensor data aggregation. Third stage includes Information Technology (IT) to perform data processing, and finally fourth stage which provides the information to the end user through the application (Sebastian and Ray, 2015);(Ray, 2018). Figure 8 shows a general IoT architecture.

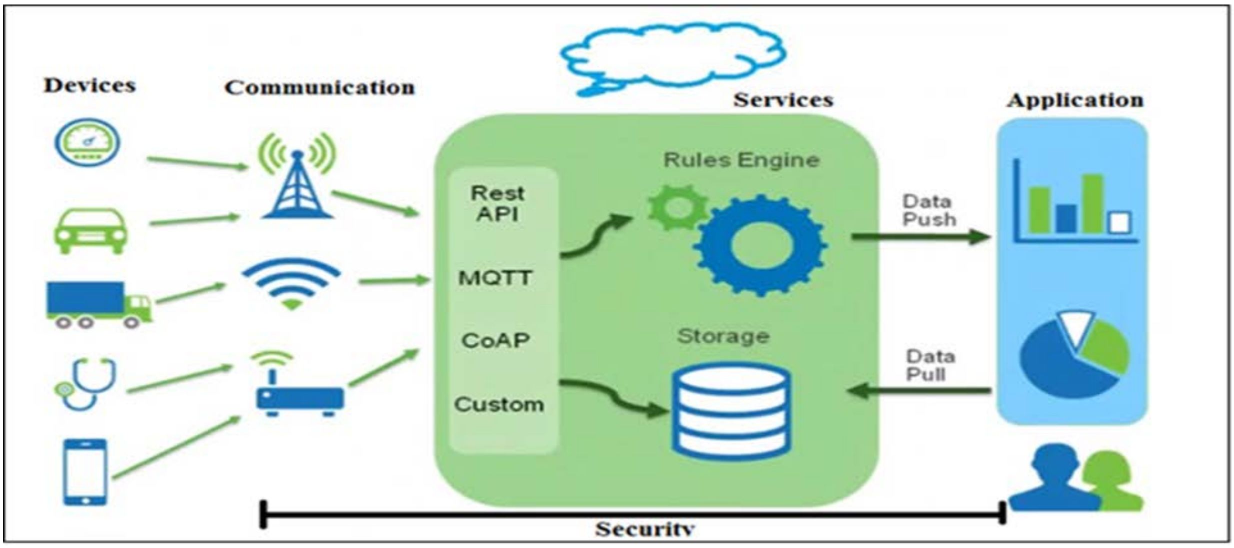

Figure 8. *IoT Architecture*

An IoT framework is dependent on constrained resources (i.e. memory, processing capacities, latency of the transmission and data rate). The main components of an IoT architecture can be classified into different layers as follows:

- Devices/sensors: enable monitoring and control tasks. IoT sensors can share information with other sensors or applications. They can gather data from sensors and process the data locally or send the data to centralized point servers or cloud-based applications for handling the data or analysis.

- Communication: is responsible to perform the communication between the devices and remote servers.

- Services: provide various functions such as modelling, data publishing, device control, device discovery and data analysis.

- Security: is responsible for providing various functions such as authorization, authentication, integrity, privacy, and data security.

- Application: works as an interface that gives essential capabilities to control and observe different parts of an IoT framework. Users can visualize the status of the system using end-user applications.

3.2 Cloud Services

The term cloud has been invented to describe systems that allow you to process and store information and data in a very large the data centres (Hosain, 2016). Cloud providers provide the capacity and flexibility to start and stop computing, storage, and network resources based on the specific needs of customers and applications using the cloud services. Cloud services provide multiple functions like storage, visualization, data analytics, real-time data capture, decision making, and device administration through remote cloud servers while implying a "pay-as-yougo" model (Ray, 2016). Cloud services provide several types of service models that can be offered to customers such as Software as a Service (SaaS) (e.g. IBM LotusLive), Platform as a Service (PaaS) (e.g. Google AppEngine) and Infrastructure as a Service (IaaS) (e.g. Amazon Web Services). Figure 9 shows these different cloud service models and their main functions (Sheltami et al., 2018).

