A SURVEY ON WIRELESS SENSOR NETWORK-BASED IOT DESIGNS FOR GAS LEAKAGE DETECTION AND FIRE-FIGHTING APPLICATIONS

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ABSTRACT

The rapid advancements in wireless sensor network (WSN) technology gave impetus for large-scale deployment of Internet-of-things (IoT) services and applications. One of the envisioned IoT applications is the use of wireless sensor nodes in gas-leakage monitoring and detection applications. Such IoT applications can provide better protection to fire fighters and provide safety and early-warning gas detection alarms within a timely manner for individuals, factories and institutions. In this article, we highlight the unique characteristics of WSNs, discuss the main WSN design requirements associated with gas leakage and monitoring applications, discuss main differences between data collection- and event detection-based WSN solutions and present a detailed overview of the works that have been accomplished on providing WSN solutions for gas leakage detection and monitoring.

KEYWORDS

Data collection, Event-driven, Hazard environment, IoT, Liquefied Petroleum Gas leakage (LPG), On-the-fly deployment, Pre-deployment, WSNs.

1. INTRODUCTION

The recent development of sensor technology along with the huge advances of the wireless communication and networking technologies resulted in moving toward an expected large-scale deployment of Internet-of-thing (IoT)-based wireless sensor networks (WSNs) (e.g., [1]–[4]). Large number of applications are envisioned for such type of wireless networks, such as environmental monitoring, military/civilian surveillance and security, precision agriculture, industrial automation, manufacturing and inventory control, transport monitoring and control, smart cities, smart homes, smart grid, …etc. (e.g., [5]–[9]).

An IoT-based WSN includes a large number of inter-connected small-size, inexpensive and low-energy dissipating devices [10], [11]. There are two types of deployment of such devices: random deployment or pre-specified manual deployment. The sensor devices are capable of self-organizing themselves to create a multi-hop wireless network. One of the most attractive features of IoT-based WSNs is the possibility of on-the-fly deployment of the sensor devices being used for unattended operations with minimum maintenance and no pre-existing infrastructure [12], [13]. Each sensor device can sense specific physical conditions or collect some required information (e.g., detect Liquefied Petroleum Gas (LPG) leakage [14]–[16]), process the collected/sensed data and send the reported measurements to a named pre-specified control node. Data aggregation and/or compression may be performed by the sensor nodes such that the communication overhead and energy consumption are reduced [17], [18]. Such attractive features and characteristics of WSNs made it a suitable candidate to be used in fire-fighting and LPG-gas detection applications [19], [20], [21].

LPG is one of the necessities of daily life, as almost all residential locations and service areas have gas cylinders (i.e., houses, factories, restaurants, hotels). However, any leakage of gas may cause the occurrence of explosions and serious fires. Thus, it is important to identify such leakage and take the appropriate action in a timely manner [22]–[23]. For this purpose, a WSN can be pre-deployed to remotely monitor and detect gas leakage in a timely manner. Such information can decrease the occurrence of explosions and serious fires and can assist in the process of controlling the spread of the gas leakage. On another hand, WSN technology along with IoT capabilities can provide better

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protection and safety to fire fighters, where the sensor nodes can be deployed on-the-fly by the firefighters operating in the hazard zone (e.g., burning building). The sensor nodes can wirelessly send information about the current status (such as gas density) inside the burning/gas leaked closed area to the internet or a command center. This allows the fire fighters to take the appropriate action before entering the dangerous area [24], [25], [26]. We note here that several WSN systems have been designed for fire-fighting, gas monitoring and detection applications based on different wireless communication technologies. However, most of these designs did not fully exploit the capabilities of IoT systems and WSN technology and did not consider their unique functionalities and requirements. Very few works have proposed LPG leakage detection systems based on the IoT technology, but the proposed systems are stand-alone sensing systems that do not utilize the WSN technology. The developed communication protocols, hardware designs and processing mechanisms for WSNs cannot be directly implemented in IoT-based WSNs. Therefore, new designs and communication protocols are needed to fully utilized the IoT functionalities and capabilities in WSNs such that network performance is improved (i.e., delay, throughput, energy consumption, connectivity …etc.).

