

Review

Enabling Emergent Configurations in the Industrial Internet of Things for Oil and Gas Explorations: A Survey

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Abstract: Several heterogeneous, intelligent, and distributed devices can be connected to interact with one another over the Internet in what is termed internet of things (IoT). Also, the concept of IoT can be exploited in the industrial environment for enhancing the production of goods and services and for mitigating the risk of disaster occurrences. This application of IoT for enhancing industrial production is known as industrial IoT (IIoT). Emergent configuration (EC) is a technology that can be adopted to enhance the operation and collaboration of IoT connected devices in order to improve the efficiency of the connected IoT systems for maximum user satisfaction. To meet user goals, the connected devices are required to cooperate with one another in an adaptive, interoperable, and homogeneous manner. In this paper, a survey of the concept of IoT is presented in addition to a review of IIoT systems. The application of ubiquitous computing-aided software define networking (SDN)-based EC architecture is propounded for enhancing the throughput of oil and gas production in the maritime ecosystems by managing the exploration process especially in emergency situations that involve anthropogenic oil and gas spillages.

Keywords: industrial internet of things; emergent configurations; maritime industry; oil and gas production

1. Introduction

Many researchers suggested different definitions for Internet of Things (IoT) in the literature. Two concise and important definitions of IoT are presented in [1]. IoT is defined in this paper as an interaction between the physical and digital world where these interactions (physical and digital world interactions) are made possible using a plethora of actuators and sensors. It further defines IoT as a paradigm that embeds computing and networking in any kind of conceivable object where devices and appliances are connected to collaborate with one another in order to achieve some complex task that requires very high degree of intelligence.

In modern-day communication technologies, computing devices such as desktop computers, laptops, palmtops, servers, smartphones etc are interconnected to communicate with one another over the Internet. The concept of IoT tries to incorporate non-electronic everyday objects such as household appliances, clothing, buildings, roads, vehicles, food etc in such a manner that they can communicate with one another and with the Internet by the use of some embedded sensors, actuators

and microprocessors [2–5]. It is documented in [6] that the number of connected things to the Internet currently exceeds the number of people living on the planet. It is also mentioned that the number of things (or devices) connected to the Internet in 2003 is 500 million whereas, the population of the world is estimated to be 6.3 billion people in same year. Furthermore, the Cisco internet business solutions group (IBSG) predicted (in 2011 as documented in [7]) that the number of internet connected devices will rise to about 50 billion by 2020. Presently, John Chambers, the former Cisco chief executive predicts that this number will rise to 500 billion by 2025. This will consequently result in higher revenue opportunities for internet service providers and mobile network operators.

IoT can be adopted for a large number of applications such as smart homes, health care/fitness, smart cities, social life/entertainment, smart environment, agriculture and industries [8–10]. The benefits of IoT can be exploited in the industries so as to yield higher through-put and maximize gains [11,12]. This application of IoT technologies for enhancing the safety of lives and properties as well as for increasing production output in the industrial sector gives birth to the concept of Industrial Internet of Things (IIoT). The oil and gas industry is faced with numerous challenges. One of the major challenges of this industrial sector is the speed and efficiency of drilling operation processes. For this challenge to be effectively addressed, the use of contemporary and autonomous technologies can be deployed to boost oil exploration procedures in addition to speeding up other internal operations. Consequently, a system architecture and benefits of ubiquitous computing-aided software define networking (SDN)-based emergent configuration (EC) are proposed in this article for enhancing the processes of business interactions in the oil and gas industry. Furthermore, this article presents a state-to-the-art review and classification of IoT-based technologies for enhancing the throughput in the stages of industrial operations. Moreover, EC can be adopted for dynamically approaching and engineering IoT systems. It is described as “a set of things with their functionalities and services that connect and cooperate temporarily to achieve a goal” [13]. As aforementioned, EC is proposed for managing oil and gas spillages in maritime environments during offshore oil and gas explorations. The rest of this paper is structured as follows. Section 2 presents a concise review of the concept of IoT while the applications of this technology especially across the industries is presented in Section 3. In Section 4, the application of EC in combating oil and gas emergencies for offshore maritime hydrocarbon exploration is propounded while the conclusions from this research presented in Section 5.

2. Overview of Internet of Things Applications

The paradigm of IoT involve equipping everyday objects with identifying, sensing, networking and processing capabilities that enable the objects to communicate with one another and with other devices and services over the Internet in order to solve a particular task [6]. The importance of the features of IoT technologies in human lives cannot be overemphasized. This technology (IoT) is essential for building smart societies, enhancing the throughput of industrial processes and for boosting security systems as summarized in Figure 1. In smart society applications, IoT is employed for building smart homes, smart offices and intelligent environments, where sensors embedded devices are deployed for efficient management of public assets and resources. Additionally, IoT technology is useful for urban management, where information and communication technology (ICT) models are brought into service for addressing the ever-growing urbanization challenges. In IoT urban management applications, electronic data collection sensors are employed for improving the quality of life. This is achieved by the transmission of information using wireless and cloud-based technologies in order to enhance business transactions and influence better daily decision making by the citizens living across municipalities.