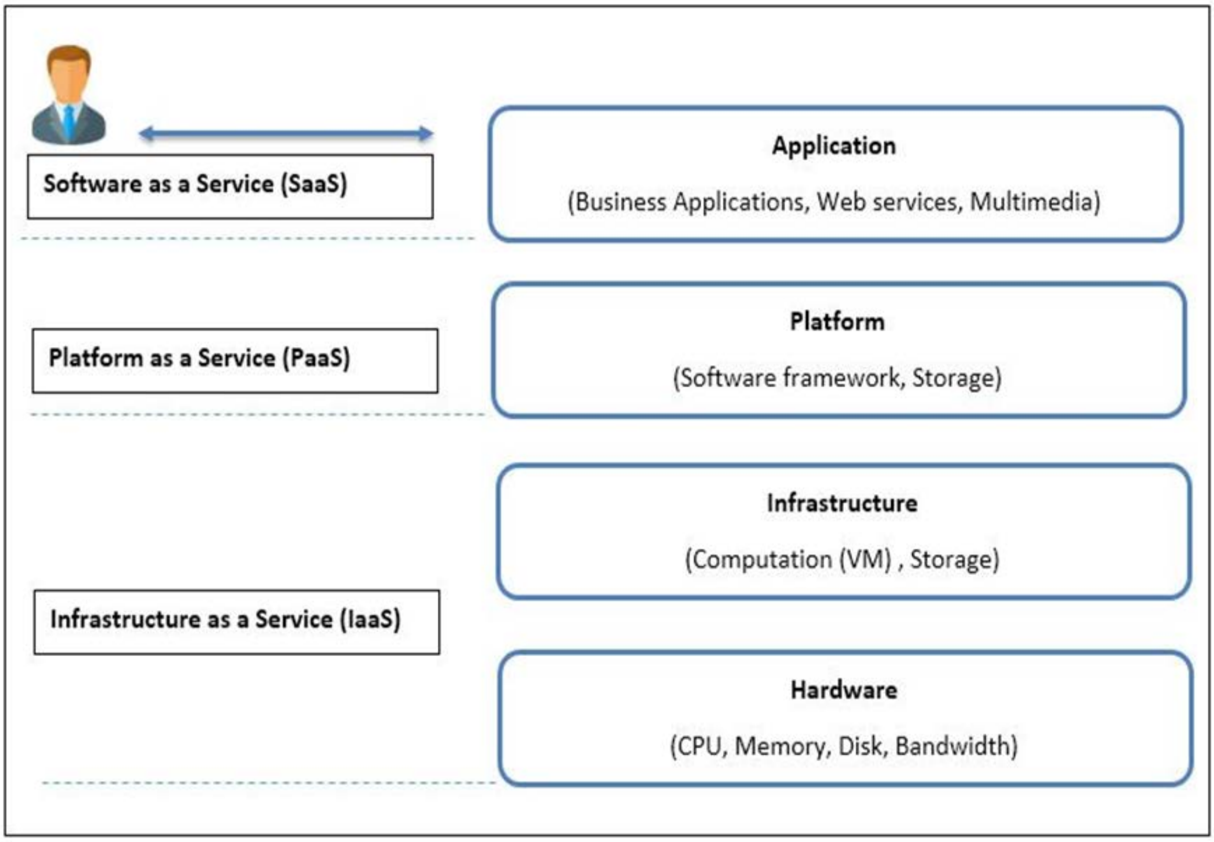

Figure 9. *Cloud Service Model*

3.3 Fog Computing

Fog computing is a distributed computing model that functions as an intermediate layer between a cloud server and IoT objects / sensors. It provides network, computing and storage services with the aim of developing cloud services as close as possible to IoT sensors, (see figure 10.) (Sheltami et al., 2018). One of the important benefits of fog computing is security. Good security practice can be implemented outside of the central servers where the device (or device groups) is located, fog computing can compromise between devices and cloud services and result in less damage to the overall deployment of applications (Hosain, 2016).