The main objective of this paper is to overview and analyze the main WSN implementations and designs that have been proposed for fire-fighting and gas-monitoring applications in the literature. Specifically, a number of WSN system implementations and IoT deployments are surveyed, in which their operation details are explained. Furthermore, we briefly highlight the design requirements and specifications for fire-fighting and gas detection and monitoring applications. The different deployment possibilities of WSNs/IoT for such specialized applications are also summarized. In addition, open problems and potential research directions are provided.

The rest of this paper is organized as follows. Section 2 provides an overview of WSNs and their key design/deployment issues and challenges. In Section 3, we summarize the design requirements for an appropriate WSN design for fire-fighting and LPG gas detection applications and highlight the differences between data-collection and event-detection WSN designs. Section 4 provides an extensive overview of the various WSN and IoT solutions designed for gas-monitoring and fire-fighting applications. Section 5 provides a detailed discussion of the surveyed systems and highlights potential research directions. Finally, conclusion remarks are provided in Section 6.

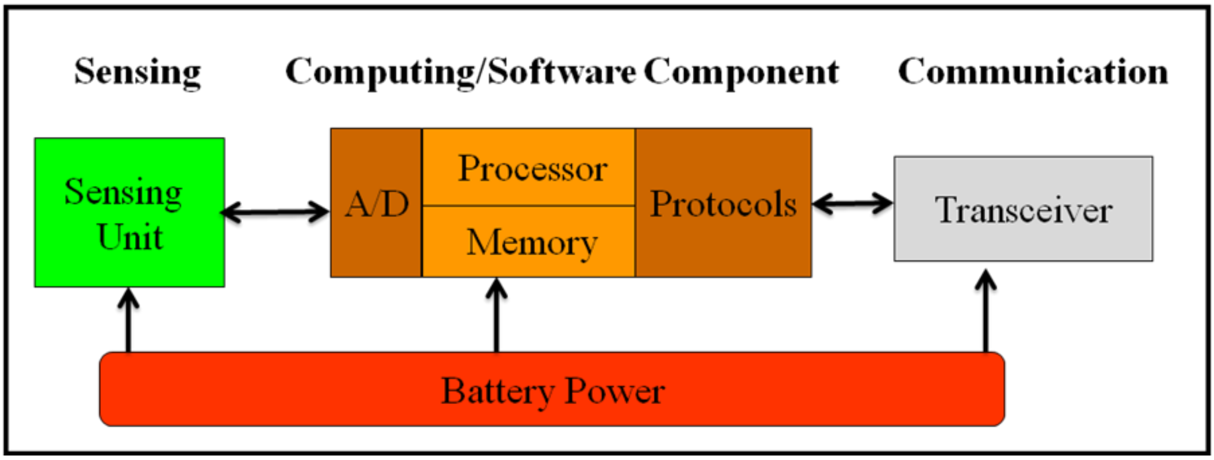

Figure 1. Sensor node architecture [24].

2. WSN Architecture and Key Design Challenges

In this section, we present the overall architecture of WSNs, describe the functionality of the different elements of such architecture and discuss the main/common design challenges in providing efficient deployment and operation of WSNs such that a designer can take them into consideration when designing a WSN that is to be used for specified tasks.

2.1 WSN Architecture

A WSN is composed of a large number of small-size spatially distributed embedded sensor devices with wireless networking capabilities that are responsible of monitoring and collecting specified physical information/events and reporting the sensed data to a centralized command device, referred to as a sink node. Sensor nodes are capable of self-organizing the communication between themselves and/or with the sink node through well-defined medium access control (MAC) and routing protocols, where single or multiple-hop communications are possible. The sensor nodes are usually battery-powered with extremely limited non-rechargeable energy sources. Therefore, sensor nodes perform data processing for gas-leakage and fire-fighting applications (e.g., aggregation, decision, fusion …etc.) of the collected raw information before conducting any transmission to save energy. WSNs measure environmental conditions, such as temperature, pollution level, gas-leakage occurrence, humidity level …etc. Several applications for WSNs with IoT capabilities are envisioned, including environment monitoring, health applications, militarily surveillance, industrial automation, smart cities, habitat research, search-and-rescue in hazard operating field and many other residential and industrial applications.