It is briefly mentioned in Sections 1 and 3 that the benefits of IoT can as well be exploited to boost the production of industrial output in addition to protection of industrial lives, properties and environment. The manufacturing, transportation, healthcare, energy and food production sector of an economy are prominent industries that exploit the benefits of IoT technologies as summarized in Figure 1, where smart sensors are deployed to monitor environmental conditions. The manufacturing

industry comprises of automotive industries, consumer electronics and pharmaceuticals etc. Additionally, IoT applies to the transportation industry with specific reference to aviation, smart car production, smart parking, 3D assisted driving and traffic congestion management. Home healthcare, hospital management, electronic health (e-health) and mobile health (m-health) are all examples of IoT applications in smart healthcare industries while smart grid and lightning are applications of IoT in smart energy environments. Smart sensors and actuators can also be used to control agricultural equipment and pumps while regulating environmental conditions such as temperature, pressure, chemical levels of the soil and humidity. This present-day technology (IoT) can also find application in the oil and gas sector. In this paper, the application of IoT in offshore oil and gas exploration using the concept of emergent configuration (EC) is presented in Section 4.

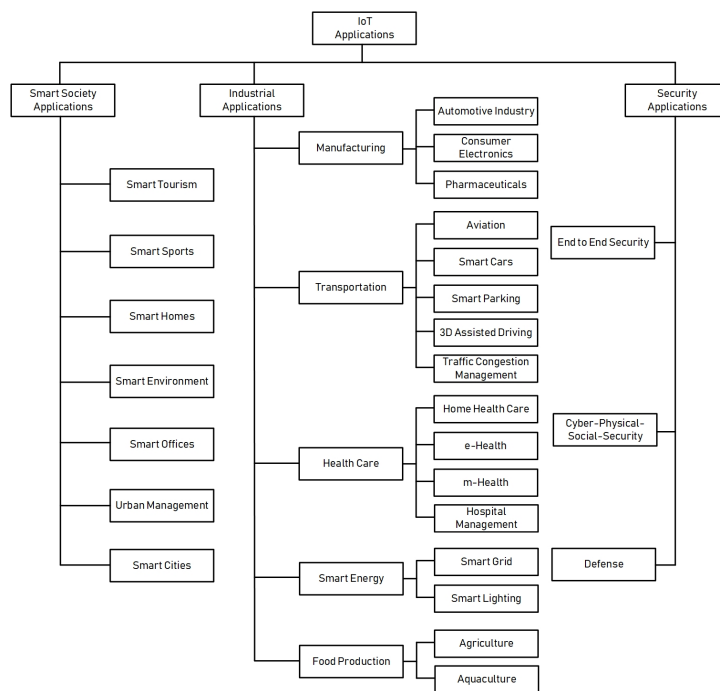


Figure 1. Summary of IoT Applications.

The concept of IoT generally finds pragmatic applications in security systems. End to end security scheme is an essential rumination for implementing IoT technologies. It is worthy to mention that IoT devices can be expertly coded to offer enhanced integrity and confidentiality of the transmitted messages. Methodical end to end encryption on devices, networks, and cloud infrastructures can prevent hackers (or attackers) from unauthorized access to user information (or properties). Furthermore, professionally programmed IoT-based software applications in sensor embedded computing devices can be exploited to enhance the operation of IoT-based systems. The implementation of these well-organized security sensor devices find use in home automation, industrial machine-to-machine (M2M) communication, electronic wearables and smart energy grids etc., for device tracking and monitoring. On the other hand, cyber-physical-social (CPS) computing involves the processing of data/knowledge obtained from the CPS world for the integration, correlation, interpretation and provision of relevant abstractions to individuals for meaningful decision-making [14,15]. Also, CPS systems (CPSS) consists of the interaction between the cyberspace, physical space, human knowledge, and sociocultural elements for meaningful decision making. The importance of CPS security cannot be overemphasized in cyber-physical systems. CPS security is required to mitigate the security vulnerability of cyber-physical systems such as intelligent transportation systems, healthcare, smart grid and so on against unlicensed users. The IoT technology can be exploited in the defense sector to stimulate/enhance the economic growth and public safety of any nation, where sensor embedded surveillance devices and other electronic wearables are employed for motoring/tracking defense equipment, aircraft maintenance/operation, crime detection

and public protection as well as rapid response to other emergency services. Aerospace comprising of commercial and military aviation and use of unmanned aerial vehicles (UAV) are also prominent areas where the benefits of IoT is exploited to aid security and defense of citizens which proportionally foster economic growth of the nation.

To improve industrial productions, the benefits of IoT was exploited in manufacturing industries such that smart factories are built using cyber-physical technologies. The authors in [16] propose an IoT-based hierarchical architecture for smart factories, where key technologies such as IoT, big data and cloud computing are used to enhance industrial productions. Contemporary research works have also reviewed the benefits of present-day IoT-enhanced technologies such as blockchain, software define networking (SDN) and network function virtualization (NFV) for IIoT applications as documented in [17–21]. Furthermore, numerous IoT-based technologies were proposed for improving the output of industrial operations in the transportation, health care, smart energy and agricultural sector in particular. Refs. [22–32] discuss recent research works in the aforementioned IoT applications.