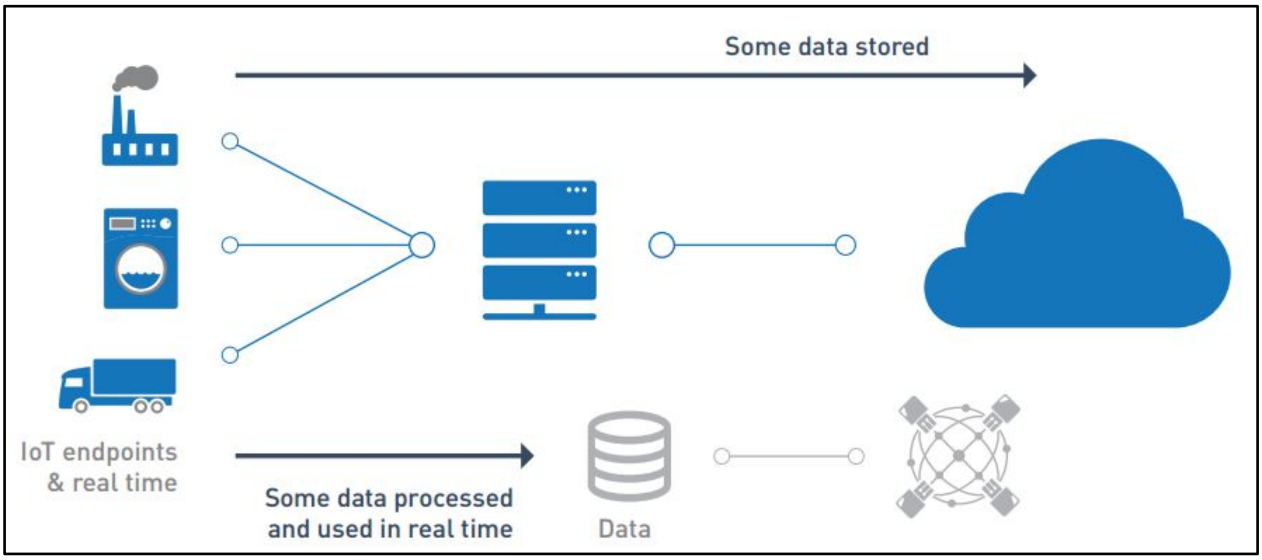

***Figure 10**: Fog Computing (Hosain, 2016)*

3.4 Communication Channels in Smart Water Applications

Figures 11 highlights the relevant components and communication channels in SWN applications. The components in water distribution system are explained briefly as follows (Hauser et al., 2016):

- Sensor: continuously measure acoustic signals, pressure, flow or other data at one point in the pipe network
- RTU: read data from local sensors and actuators and send it to the SCADA periodically. In addition, it can provide local control of pumps and valves.
- Data logger: Read the sensor data (flow, pressure, etc.), store them at regular intervals and transmit them SCADA system.
- SCADA: Receives and combines the data of several facilities for monitoring and network management in near / real time. It may store historical data for later use.
- Analytics/Server: Data analysis and big data: capable of processing massive and heterogeneous data. It can process structured and unstructured information.

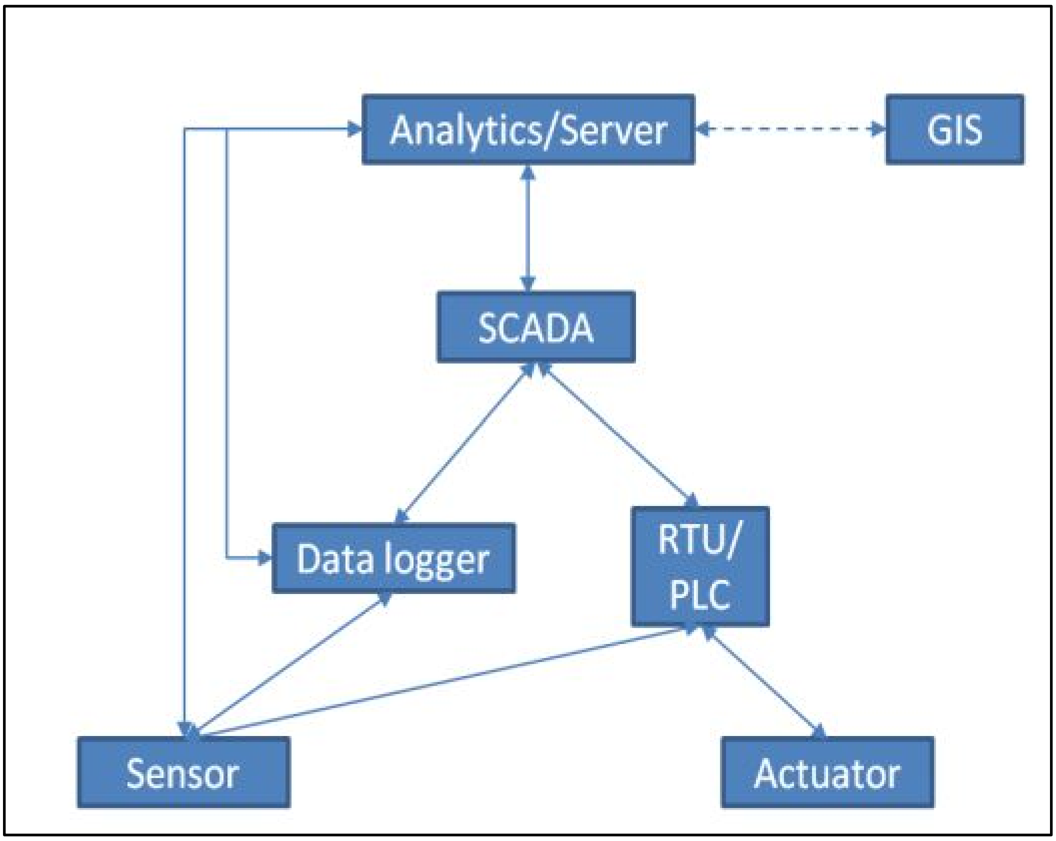

Figure 11: *Communication Channels in SWN applications (Hauser et al., 2016)*

As the communication between the sensors, data logger, PLCs and RTU is considered as essential part for the communication channels, the most important network topologies for the smart elements (sensors) as follows:

- Star: In the star topology, the coordinator (gateway) is responsible for the network. All other devices are end nodes and interact directly with the coordinator. This topology is more appropriate for networks with centralized device and for time critical applications, see figure 12 (a) (Li et al., 2010).
- Peer to Peer (P2P): This topology can be permanent or switched. A point-to-point permanent topology is a wired connection between two points. A switched connection is a point-to-point connection that can be moved between different end nodes (Mcgrath and Scanaill, 2013), see figure 12 (b).
- Mesh: The gateway and nodes are work together to form a mesh. The coordinate still responsible for initiating and maintaining the network. Because each node joins a network rather than a particular node or gateway, it can find a new path to the gateway in case the original path is lost or blocked to its existing network gateway. Thus, the mesh network is formed and regenerated automatically. However, this can also reduce network bandwidth because there is no way to force the gateway or end device to connect to a particular network device, see figure 12 (c) (Marais et al., 2016).

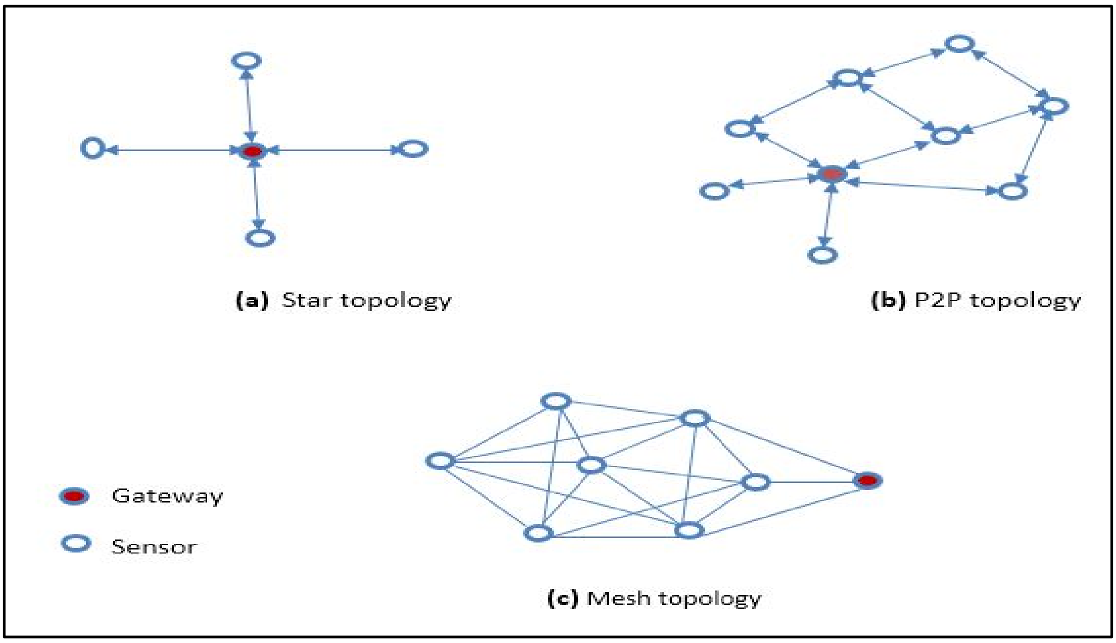

Figure 12: *Network Topologies*

3.5 Comparative Analysis of IoT and Current Existing System (SCADA)

As SCADA and telemetry system have been utilized by water distribution system for decades. As increasing low cost sensor and communication technologies and Internet of Things (IoT) development, this section will give a comparison between IoT and SCADA for industrial use