Several information and communication technologies are utilized in WSN systems including hardware components, software implementations and wireless networking capabilities. Specifically, a sensor node architecture is composed of 6 major inter-connected elements [24]: (1) A power-supply unit, which is, in general, a limited energy battery, (2) a transmission/reception unit, which is a radio frequency (RF) transceiver, (3) a sensing element, which depends on the physical condition that is to be monitored, (4) an analog-to-digital (A/D) converter unit, as most of the measured data are analog signals, (5) a micro-processor unit, which is needed to perform data aggregation and analysis and (6) a data storage unit, which is generally a memory with limited size. Figure 1 shows the architecture diagram of a sensor device.

2.2 Key Design Issues in WSNs

The key design challenges in providing effective WSN deployment and operation can be summarized as follows:

- Hierarchical architecture (clustering): Providing effective clustering mechanisms for WSNs is essential to provide a scalable approach to routing and network management in a large-scale WSN as well as prolonging network life-time.
- Coverage and redundancy elimination (using sleep/wakeup mode): Providing efficient deployment mechanisms that guarantee network connectivity and field coverage with minimum possible sensor redundancy is essential to prolonging network life-time without affecting coverage and connectivity.
- Channel access (MAC): Providing efficient MAC protocols that well-suit the unique characteristics of WSNs is important to guarantee proper functionality and preserve nodes' energy.
- Localization and attribute-routing: Providing efficient localization mechanisms is essential in the operation of WSNs, as most of the sensed data and measurements are attribute-based. Localization facilitates attribute-based routing, which indeed preserves network energy.
- Cooperative signal processing (multi-model sensing): Designing effective data aggregation and processing algorithms is very important to reduce communication overhead and prolong network life-time.

3. WSN Design Requirements and Operation Modes For Gas Monitoring Applications

3.1 Key Design Requirements

It is well-known that acquiring information from the inside of a burning/gas-leaked closed area is a challenging problem. Required information by the fire department/control unit can be remotely obtained using WSNs. The different information and the potential WSN solutions are given in Table 1 [27]. Depending on the application requirements, each sensor node can be equipped with one (or more) kind of the aforementioned sensitive sensor units.

Table 1. The different information needed for fire-fighting applications and sensing solutions.

Types of Needed Information	**Needed Sensor Device**
Information about the proximity of fire-fighters to danger.	Temperature, smoke, oxygen and olfactory sensors
Information required to decide on the likelihood of flashover.	Temperature sensor
Information required to decide on the possibility of backdrafts.	Oxygen sensor
Information needed to detest hidden.	Temperature and smoke sensors
Information needed to identify structural collapse issues.	Accelerometer sensor
Information regarding the existence of gas leaks (gas concentration).	Gas sensor

3.2 Operation Modes: Data-Collection *versus* Event-Detection Design

As stated before, two main types of WSNs can be implemented: pre-deployed and on-the-fly WSNs. The pre-deployed WSNs are categorized as event-detection networks, whereas an on-the-fly WSN can be characterized as a data-collection network. In fire-fighting applications, in which data collection and reporting are the main objectives, the sensors will be responsible of collecting data on short-duration basis and then sending information to a command centre. Thus, the sensor should remain awake during the operation. However, in the gas-leakage applications, where a WSN is to be used for event detection, the sensor nodes must stay into sleep mode if there is no event to report, which preserves their precious limited energy. Figure 2 depicts a network model for an IoT-enabled WSN that can be used for LPG monitoring.

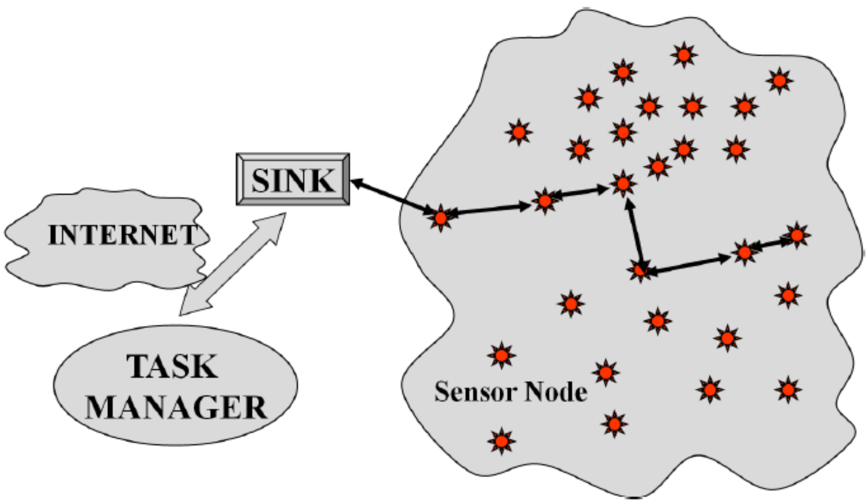

Figure 2. An illustrative WSN with a pre-deployed IoT-enabled WSN.