2.1. Internet of Things and Next Generation Networks

The current 4G/LTE networks in comparison with the previous generation of networks is designed using Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) technology to specifically offer higher data transmission rates in addition to enhanced system capacity due to the high demands for the sparely available radio frequency spectrum. As earlier mentioned, it is estimated that the number of internet-connected devices will exceed 50 billion by 2020. Hence, it is required that contemporary network technologies with the capability of offering higher data rate applications, ultra-low/reliable end-to-end latency, very high reliability/scalability, improved security features in addition to low power consumption capacity be developed so as to enhance the quality of service (QoS) delivery in addition to the quality of experience (QoE) requirements of network users. As such, next-generation (xG) networks are carefully designed to meet the above-mentioned fundamental requirements. It is important to mention that the emerging xG network is the 5G network of technologies which are designed to offer about 10–100 times higher data rates in addition to lower energy consumptions as compared to the current LTE-based networks. Consequently, about 10 enabling technologies were proposed as promising air interface for realizing xG networks [33]. These technologies include SDN, NFV, massive Multiple Input Multiple Output (MIMO), radio access techniques, mobile cloud computing, millimetre-wave communication, IoT, Device-to-Device (D2D) communications, green communications and ultra-densification. 5G networks generally possess the capabilities of managing and supporting the high demanding requirements of D2D-based IoT communication applications by integrating numerous heterogeneous access technologies for seamless connectivity of devices/objects with the internet. Refs. [34–37] provide a comprehensive review of architecture, business models, technology drivers, and applications of IoT for xG networks.

3. Internet of Things in Industrial Applications

The concept of IoT can be deployed in the manufacturing sector to boost production efficiency and reduce manufacturing cost without compromising the quality of the industrial products. Industrial internet of things (IIoT) [38] involves the deployment of the concept of IoT and its technologies in industrial systems such as small-scale and automobile manufacturing sector, transportation, medicine, and logistics systems. Adopting the IoT concept in industries and smart factories offer several operational benefits such as test time reduction and calibration, production downtime minimization, warranty cost reduction, improved yield, quality and supply chain efficiency as well as the performance of predictive maintenance [39–41]. In this section, a review of IIoT is presented. In addition, findings from recent research works in the area of IIoT as documented in the literature are summarized and illustrated in Table 1. To sum up this section, recent research efforts made particularly in the maritime industrial internet of things is documented in Section 3.2 and summarised in Table 2.

Table 1. Summary of research trends in the IIoT.

Reference	Aim of Research	Technological Approach	Methodology	Contributions	Obtained Results/Conclusions
[41]	To address the key distribution challenges of end-to-end private key cryptography using BYOK principle based on NFC technology in order to enhance the protection and confidentiality of transmitted data in IIoT environments.	Transfer of generated key materials using NFC technology between devices with use of authenticated encryption (AE) for cryptographic protection of transferred data.	A prototypical implementation of end-to-end encrypted data transfer using Nexus S smart phone installed with Android 4.1.2 Jelly Bean.	Development of key generation technology using BYOK principle based on the trustworthiness of devices and operators.	The developed BYOK prototype demonstrated robustness against external effects that may occur due to adding more interfaces into manufacturing devices.
[42]	A review of current research trends, industrial challenges, technologies and application of IoT in industries for fire disaster management.	Use of low power and low cost multiple sensor nodes for WSN-based fire detection and elimination applications in industries.	Extensive literature review.	<ul style="list-style-type: none"> • Development of a four-layered IoT-based SoA for industrial fire disaster management. • Description of issues/challenges in the fire industries. 	IoT-based devices can be deployed for automated monitoring, management, control and maintenance of fire disaster occurrence/equipment in industrial applications.
[43]	Minimization of fire accidents using IoT-based technologies in the fire industry.	Use of fused sensors that are integrated based on copula theory.	Fusion of temperature and relative humidity sensors for fire detection and use of a fusion center for integrating all network node decisions in order to enhance final decision making.	Development of a novel fire detection method based on copula functions.	Copula-based detection scheme outperforms two other existing schemes when compared for local fire detection.
[40]	To investigate the characteristic performance of IoT-aided robotic aided systems for environmental monitoring.	Use of IoT devices connected to a drone (UAV) for environmental monitoring and creation of IoT network for environmental data sensing.	Extensive experimental analysis to determine the pros and cons of IoT-aided robotic systems.	<ul style="list-style-type: none"> • Documentation of the scientific background and interaction of robotic systems over 6TiSCH technology. • Development and documentation of experimental testbed that evaluates the operation of connected IoT devices on robotic systems. 	<ul style="list-style-type: none"> • IoT-aided objects do not attract significant overhead as a result of onboard IoT-based equipment (e.g., mote). • Surveying and patrolling activities of IoT-aided robotic systems are achieved with good performance in terms of network joining time, packet loss ratio and data retrieval delay.

Table 1. Cont.