Table 3: Comparative analysis between IoT and SCADA

Feature	SCADA	IoT
Device interoperability	The integration of devices created by different manufacturers is not easy. Sometimes, even if the devices come from the same manufacturer, it is difficult to use them interchangeably if they use different version. SCADA systems do not have the much-needed interoperability, which is essential for developing seamless programming capabilities for devices and sensors.	The IoT ecosystem depends on the concept of interoperability. The main purpose of industrial IoT is to ensure communication between different devices, regardless of their model or manufacturer. IoT uses protocols, such as MQTT, to provide communication between various devices throughout the system.
System ownership and cost	With the help of SCADA systems, companies can only store data to a certain extent, after which this data will be overwritten by more recent data. This means that to store more data, companies must finance in additional servers with	IoT can dramatically reduce the cost of ownership of equipment and systems for businesses, while eliminating the need for software

	higher storage. In addition, when it comes to licensing software or obtaining additional features, SCADA users must purchase separate licenses for additional services and regularly pay for the system update.	licenses and upgrades using cloud services.
Insight from data	Companies have limitations in analyzing and then interpreting historical data when working with SCADA systems, it does not focus on collecting or analyzing data generated daily by a company. The data contained in SCADA does not bring much benefit to the company or provide any assistance to decision-makers, as it does not reveal the contextual information of the datasets, which complicates their understanding	In terms of data analysis, the IoT shines much more than the SCADA. Industrial IoT collects and stores data about each business process, then applies big data analyzing and machine learning algorithms to predict efficiency and potential results.
Scalability	The SCADA system leave out important information from various devices because the system does not store or analyze data. The reason for the lack of connection devices is the performance and security of the system, as the number of users increases, the bandwidth required for operation also increases, increasing the company's overhead. In addition, in SCADA systems, it is extremely difficult to get insightful reports from a centralized system for devices located in remote locations	The IoT ecosystem, all data is stored in the cloud and is easily accessible from any location. In addition, the ability to connect additional devices provides access to all data that can play a critical role in the decision-making process.

Based on the above comparation, Industrial IoT has potentials to extend SCADA to develop smart water networks, which makes it intelligent, smarter and expands existing capabilities such as data logging, data analysis, real-time data capture, anomaly machine breakdown, and visualization.

4. Related Research for SWN

Currently, a lot of research has been conducted related to smart water development. In this report, the review will focus on sensing and communication layers in IOT enabled environment. The related research work is examined on techniques and strategies of the sensor deployment and connectivity of WSN in IoT environment in general, especially address on sensor deployment methods and connectivity in context of water network for applications of real time monitoring for water quality and leak detection.

Sensor deployment is one of the most fundamental and critical issues in WSN because the location of the nodes has a significant impact on the efficiency and performance of WSN. The choice of deployment model depends largely on the type of sensors, the application, and the environment in which they will operate. The deployment techniques take care of the four important factors which are coverage maximization, connectivity enhancement, power optimization, and deployment cost and multi objectivity.

4.1 Coverage and Connectivity of Sensor Deployment

Coverage maximization of the interest area is an optimization problem. The coverage problem can be defined as that each point of interested field should be in the sensing range of the deployed sensors that make up the network. For coverage and connectivity of sensor deployment, Ting-Yu et al. (Lin et al., 2015) have proposed a coverage aware sensor automation (CASA) protocol to realize and monitor the smart network automatically. The proposed protocol includes two centralized algorithms EVFA-B and SSOA to provide and maintain maximum sensing coverage. SSOA is activated when the energy of the sensor is consumed, or unexpected failures are happened, it performs local repair by relocating the sensor around uncovered area. This feature of local repair gives some advantages of keeping the communication and moving energies. The performance of proposed method is evaluated in terms of maximizing the coverage, moving energy consumption, and monitoring density. Yoon and Kim (Yoon and Kim, 2013) have proposed a genetic algorithm (MCSDP) for maximize the coverage and reducing the number of deployed sensors using novel normalization method. The results showed that the performance of genetic algorithms has been improved using normalization method and the sensor deployment was evaluated using Monte Carlo method resulting on reducing time cost. Liao et al. (Liao et al., 2011) have proposed new mechanism of sensor deployment to maximize the coverage-based glowworm swarm optimization (GSO). Starts by initial deployment of sensors and then each sensor treated as separate glowworm emitting a luminous substance, called luciferin, and the intensity of luciferin depends on the distance between the sensor node and the adjacent sensors. The sensory node is attracted to its neighbors with less luciferin intensity and decides to move to one of them. The results show that proposed algorithms provide high coverage with static sensor nodes. Senel et al. (Senel et al., 2015) have proposed an efficient deployment scheme for under water acoustic sensor network (UWASN) which grantee the sensors connectivity while maximizing the coverage. The idea relies on determining the connected dominating set (CDS) on the water surface then to minimize the coverage overlaps between the sensors needs to adjust the depth of all neighbors of dominator node. The main goal is to exploit the sensor mobility and the network extends in 2-D to improve the coverage in 3-D network. The proposed scheme performance is validated using simulation and the results show that the connectivity is granted regardless of the sensing and transmission range. Frattolillo (Frattolillo, 2016) has proposed new deterministic algorithm to enhance the network coverage of the interested area using WSN. The algorithms rely on sensing and communication range of the sensors. It starts compute the coverage of the internal edges of the area then compute the coverage of the remain edges of the area. Moreover, the proposed algorithm allows you to control the degree of redundancy that can be achieved by covering the area of interest to ensure the deployment of a network characterized by the minimum number of wireless sensor nodes.