4. Existing WSN Solutions for Gas-Monitoring and Fire-Fighting Applications

Several designs have been proposed to utilize the WSN technology fire-fighting and LPG-gas leakage monitoring and processing applications (e.g., [23]- [56]). In [23], [24], the authors proposed a multi-level cluster-based WSN for gas-leakage detection applications that provides early-warning alarms in case of LPG leakage. They provided communication protocols and hardware implementations based on cognitive radio technology. In [25], a wireless gas sensor network (WGSN) is designed for explosive gas detection. In case of gas leakage, the sink node sends an alert message to the command center using GSM/GPRS or Ethernet connection. Such system can use a wireless actuator to autonomously control gas emission source.

In [26], the authors designed a gas-leakage sensing device with networking capability to form a WSN. The developed WSN creates a smart platform that collects, processes and analyzes the sensed information, in which an access to the sensed data is made available anywhere and anytime. A method for unauthorized access detection to oil or gas pipes is presented in [28]. This can be accomplished by measuring the protective cathodic voltage and reporting any differences in the measured voltage, which can be used as an indicator of a technical failure or an unauthorized access to the pipe. In [29], the authors proposed the use of the Electronics Line Ltd's wireless gas-leak detector. Such line is capable of detecting mixtures of air and hazard gases (e.g., butane, methane, natural gas and propane). In case of detecting gas leakage, the detector sends notification messages to the control panel. In [30], the authors proposed a practical gas-leak detection system that consists of two main modules: a detector with wireless capability module and a wireless hand-held remote module. The hand-held module is responsible of displaying the gas-leak level and rate as sensed by the detector in alphanumeric values. The remote module and the detector module communicate over a wireless channel to exchange data.

A WSN prototype for hydrogen gas-leak detection was manufactured to be used in hydrogen filling stations [31]. The manufactured WSN prototype consists of ten sensor devices that are able to detect hydrogen gas leakage and track the spatial distribution of the leaks. In [32], the author developed a WSN to provide safety in Petrochemical Industry. The developed WSN is meant to reduce the time of rescue operation. The system in [32] can wirelessly report the data from the monitoring sites to the command controller (sink). The authors in [32] proposed two design variants for their WSN system: fixed-point and dynamic-mobile monitoring variants. A WSN for monitoring gas emission levels in industrial facilities is developed in [33]. When the emission level increases above a threshold level, the proposed WSN generates alarm messages containing the emission levels.

In [34], the authors developed a context-aware WSN system that provides tacit networking between fire-fighters. Each fire-fighter is equipped with a WiFi capable PDA that contains a sensor device. The sensor device in the PDA collects the required information from other nodes that are pre-existing inside the building to notify the fire-fighters of any danger and possible hazards. The pre-allocated sensors are also used as location anchors, which enables the fire-fighters to explore their path inside the building. The paper in [35] addressed the high energy consumption of the LPG sensor unit, which can result in fully depleting nodes' energy keeping no enough energy to transmit alarm messages. To solve this problem, the authors advised the use of two power supplies: digital and analogue. The digital supply feeds energy to the processing and RF communication sub-units and the analogue one provides energy to the sensing sub-unit. In [36], the authors presented a novel design of a WSN for mine safety, called WMSS. In WMSS, the underground node deployment satisfied the principle of minimum coverage (using minimum number of nodes while ensuring coverage). Sensor nodes consist of a gas-sensing unit, a micro-embedded processor from ATMEL and a wireless communication module operating on the 2:4 GHz-band. The operating system used in each sensor node is the TinyOS (Tiny Micro Threading Operating System). TinyOS is affair-driven with 2-level scheduling: task and hardware levels. Once a task is being scheduled, other tasks cannot interrupt it. TinyOS maintains a task-scheduling table based on a simple first-in-first-out (FIFO) algorithm. When the table has no entries, the sensor node is switched into sleep mode unless an affair awakes it. The system in [36] has implemented an energy- saving strategy that is based on a dynamic energy consumption control and management through employing efficient and dynamic/adaptive voltage monitoring mechanisms.