Reference	Aim of research	Technological Approach	Methodology	Contributions	Obtained Results/ Conclusions
[44]	<ul style="list-style-type: none"> • Development of an energy-efficient and robust time synchronization scheme (without isolated nodes) named R-Sync, for the IIoT. • Design of a root selection algorithm that extends the life time of sensor networks achieved by balancing energies between nodes. 	Use of two timers where one is used for time synchronization while the other is used for connecting isolated nodes to synchronized networks.	Experimentation through computer-based simulation using NS-2 as well as experiment testbed using wireless hardware nodes where the proposed R-Sync is compared with existing synchronization schemes such as TPSN, GPA and STETS.	<ul style="list-style-type: none"> • Implementation and performance analysis of a novel robust time synchronization scheme (R-Sync) for IIoT. • Development and documentation of a root node selection algorithm for balancing sensor node energy consumption. 	<ul style="list-style-type: none"> • Simulation results showed that R-Sync consumed less energy in comparison to GPA and TPSN, showing best performance in densely connected and large-scale networks. • Percentage of synchronized nodes is more in R-Sync in comparison to STETS. • Energy consumption of R-sync is more balanced than GPA and TPSN.
[45]	To develop optimal ticket-based QoS routing protocol using generic algorithms for smart grid WSN applications.	Use of GA-TBR algorithm for optimal route selection among sensor nodes in smart grid WSN applications.	Use of genetic algorithms for improving the initial population with high-quality outcomes which consequently improves the discovery of route selection using TBR	<ul style="list-style-type: none"> • Design and implementation of an efficient, reliable and low computational complexity GA-TBR algorithm for optimal route selection in accordance with a predefined set of QoS requirements using minimal probing tickets. • Evaluation of an in-depth performance analysis of GA features such as validity checking in addition to fitness function 	Results obtained demonstrated that the proposed GA-TBR scheme offers 28% improvement in the routing selection path as compared to the IEEE 802.11s adopted AODV.

Table 1. Cont.

Reference	Aim of research	Technological Approach	Methodology	Contributions	Obtained Results/ Conclusions
[46]	Design of novel SDN IIoT-based technology for resiliency support during failures or natural disturbances in smart grid networks.	Exchange of updating information with the associated SDN switches by use of OpenFlow protocol. Experimental validation of proposed SDN platform for enhanced resilience in smart grid applications using three topologies named fault detection, conventional network and network upgrading topology.	Use of SDN controller in smart grid networks for multi-functionality control and optimal performance using real-time data monitoring.	<ul style="list-style-type: none"> • Development of SDN platform for industrial real-time data energy profiles dynamic route establishment for grid control in smart grid IIoT networks. • Evaluation and documentation of different topologies for re-routing data among SDN switches in smart grid applications. 	<ul style="list-style-type: none"> • The network upgrading topology demonstrated lower end-to-end latency at all interval of time in comparison to conventional network topology which offered lower latency as compared to fault detection scenarios. • Network upgrading scenarios offered highest data flow traffic at various time intervals in comparison to other scenarios. • The dynamic end to end route can be achieved within tens of milliseconds.
[47]	<ul style="list-style-type: none"> • To review fog computing infrastructures and protocols in application to IIoT. • To identify IIoT challenges and proffer working solutions to the mentioned. 	Description of routing protocols, resource allocation methods and load balancing for fog computing in application to IIoT.	Description and classification of fog computing technology in particular application to sensor enhanced industrial operations.	<ul style="list-style-type: none"> • Review and documentation of state-of-the-art techniques in application to fog computing technology for enabling IIoT. • Comprehensive classification of the “industrial revolution” theory in relation to enabling IIoT. Furthermore, the discussion of elaborate open research domains with respect to fog computing as an enabler in application to IIoT is presented. 	<ul style="list-style-type: none"> • The fog computing technology gives an alternative platform for controlling, computing, managing and storing IIoT devices in comparison to cloud computing techniques. • Fog computing will enhance sensor supported industrial operations when integrated with efficient communication technologies such as SDN, NFV, 5G, and CPS systems.

Table 2. Summary of Contemporary Research Works in the Maritime IoT.