4.2 Network Connectivity

Network connectivity is another important point for WSN, which is considered as connected network if each pair of nodes can communicate directly or indirectly with other nodes. The connected network aims to find the minimum subset of active nodes to send the measured data to the sink node (gateway). Ranga et al. (Ranga et al., 2015) have proposed a new strategy for restore lost network connectivity based on spiral format of Fermat points using centroid for relies node placement. This scheme groups each three segments as triangle and computes the centroid of the triangle that acts as Fermat point of triangle. The Fermat point is a point in the triangle in which the sum of the distances between the point and three vertices of the triangle are minimized. The simulation results prove the efficiency of the proposed scheme. Hashim et al. (Hashim et al., 2016) have proposed an enhance algorithms for sensor deployment based on Artificial Bee Colony (ABC). ABC works based on two phases relay node deployment in 3-D space. In the first phase, the core (backbone) network is connected using a smallest number of relay nodes to ensure profitability. In the second phase, At the second stage, a new approach is introduced using the heuristic method to search for global optima. The network connectivity is maintained and guaranteed by optimizing the network parameters. The results show that the proposed algorithm enhances the lifetime of the network and validate the effectiveness of the proposed scheme. Lee et al. (Lee et al., 2015) have proposed a connectivity restoration with assured fault tolerance (CRAFT) algorithm. CRAFT tends to form the largest inner cycle or backbone polygon (BP) around the center of the damaged area, where there are no partitions inside. The RNs are then deployed to connect each external partition to the BP via two non-overlap paths. The results show that the proposed algorithm CRAFT is highly connected with short inter-partition routes while utilizing RS than competing schemes.

4.3 Power Management for sensor Development

The energy constrained is the nature of IoT environment and challenges in IoT environment. For energy aware sensor deployment, Gupta and Pandey (Gupta and Pandey, 2016) have proposed enhanced the energy aware distributed unequal clustering protocol (EADUC). EDADUC used to solve the problem of energy hole in multi-hop WSN protocol. EADUC uses the location of base station and the residual energy as cluster parameters to elect the cluster head. In addition, for the selection of the next hop node, the energy expense and number of neighbors are used instead of the only using the distance and the data transmission has been extended. The overhead of selecting the cluster head is reduced by using the cluster head for few rounds. The proposed method has been verified under three different scenarios and compared with the existing protocols, the results show that the enhanced EADUC outperforms the existing protocols in term of network life-time. Pradhan and Panda (Pradhan and Panda, 2012) have attempted to enhance the network life time and connectivity using MOPSO algorithm. It proposes the use of energy efficient sensors based on a multipurpose particle swarm optimization algorithm, which is compared with a non-dominant genetic sorting algorithm. During the optimization process, sensor nodes are moved to a fully connected network. The results show that the proposed algorithm is outperform the others to solve the problem of multi objective sensor deploying.

Moreover, fuzzy logic algorithm has been used to select the best compromised solution. Restuccia and Das (Restuccia and Das, 2015) have proposed a novel algorithm named Swarm-Intelligence-based Sensor Selection Algorithm (SISSA) to optimize the network lifetime and satisfied the pre-determine QoS constraints. They analyze and derive the mathematical model of power consumption, coverage time, and the number of messages transmitted. The efficiency of the proposed algorithm is evaluated with a testbed using 40 sensors and the results show that SISSA is highly in term of power-efficiency and scalable and provides average of 56% of the lifetime.