The authors in [37] proposed a framework for residential fire detection system based on interval-message-ration metric. They showed that their framework is applicable for any disaster recovery situations. In [37], an alarm system was proposed to assist with fire-fighting operations. In this system, temperature, humidity and light sensors are considered in an operating environment that cannot be easily accessed. The proposed design accounted for the scenario, where sensor devices can be destroyed by the fire. The authors in [38] developed a GPS-based WSN for realistic fire detection in forests, where each senor device contains a thermometer. The authors proposed a dynamic routing protocol, as sensor nodes might be destroyed by fire. They also indicated that deploying 3 sensor nodes to monitor a given location is sufficient for accurate fire detection.

The system model in [39] illustrated the design and implementation of a WSN for smoke detection. The objective of the implemented WSN is to provide timely alerts and put off all smoke sensor units in the WSN when at least one smoke sensing device goes into off mode. Each sensor node consists of a PIC micro-controller (the software elements consist of programs and codes that are uploaded into the PIC), temperature and smoke sensors, limited-power battery and RF radios. The proposed WSN was tested and showed a proper operation. The authors in [40] developed a WSN that detects temperature, humidity and smoke based on multi-parameter coincidence technique. A multi-parameter wireless node with intelligent fire-detection capability is developed. Such capability integrates signal detection and signal processing within the detector without using the RF communication circuitry. This enhances signal detection accuracy. According to the proposed WSN in [40], each sensor is equipped with three sensing devices: temperature detection device, humidity detection device and photoelectric-type smoke detection device. The operating principle of the photoelectric device is based on the fact that smoke particles of the same wavelength re-radiate energy when smoke particles interact with light. Smoke particle signal detection is accomplished using a transmitting and receiving pair of infrared light diodes. The transmitting infrared diode sends light pulses to the detection area. When no smoke particles are present in the detection area, the emitted light will not reach the receiving diode because of the light resistance shading plate. In case of fire, smoke particles will exist in the detection area and hence the infrared light will be scattered by the existing smoke particles, resulting in reaching the photodiode and exciting a current signal that increases with the intensity of smoke. However, this scheme may trigger false alarms due to some other particles other than smoke particles.

The work in [41] proposed a wireless gas sensor network (WGSN) for monitoring and identifying of hazard gases in buildings, residential and industrial facilities, with the use of solid-state types of sensors with metal oxides (e.g., tungsten-oxide). A heating element is used in each sensor node to regulate the sensor temperature, since this gas sensor exhibits different gas response characteristics at different temperature ranges. Solid-state sensors are adaptable and long lived. These sensors have the ability of detecting very low to very high LPG concentration, making them suitable for identifying/monitoring poisoning and dangerous/explosive gas levels. However, a solid-state-based WSN has poor selectivity toward a gas to be detected. Worse yet, solid-state-based sensors consume high power, which requires a bulky and continuous power supply. The paper in [42] developed a new wireless sensor device for CO_2 and LPG level monitoring using spectroscopy absorption mechanisms with C-band type laser diodes. The proposed sensor unit integrates optical fiber sensor devices with wireless networking capabilities, which can realize a distributed remote gas monitoring on real-time basis using low-cost/low-power RF radios CC2500. In [43], a WSN was used for gas and fire detection in indoor and outdoor environments. In this work, the authors proposed a monitoring system for safety and environmental monitoring scenarios. The developed system includes: sensing mechanisms, over-the-air programming (OTAP), gas detection (for oxygen (O_2), methane (CH_4), temperature level, carbon monoxide (CO), carbon dioxide (CO_2), flammable alcohols and nitrogen dioxide (NO_2)), GPRS unit (capable of providing SMS messaging or direct calls, FTP database to upload and download data, Internet connection using TCP/UDP), GPS unit (capable of providing global time-synchronization, longitude, latitude and velocity), e-mail server (capable of generating e-mail updates on regular basis associated with the operation of the network).