Reference	Aim of research	Technological Approach	Methodology	Contributions	Obtained Results/ Conclusions
[48]	To develop High-speed maritime communication system based on LTE technology that is capable of supporting high data rate applications in the communication range of 100 km.	Connection of marine BSs to LTE-maritime testbed centres consisting of numerous servers, evolved packet core (EPC) equipment and entity management systems.	Implementation and performance evaluation of LTE-maritime test bed in addition to conduction of onboard experiments across South Korean sea waters.	Development of a maritime communication network architecture based on LTE technology using remotely mounted (high-altitude) multiple radio and digital units in addition to vessel embedded routers for the enhancement of nautical communication networks in terms of signal coverage and through-put.	LTE-Maritime communication networks can offer higher system data rates (in Mbps) in addition to the provision of longer network coverages in the order of about 100 km for oceanic propagations and activities.
[49]	To develop antenna selection technologies in application to maritime IoT.	Deployment of massive distributed antenna technologies for enhancing QoS-guaranteed communications during the management and operations of maritime activities.	Embedment of routers on marine vessels in addition to subsequent communication network performance evaluation considering numerous on-shore positioned directional antennas.	<ul style="list-style-type: none"> • Development of a user-centric communication model for marine communication systems based on distributed antennas. • Development of antenna selection schemes for coastal communication networks for user QoS enhancement. 	Simulation results demonstrate that the probability of QoS enhancement in marine operations increases with increasing antenna service cloud size. It is shown that maritime operations can be enhanced using dynamic service cloud architecture consisting of accurate antenna selection methods.
[50]	To develop an antenna selection scheme for enhancing maritime IoT communication networks.	Use of MUEs and distributed antennas for communication with on-shore cellular base stations.	A variety of directional antennas are positioned to communicate between seashore BSs and vessel mounted MUEs.	<ul style="list-style-type: none"> • Development of a hierarchical architecture for uplink maritime radio communications. • Development of antenna selection algorithms for supporting QoS requirements in coastal networks. 	The developed antenna selection algorithm is capable of complementing maritime operations by the provision of energy and cost-efficient oceanic communication networks.
[51]	A comprehensive review of wireless mesh communication technologies and protocols for maritime operations.	Development of a typical coastal mesh network and classification of marine communication protocols.	Classification of maritime mesh networks and systems in addition to numerous marine communication protocols.	<ul style="list-style-type: none"> • Review and documentation of coastal communications technologies and networks. • Overview of maritime wireless mesh network communication protocols and their operational mechanisms. 	The research work presents information/guidelines to wireless service providers on the incorporation of the benefits of broadband terrestrial communications technologies with maritime operations.

Table 2. Cont.

Reference	Aim of research	Technological Approach	Methodology	Contributions	Obtained Results/ Conclusions
[52]	To develop a maritime communication architecture capable of providing affordable and real-time broadband access by reducing the power consumption of shipborne base stations through resource allocation techniques.	<ul style="list-style-type: none"> • Development of a novel voyage-based resource allocation (VB-RA) algorithm for shipborne BS switching and cooperative downlink power adjustment. • Development of system architecture for serving sparse marine vessels beyond the coverage of onshore LTE base stations for offloading the expensive satellite traffic. 	<ul style="list-style-type: none"> • Use of voyage-based shipborne BS switching actions for recovering blocked user ships from link failures and inter-cell interference mitigation. • Power consumption reduction by considering the sailing positions of the farthest user ship of individual shipborne BS during adjustment of downlink power of the seaborne-BS. 	<ul style="list-style-type: none"> • Design of a coordinated satellite and terrestrial architecture for marine broadband and real-time access. • Development of a voyage-based cooperative resource allocation algorithm for mitigating the inter-cell interference of shipborne base stations in addition to its power consumption management. 	The developed algorithm demonstrated that the designed coordinated satellite and terrestrial architecture in addition to the voyage-based cooperative resource allocation scheme is capable of providing mobility robustness and efficient system power use for broadband maritime communication networks. The proposed VB-RA scheme offered system improvement as compared to classical allocation methods.
[53]	To review and classify maritime communication technologies in addition to provision of radio engineering challenges for marine environments.	Enhancement of digital maritime communication systems using wide and narrowband access technologies.	Categorization of market pull and technology push marine communications.	<ul style="list-style-type: none"> • Classification and documentation of available digital marine communication technologies • Discussion of marine high north challenges and future trends. 	Coastal regions can be sufficiently covered using terrestrial system technologies such as sub-GHz WiMAX and enhanced wireless narrowband access such as digital very high-frequency technologies.

Table 2. Cont.

Reference	Aim of research	Technological Approach	Methodology	Contributions	Obtained Results/ Conclusions
[54]	To develop an improved OceanNet architecture that will enhance internet connectivity for marine users through coverage distances of over 60 km.	Collection of monitored data using underwater nodes and designing a wireless multi-hop backhaul network for extending signal coverage and connectivity improvement in maritime networks through a selection of the best path from marine user position.	Development of hardware testbed for analysing system performance in terms of throughput and signal coverage.	Development of a hybrid network architecture for coastal networks based on LTE technology for maritime overwater and underwater communication systems.	<ul style="list-style-type: none"> • The developed network architecture offers novel and efficient network potentials for coastal communication systems • Packet delivery ratio is significantly enhanced using the proposed path selection schemes for the benefits of fishermen and other marine users.

3.1. Recapitulation of Contemporary Research Developments in the IIoT

The privileges of wireless sensor network (WSN) technology as earlier-mentioned find rewarding applications in the industries in what is termed IIoT. The numerous benefits of this technology can be exploited in a considerable number of industries such as the fire industry, manufacturing, power generation and transmission industry, security systems etc. Some neoteric findings were made for use of WSN in IIoT and are discussed as follows.