Table 4: *Summarize of existing work*

Ref.	Algorithms	Objectives	Pros	Cons
(Lin et al., 2015)	CASA, EVFA, SSOA	Maximize network coverage	. local and global network coverage maximization. . Self-deployment and organized	. high complexity . more overhead for self-deployment
(Yoon and Kim, 2013)	MCSDP, genetic algorithm	Maximize network coverage	. simple . fast . less overhead	Limited with static sensor deployment
(Liao et al., 2011)	GSO	Optimize network coverage	. use decentralized approach . easily scalable for large scale network	. more overhead to move the node to its neighbor . limited with sensor movement
(Senel et al., 2015)	CDS,UWASN	Maximize network coverage	. fast deployment time	. tested under 3-D space. . depends on connected network only
(Ranga et al., 2015)	RPLC, CTD	Maximize the connectivity of partial network	. large scale . fault tolerant . less number of relay node	. limit number of segment network
(Frattolillo, 2016)	Deterministic algorithm	Enhance the coverage and network connectivity	. required low number of sensors	. limit size of study area . consume more power due to increase sensing and communication range of sensors

(Hashim et al., 2016)	ABC	Maximize the network connectivity	. used in different applications such as volcano monitoring, deploy node in forest to detect fire, CO2 flux monitoring	. more complexity due to 3-D space
Gupta and Pandey, 2016	Enhance of EADUC	Power optimization and maximize network life time	. remove the overhead of cluster head election	. limited to static node only
(Pradhan and Panda, 2012)	MOPSO, fuzzy logic	Enhance network connectivity and life-time	. mobile nodes . low cost	. low number of nodes . more power consumption due to node movement
(Restuccia and Das, 2015)	SISSA	Maximized network life time and reduce power consumption of sensors	. Scalable easily . no need for synchronization between sensors	. tested in ideal environment without interferences

4.4 Sensor Deployment for Water Distribution Network

Sensor deployment techniques has been applied in water distribution system to detect contamination in drinking water systems, such as optimal Deployment of sensor networks for water quality monitoring, which is optimal location based on the hydraulic situation and critical locations and worst points in water distribution network. Jin and Wu (Jin et al, 2008) have applied optimal placement of pressure monitors in water supply network with elitist genetic algorithm. Berry et al. (Berry et al., 2006) have described the mixed-integer programming (MIP) formulation for optimizing the location of sensors in water distribution systems, including information on the temporal characteristics of pollution derived from standard network simulation models. Water quality simulation calculates the time series of contaminant concentrations for each compound in the system. These time series are then used to evaluate the impact of a pollution event, including the effects of detection at various network nodes. Therefore, the MIP model can be used for different sensor placement purposes, and improvements in water quality modeling can be integrated without changing the strategy of the basic solution for sensor placement. Amruta and Satish (Amruta and Satish, 2013) have proposed a frame work for monitoring the water quality by collecting comprehensive data and achieving the sequential follow up of water contamination status remotely. The proposed work provides a quick discovery of an urgent water pollution accident and then transferring the abnormal water quality information to the monitoring center. Rathi and Gupta (Rathi and Gupta, 2016) have proposed a method that formulated the sensor placement task to simultaneously covert: assuring water quality deliver to consumers and early detection of water contamination events by maximizing: demand coverage and detection like-hood of time-constrained. The genetic algorithm (GA) is used to obtain the optimal location of the sensors. The results show that the proposed work provided optimal solution for sensors placement compared to other techniques. Tinelli et al. (Tinelli et al., 2017) have proposed a method for the selection of the most characteristic contamination cases in the context of the optimal placement of the sensor with two minimized objective functions, namely the redundancy of the sensors and a polluted population. Sampling was being done according to four variables: injection site, start time, mass flow, and duration. The injection location was selected based on the distance of the source depending on the network connection. The results show that the optimal location of the sensor did not change significantly when the selected pollution events were used in the optimization instead of a set of possible pollution events.

Another type of application which requires more consideration of the sensor deployment is event or leak detection. Rosich et al. (Rosich et al., 2012) have proposed an iterative methodology concerned on the identification of the main sensors, which ultimately leads to an improvement in the optimal efficiency of detecting and isolating the leaks in a DMA. The algorithm presented in the work successfully applied to areal DMA network in Barcelona. So that the benefit of the proposed work is the selection of the sensor location technique based on a structural model of water distribution network. Cugueró Escofet et al. (Cugueró Escofet et al., 2015) have proposed a general method for placing sensors, taking into account leak diagnosis trade-offs related with isolation accuracy by combining geographically leaked into an acceptable isolation area in terms of application. The proposed method gave promising results in isolating leaks, assessed using a general assessment method, also proposed for diagnosing leaks in water distribution systems, at the DMA located Barcelona. Gamboa-Medina and Reis (Gamboa-Medina and Reis, 2017) have proposed a sampling design (SD) technique to locate and quantify pressure sensors in a WDS to detect leaks. According to the proposed method, the search for an appropriate SD is determined by four criteria: the maximization of the overall leakage sensitivity and the coherence of the sensitivity, as well as the minimization of the redundancy of information and the number of sensors. The sensitivity analysis is designed using a hydraulic network simulation model and includes artificial leaking node as pressure requirements. Entropy is used to assess sensitivity to all considered leak events. Redundancy is estimated by the correlation between the simulated responses, in terms of pressure at the potential nodes for deployment of sensors. Finally, the goal is to reduce the number of sensors, knowing that their overall availability is limited. The optimization procedure uses the NSGAII genetic algorithm approach to search for a complete set of nodes for sensor deployment. The proposed method can be applied to sampling design for any water distribution network, requiring as input a complete hydraulic model.