In [44], the authors developed a centralized monitoring and early gas-leakage detection system using WSN nodes that are based on a microcontroller and control system. The developed system uses XBee PRO S2B nirkable devices to enable wireless networking to send the sensed data to a PC and software-integrated Visual Basic. In [45], the authors have developed a WSN for detecting gas leakage by pacing sensors around the gas tube and its distribution line. They used MQ-6 as a gas sensor and wireless Bluetooth module HC-05. Upon detecting gas leaks, the sensor wirelessly sends the data to an Arduino module that activates an explosion prevention system. In [46], a WSN is designed to detect, monitor and control the hazardous gas hydrogen sulfide in an industrial transportation system. Each sensor node in this design consists of an advanced PIC 18F4550 microcontroller along with sensing and signal conditioning capabilities and an IEEE 802.15.4 slandered-based ZigBee module. The sensed data is sent to a sink node that can close the main valve of the gas source. A wireless sensor actuator network (WSAN) was developed in [47] to monitor, detect and control the leakage of hazardous gases in an industrial transportation system to prevent catastrophic accidents. Each sensor-actuator node in this design is equipped with a PIC 18F4550 microcontroller along with sensing devices and an IEEE 802.15.4. A sink node can perform a control electromechanical action. In [48], hardware and software implementations are proposed to enhance safety and effectiveness of fire-fighting operations. The developed system contains three main subsystems: (1) a WSN referred to as SmokeNet, which is the main part of the system, (2) a display subsystem that is head mounted for each firefighter referred to as FireEye and (3) a command system referred to as eICS. The eICS is a visual display that shows information including location of fire-fighters and their biometric data. TinyOS is used to implement SmokeNet, which utilizes Crossbow wireless smoke and temperature sensors. When no alert is generated, sensor devices sense the status of the environment every 10 seconds and transmit the sensed data along with their battery level to a central command node every 5 minutes. Once a fire is detected, a sensor device generates alarm messages that switch the entire WSN to the alert state. In such state, each sensor node senses the occurrence of fire in a time scale of 5 seconds and transmits the collected data to a control unit every 2 minutes in case of no fire detection to verify that the network is still correctly operating (i.e., alive) [48]. The works in [49]-[54] also used the same design methodology of those proposed in [46]-[47] and [48].

Very few works have been proposed to design IoT-based LPG early detection systems (e.g., [55]-[57]). In [55] and [56], the authors modified an existing safety system that is already implemented in industries, homes and offices by designing microcontroller-based LPG and propane gas detecting and alerting system. The LPG concentration is continuously monitored and reported to an LCD display. If the LPG level exceeds the accepted level, the system immediately generates an alarm message (e-mail) and sends it through the Internet using ARM development board to the person in charge. In [57], the authors developed an LPG leakage detector that is connected to the Internet (IoT-capable) using ESP module and Arduino controller. This system is used to detect LPG leakage from cylinders and alert the users through IoT software. However, the aforementioned proposed IoT-based systems were designed as stand-alone sensing systems that do not fully utilize the WSN technology. Table 2 summarizes the various surveyed WSN/IoT approaches in terms of IoT support, wireless transmission strategy, deployment strategy, networking support and the type of used sensing device.

Table 2. Comparison between the various surveyed WSN/IoT approaches.

System Design	IoT Support	Transmission Module	Deployment Strategy	Networking Support	Sensing Device
Multi-level cluster-based WSN [23]-[24]	Partially (Integration with Internet services)	Cognitive Radio Module	Pre-deployed cluster network	Yes	Gas sensor MQ6
WGSN in [25],[27]	Partially (Integration with Internet services)	ZigBee module (IEEE 802.15.4 protocol) and GSM/GPRS connection for sink	Pre-deployed flat network	Yes	2D semiconductor sensor
Visual WSN in [26]	No	Long Range-Low Power Data Radio Modem LR96	Pre-deployed flat network	Yes	Visual and gas leakage sensors
Stand-alone gas-detection wireless systems [28]-[30]	No	A detector with wireless capability module and a wireless hand-held remote module	Pre-deployed flat network	No (Stand-alone warning systems)	2D semiconductor sensor
WSN prototype for hydrogen gas-leak detection [31]	No	Generic 433 MHz transmitter/reciever wireless module	Pre-deployed flat network	Yes (10 wireless nodes)	Field-effect-transistor (FET) sensors with a diode thermometer
Gas leak detection-location system based on ZigBee [32]	No	2.4 GHz IEEE 802.15.4/ZigBee Module (CC2430)	Hybrid (Pre-deployed and on-the-spot dynamic-mobile nodes)	Yes	Gas sensors MQ4 and MQ6
Siren system: a context-aware WSN [34]	No	2.4-WiFi capable PDA	Hybrid pre-deployed and on-the-spot (tacit networking between fire-fighters and pre-existing nodes inside building)	Yes	Generic temperature sensor, gas sensor, and smart dust sensor