An update of research trends and challenges in the fire industry are summarized as reported in [42]. A SoA for fire IoT consisting of four layers namely *sensing layer*, *network layer*, *service layer* and *interface layer* is also presented in this paper. The importance of IoT in the fire industry cannot be overemphasized as fire security technologies offer warning information to industry owners, security agencies such as police and fire brigade services as well as other emergency management services for the safeguarding of lives and industrial properties. The timely fire information provided by the IIoT technologies can be used to alert occupants/workers to minimize the occurrence of injury, destruction of properties and possible death that may arise from fire emergencies. The fire IoT is designed to integrate several devices which are equipped with identification, sensing, processing, communication and networking devices for the minimization of fire disaster in the industry. Furthermore, IoT technology can be employed in the industries for check-mating the disastrous effects of fire explosions through the fusion of correlated sensor measurements. This IoT-based fire detection technique is achieved by fusing sensor data connected between nodes. As such, a data fusion fire detection method consisting of the fusion of temperature and relative humidity smart nodes is proposed in [43], where the correlation of both temperature and relative humidity sensors are resolved using copular theory. The performance of the proposed sensor fusion-based scheme is compared with existing techniques such as conditional independence sensor scheme and bivariate Gaussian method as proposed in [55]. Results obtained demonstrated that the copula-based detection scheme enhances the performance of local detection across nodes in a significant manner in comparison with the compared schemes. Interested readers are referred to [43,56,57] for further reading on copula functions.

In [40], the concept of IoT is adopted for environmental monitoring under the aid of robotics where the robots are designed to move autonomously while interacting with the environment. A good example of an IoT-aided robotic system is a *self-driving car* [58]. In this paper, an experimental test bed is developed consisting of an IoT device that is connected to an UAV (commonly known as *drone*) which executes a monitoring mission around a specified area with an IoT network for the exploration of environmental data. In general, robotic networks consist of many robots working together in a collaborative manner, where the robots are equipped with sensing, computing and communication devices in order to enhance the exchange of information over a communication network so that a particular task can be effectively accomplished. Results obtained from this paper [40] (which can be developed further in larger-scale environment) shows that onboard of IoT equipment to the UAV does not incur significant overhead while the overall QoS expressed in terms of data retrieval delay, network joining time and packet loss ratio satisfies the requirements of this experiment.

In industrial wireless applications, a robust *time synchronization scheme* is required for efficient exchange of information and data processing. The synchronization schemes are necessary to enhance the collaborative coordination of the wireless sensor nodes in order to accomplish some useful task for the industrial environment. A good number of time synchronization schemes were presented in the literature for achieving high accuracy and productivity in IIoT systems. Pair broadcast synchronization protocol (PBS), group pair selection algorithm (GPA) and spanning tree-based energy-efficient time synchronization (STETS) [44], are a few examples of time synchronization schemes for IIoT as documented in the literature. In [44], a robust time synchronization scheme named *R-sync* is proposed for distributed systems in IIoT that adopts two timers for timing synchronization using two-way message exchange synchronization. A root node selection algorithm is also presented in this paper [44] for balancing the energy consumption of connected sensor nodes and for extending the lifetime of IIoT networks. It is noteworthy to note that energy consumption and accuracy are crucial consideration

points to bear in mind when designing time synchronization schemes because the energy of sensor nodes are usually limited. The performance of the proposed robust synchronization scheme (R-sync) is compared with three existing time synchronization schemes including GPA, STETS and timing-sync protocol for sensor networks (TPSN) using NS-2 simulation tool as well as experimental-based evaluation using wireless hardware nodes. Results obtained demonstrated the superior performance of the proposed R-sync time synchronization scheme in comparison to GPA, STETS and (TPSN). From the results obtained, all nodes were synchronized with greater energy-efficiency hence, the proposed R-sync algorithm demonstrated better timing synchronization in comparison to other synchronization schemes. The number of broadcast messages using R-sync, GPA and TPSN algorithms are compared together in the experiment using different communication range for the entire network, where 240 different sensor nodes are deployed in a random manner over an area. The number of broadcast message is need for analyzing the energy-efficiency of an algorithm as propagating messages require maximum consumption of energy during the life time of a node. Further results obtained from the experiment showed that as the communication range increases, R-sync requires a much lower number of broadcast message in comparison to other analyzed synchronization algorithms. The number of broadcast messages are also compared with different number of sensor nodes assuming R-sync, GPA and TPSN with each node set to a communication range of 85 m. The results obtained demonstrated that R-sync offered the least broadcast messages while increasing much slower in comparison to GPA and TPSN. Based on these results, it can be concluded that the energy consumption of R-sync is much lower than other compared synchronization algorithms especially in large-scale and densely connected IIoT systems.