5. The challenges of IoT Framework for Smart Water Networks

Based on the literature review carried out in the previous section, we highlight the research gaps in IoT framework for SWN mainly in two areas of sensor deployment and communication for water distribution network. In IIOT environment there are many small sensor nodes connected each other. These sensor nodes have limited resources such as power and processing capabilities. The lifetime of the individual sensor node is not easy to predict depending on their monitoring position and their main functionalities. The large sensor network ideally can be configured autonomously according to requirement of monitoring applications in the IOT environment. This directly link to sensors deployment and network connectivity problems concerned while designing WSN in IIOT. Deployment of sensor networks aims to find an optimal placement method of sensor nodes that would reduce computation and communication overhead, minimize cost, provide a high degree of coverage with network connectivity, and be resilient to node failures at same time subject to the requirement of hydraulic and water quality monitoring in water distribution network. This research will address on this challenge of optimal sensor deployment in water distribution system and investigate the various methods and techniques of sensor deployment according to the requirements

- Dynamic sensor deployment: In the literature, static sensor deployment is typically carried out in one of two approaches: random deployment and deterministic deployment. However, when sensors can move on their own, dynamic deployment can be exploited to enhance the network performance, this kind of deployment called dynamic sensor deployment. Deployment of mobile sensors consider two main issues named: movement assisted sensor deployment and sensor relocation. In movement assisted sensor deployment, mobile sensors can be able to be reconfigured automatically after initial deployment, allowing for better location and network performance. In addition, in sensor relocation, dynamic repositioning of nodes while the network is working is necessary to improve network performance.
- Linear Sensor Network (LSN): define as new category of WSN where the sensors are deployed in strictly line or semi-linear form. As this LSN architecture uses a linear structure, it can contribute to solve the problems of reliability, communication sequencing, and security problems. The goal of this architecture is to reduce installation and maintenance costs, improve network reliability and fault tolerance, increase sensor battery life, and reduce latency of end-to-end communication resulting in improving the quality of service of measured data. This LSN architecture has been applied in the applications with linearity nature such as, monitoring of roads, monitoring long pipeline of water or oil, monitoring river environment, and monitoring international borders for illegal crossing.
- Power management and optimization: An advance node deployment method can effectively reduce the power consumption of WSN and extend the corresponding network lifetime.

Another key issue in designing WSN in IIOT is to keep the network connectivity with the goal that specific network performance can be accomplished in water distribution network. In the network, every sensor has a sensing range. Out of their transmission range, the sensor can't communicate each other directly, however they can connect in a multi-hop way. The major issues of communicating sensor network in water distribution system will be investigated in this research according to the specific sensor deployment strategies.

- Connectivity and coverage: Network coverage parameters like the transmission range and direction flow of the data play an important role in the SWN. Similarly, connection between the nodes are also important in term of knowing whether they are linearly connected.
- Centralize monitoring: Most of the existing monitoring application used the centralized monitoring systems. However, this type of system is not suitable for large scale monitoring system especially for underground pipeline monitoring, which affects the overall network performance and increases the latency.

- Efficiency of sensing data: Most of the existing framework has addressed on data collection, not many research concerns about the data quality and their meaning and its purpose, which leads to redundant data. This redundant data can be removed or reduced using an appropriate algorithm which leads to reduce the communication cost.

6. Conclusion

In this research, comprehensive review has been carried out on Internet of Thing (IoT) and advanced technologies for smart water system, emerging and enabling technologies of sensor, advanced communication, cloud computing and data intelligence are explained and potential solutions to develop water smart system have been analysed and discussed. This research focus on sensing and commination layer in IoT architecture of smart water framework, especially on investigation of optimal sensor deployment and energy aware communication in Industrial IOT environment. Current related research in SWN applications, especially for real time monitoring and managing water distribution for water leakage detection and water quality applications have been reviewed. The challenges of developing SWN in IOT environment are summarized and the research gaps for achieving a context-aware IoT framework for SWN are highlighted with specific regard to the two layers of sensing and communication in the SWN architecture. This research will address on the challenges of the dynamic and optimal deployment of sensors and energy aware communication in the context of water supply and distribution network to achieve water smart system.

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