Energy-efficient LPG WSN system [35]	No	ETRX357 ZigBee transceiver (IEEE 802.15.4 protocol)	Pre-deployed flat topology	Yes	Catalytic gas sensor (e.g., DTK-2, NAP-66A)
A mine safety system based on WSN (WMSS) [36]	No	2.4 GHz ZigBee module	Pre-deployed nodes and movable nodes	Yes	Generic gas sensors
Residential fire detection system based on interval-message-ration [37]	No	A Zigbee-module based on IEEE802.15.4	Pre-deployed (ten sensor TIP710CM motes)	Yes	Generic temperature, humidity and light sensors
Firementor: A GPS-based WSN for realistic fire detection in forests [38]	No	RF transceiver CC1000Chipcon (433MHz)	Pre-deployed (deploying 3 sensors in a given location is sufficient for fire detection)	Yes	Electronic thermometer sensor
A wireless smoke /fire detection system [39]	No	FSIOOOA 315 MHz Wireless Radio Transmitting Module	Pre-deployed	Yes	Photoelectric smoke and thermometer sensors
a WSN based on multi-parameter coincidence technique [40]	No	CC2420 Series 2.4 GHz RF Transceiver (IEEE 802.15.4 protocol)	Pre-deployed	Yes	The intelligent temperature and humidity sensor chip SHT11
A WGSN for monitoring and identifying of hazard gases [41]	No	2.4 GHz ZigBee module (IEEE 802.15.4 protocol)	Pre-deployed flat topology	Yes	Solid-state types of sensors with metal oxides (e.g., tungsten-oxide)
Wireless sensor node gas level monitoring [42]	No	The CC2500 module:2.4 GHz transceiver designed for very low-power wireless applications	Pre-deployed	No (Single-node design)	The sensing unit includes laser current and temperature controller, laser diode, thermoelectric cooler, gas cell, photo diode and analogue-digital converter
WSN for fire emergency and gas detection [43]	Partially (Integration with Internet services)	2.4-GHz ZigBee module (IEEE 802.15.4 protocol) and GPRS connection for sink	Pre-deployed	Yes	O_2 sensor (SK-25), methane sensor, temperature sensor, CO/CO_2 sensor, NO_2 sensor (MiCS-2710)
Early detection of LPG gas leakage system [44]	No	2.4 GHz ZigBee Module (XBee PRO S2B) GPRS connection for monitoring node (sink)	Pre-deployed	Yes	Gas sensor MQ-4
LPG gas leak detection and automatic gas regulator system using Arduino [45]	No	Wireless Bluetooth module HC-05	Pre-deployed	No (Single-node design)	Gas sensor MQ-6
Wireless Sensor Actuator Network (WSAN) [46]-[54]	No	IEEE 802.15.4 slandered-based ZigBee module	Pre-deployed	Yes	Gas sensor [49]-[51] Temperature sensor Smoke sensor environmental

					temperature, air pressure around the firefighter [52]-[56]
IoT-based gas leakage monitoring system [55]	Yes	Raspberry pi : a single-board computer with wireless LAN and Bluetooth	Pre-deployed of single-device that sends an alert message (e-mail) to the authorized person *via* the Internet	No (Standalone device with IoT capability)	Gas sensor MQ-6
IoT-based gas leakage monitoring system [56]	Yes	Raspberry pi : a single-board computer with wireless LAN and Bluetooth	Pre-deployed of single-device that sends an alert message (Email) to the authorized person via the Internet	No (Standalone device with IoT capability)	Gas sensor MQ-2
IoT-based LPG leakage detector using ESP module and Arduino controller [57]	Yes	ESP module	Pre-deployed of single devices, where the ESP module is used as Wi-Fi module to connect the with IoT	No (Standalone device with IoT capability)	Gas sensor MQ-6