The IoT technology also finds beneficial applications in the power generation, power transmission and power distribution industries in application to WSN-based smart grid. A smart grid can simply be described as a fast-emerging and next-generation electricity grid technology that aims at enhancing the efficiency and reliability of the present conventional electric power grid infrastructures through the use of contemporary WSN-enhanced communication technologies for the efficient controls and automation of power grid systems. Since the demand and supply of electric power are designed to be automatically controlled using a two-way communication system in smart grid WSN applications, there is an enormous necessity for developing energy-efficient and energy-balanced routing protocols that will coordinate the transmission and reception of electric power for enhanced reliability and efficiency in electric energy consumption. As a result, a ticket-based routing (TBR) optimization using a genetic algorithm is developed for smart grid applications in [45]. Furthermore, a genetic algorithm is used to minimize the overhead of discovery messages in addition to minimizing the number of tickets. This is aimed at developing a novel GA-TBR protocol for optimal selection of routes in WSN smart grid environments. Results obtained showed that the GA-TBR algorithm could select optimal routes with minimum possible delays. More so, a 20% performance improvement is observed when the GA-TBR protocol is compared with the existing IEEE 802.11s (wireless LAN standard for mesh networking) ad-hoc on demand distance vector routing (AODV) protocol. Additionally, the concept of SDN is adopted in [46] for IIoT in the context of smart grid infrastructure, in order to meet the high demands of seamless data transmission during critical events such as natural disturbances or system failures. SDN is a useful technology adopted to enhance the application of IoT in the industry by providing dynamic reconfiguration for the improvement of data network robustness. A new SDN platform is proposed in this paper for IIoT systems in order to support resiliency by reacting immediately whenever a failure occurs. This is fore the recovery of smart grid networks using real-time monitoring techniques. To achieve multi-functionality control and over come the challenges of optimization by operators, a SDN controller is adopted for providing real-time data monitoring in order to manage demand and increase system reliability and resources. The proposed IIoT SDN platform uses a three layer controller namely; *infrastructure layer*, *control layer* and *application layer*. The physical layer carries all physical equipment and hardware components for route switching performance between the network clusters and SDN switches. The devices contained in this infrastructure layer include

smart sensors and actuators, demand response systems (DRS), advance metering infrastructure (AMI) and field bus control. The control layer receives routing information from SDN switches whenever new traffic flows are received by the switches. In other words, it serves as an interface between the application layer and the physical infrastructure. Data path allocation procedures are then allocated by the control layer after which requested paths are processed by the assignment of new routing rules and policies in agreement with the application layer. The application layer is the top most layer of the proposed SDN platform. Services for utility authentication are managed by this layer at the back-end system where information of each service request is exchanged and delivered. Data centers, storage, servers, processing, analysis and applications all constitute the application layer of the SDN platform. Experimental results obtained from this paper revealed that SDN controllers showed great potentials for supporting resilience of smart grids even at faulty situations. The results demonstrated that the dynamic end-to-end reroute can be realized in a few milliseconds, hence SDN-based IIoT systems can significantly improve grid reliability for smart grid resilience enhancement.

The bring your own key (BYOK) principle based on near field communication (NFC) is proposed in [41] for mitigating the drawbacks of end-to-end private key cryptography and factory installed keys in the IIoT systems. For confidential and relevant production information to be transmitted over the Internet in industrial systems, appropriate cryptography methods [59] such as end-to-end encryption using transport layer security (TLS) needs to be employed. Asymmetric cryptography provides an end-to-end encryption method that is not feasible in large data applications. Symmetric cryptography on the other hand, can be adopted for this purpose but requires both the sender and receiver to share the same key as a direct connection cannot be established using Message Queue Telemetry Transport (MQTT) protocols and key exchange algorithms such as the Diffie-Hellman cannot be adopted. The proposed BYOK scheme in this paper is used to mitigate these drawbacks where device owners can change keys needed for end-to-end encryption and NFC technology is employed for transferring key materials between devices. In this proposed method, the transferred keys using NFC technology is protected using authenticated encryption (AE) so as to ensure confidentiality, authenticity and integrity of the transmitted keys. The concept of BYOK principle originates from the bring your own device (BYOD) concept where employees can use their own tablets, laptops, phones and computers in company networks. Two key generating scenarios are also proposed in this paper which depends on the trustworthiness of the connected devices and its corresponding operators. In the first scenario, if an untrustworthy personnel and/or device deploys keys, then the keys will be generated at the back end. The key material is then encrypted and sent to the device and the keys will subsequently be protected from extraction and use by unwanted users with the aid of the applied encryption. In the second scenario, keys are generated directly at the connected device if the personnel and connected devices are considered trustworthy in the second scenario.

3.2. Recap of Present-Time Research Trends in the Maritime IIoT

As mentioned, sensors can be deployed to enhance communication performance and throughput in a variety of industries for higher profit applications and environmental safety procedures. Similarly, sensor networks can still be deployed in the maritime industry to monitor both on-shore and off-shore activities where vessels are embedded with sensors to communicate with one and other in addition to a remotely controlled base station (BS) as illustrated in Figure 2. The propagation of marine signals may also be enhanced using massive directional antennas for better user QoS experience in the maritime sector. As such a limited number of technologies were developed in the literature to address maritime communication systems and will be summarized as follows.