5. Discussion and Open Research Problems

As demonstrated in the previous section, large number of WSN systems have been designed for fire-fighting, gas monitoring and detection applications based on different wireless communication technologies (e.g., WIFI, Cognitive radio, IEEE 802.15.4). However, most of these designs did not fully exploit the capabilities of IoT systems and WSN technology and did not consider their unique functionalities and requirements. On the other hand, existing IoT-based LPG-detection systems were designed as stand-alone systems that did not integrate the WSN technology. Specifically, when IoT is considered, the sensor nodes can either directly transmit their sensed data immediately or periodically to the Internet (where a server can analyze the sensed data and take action) or operate as a regular sensor by forwarding their sensed data to the sink node. The sink node can be utilized by the IoT system through communicating the gathered data to the Internet. The developed communication protocols, hardware designs and processing mechanisms for WSNs cannot be directly implemented in IoT-based WSNs. Therefore, new designs and communication protocols are needed to fully utilize the IoT functionalities and capabilities in WSNs such that network performance is improved (i.e., delay, throughput, energy consumption, connectivity …etc.).

Specifically, many interesting open design issues are still to be addressed. Considering the IoT capability of allowing sensor nodes to directly communicate their sensed information to the Internet along with their communication with the sink node is quite promising, but their design assumptions and feasibility should be carefully studied. Research should emphasize also on how to communicate the sensed data such that performance guarantees are provided. Moreover, utilizing cloud-computing and storage is very promising in improving IoT-based WSN performance in terms of energy, delay and processing overhead. In conclusion, huge research efforts has been carried out on providing WSN system architectures, but none of them is totally satisfactory in terms of fully utilizing the IoT technology. Therefore, more research efforts need to be carried out to provide comprehensive IoT-based WSN solutions and designs that are well-suited to gas-leakage detection, monitoring and fire-fighting applications while exploiting the additional features and functionality of the IoT architecture and WSN technology.

6. Conclusions

A comprehensive overview of existing and emerging system designs for gas-leakage monitoring and detection using IoT-based WSNs is provided in this survey. We highlighted the main features of such networks and showed the main differences between event-driven and data-collection networks. With the huge advancement of sensing technologies and the emerging wave of large-scale IoT deployment, gas-leakage detection and monitoring techniques are analyzed from the point-of-view of precision, system architecture, simplicity, robustness and energy consumption issues. Furthermore, we summarized the state-of-the-art designs of WSNs for gas-leakage and fire-fighting applications.

We showed that these WSN systems differ in their performance objectives and most of them did not exploit the potential benefits of IoT systems such as allowing sensor nodes to communicate their sensed data directly to the Internet and utilizing cloud processing and storage capabilities. We also showed that the existing IoT-based systems for LPG leakage detection were designed to operate as stand-alone sensing systems that did not exploit the WSN technology.

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ملخص البحث:

لقد أعطت التطورات المتسارعة في مجال شبكات المجسات اللاسلكية دافعاً قوياً لتوظيف إنترنت الأشياء على نطاق واسع في العديد من التطبيقات والخدمات. أحد هذه التطبيقات يتمثل في استخدام عُقَد المجسات اللاسلكية في رصد تسرّب الغاز والكشف عنه. والجدير بالذكر أنّ من شأن مثل هذه التطبيقات لإنترنت الأشياء أن توفر حماية أفضل لرجال مكافحة الحرائق وتؤمّن شيئاً من السلامة والإنذار المبكر في الوقت المناسب للأفراد والشركات والمؤسسات على حدّ سواء.

في هذه الورقة البحثية، نسلّط الضوء على الخصائص التي تتفرّد بها شبكات المجسّات اللاسلكية، ونناقش المتطلبات التصميمية لتلك الشبكات فيما يتعلق بتطبيقات رصد تسرّب الغاز والكشف عنه. كما نناقش الاختلافات الرئيسية بين حلول شبكات المجسّات اللاسلكية القائمة على جمع البيانات وتلك القائمة على الكشف عن الاحداث.

من جهة أخرى، تتضمن هذه الورقة مراجعة تفصيلية للدراسات والبحوث السابقة التي تم إنجازها في مجال توفير حلول عبر شبكات المجسات اللاسلكية للتطبيقات المتعلقة برصد تسرّب الغاز والكشف عنه.