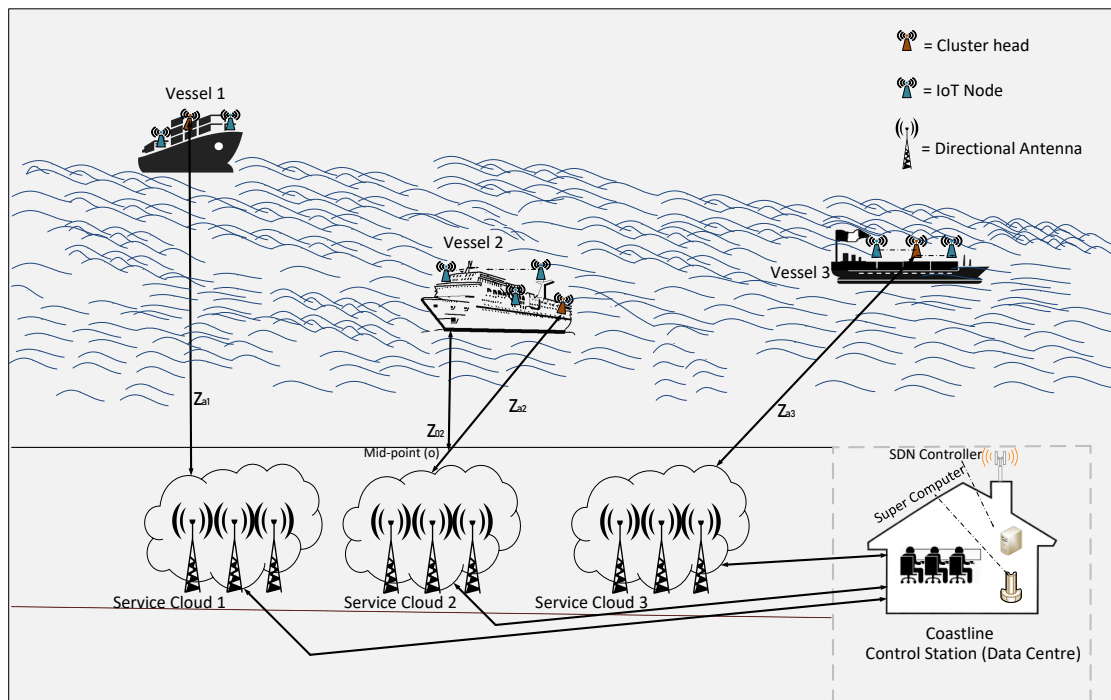


Figure 2. Sensor-based communication architecture for maritime IoT.

An appreciable amount of research works is currently advancing in different parts of the globe (especially in the Republic of Korea) where attempts are being made to improve the performance of maritime operational activities. Consequently, a variety of maritime communication projects such as digital selective calling (DSC), automatic identification system (AIS), navigation data (NAVDAT), very high-frequency data exchange system (VDES) and India project etc., attempted to improve the QoS requirements of nautical communication networks at tremendously low cost. Nonetheless, the maximum data rate offered by the aforementioned riverine communication projects is limited in comparison to other high implementation cost technologies such as satellite communication nexus. Satellite communication systems are generally designed to offer high data rates in addition to continental communication coverages. Nevertheless, these communication systems are not capable enough to efficiently support underwater communication systems and are known to habitually communicate at a significant high cost due to the launching of satellites into the orbit, where onboard antennas require stabilization. As such, geostationary orbit (GEO) and low earth orbit (LEO) satellite projects such as inmarsat, very small aperture terminal (VSAT) and iridium are subsequently developed to provide global oceanic communication coverage at very high data rates and implementation cost. To provide a significant tradeoff between the high cost of satellite communication and a considerable system data rate, the benefits of communication systems such as WISEPORT, TRION, BLUECOM+ and maritime broadband communication (MariComm) are exploited where the characteristics of these nautical communication projects are recapitulated as illustrated in Table 3 [48] while Table 4 [60] presents more information on the various types and main features of satellite orbits. In [52], appreciable efforts are made to support real-time and affordable internet broadband access for maritime communication systems by developing a communication architecture that offers a trade-off between the consumption of network power and the users' communication quality. In this method, shipborne BSs are adopted for maritime operations such that a voyage-based cooperative resource allocation scheme (VB-RA) is designed for mitigating the effects of dynamic system inter-cell interference in addition to user handoff procedures for seamless QoS experiences during thalassic

operations. The VB-RA scheme is designed to do shipborne BS switching for recovering blocked user vessels from link failures in addition to management of the inter-cell interference caused by overlap coverages of shipborne stations. Additionally, this allocation scheme reduces system power consumption by considering the sailing position of the farthest user vessel of individual shipborne BS as a constraint. The proposed scheme is compared with a conventional allocation scheme named dynamic traffic-and-interference aware in terms of signal interference to noise ratio (SINR), number of user ship handover and the number of hand over-related link failures. The proposed VB-RA scheme demonstrates superior performance in comparison to classical methods even when the average power consumption of shipborne-BS is considered. Because of the demerits of satellite and cellular communication systems which include high cost and network coverage for maritime applications, marine users habitually find it difficult to connect with other vessels and people based onshore. To support better communication applications such as extended signal coverages and connectivity improvements, a wireless multi-hop backhaul network is developed in [53] by selecting the best path from marine user devices to onshore-based terrestrial users. This is achieved by the elimination of quality degraded links using system signal to noise ratio (SNR) in long-range Wi-Fi networks. Furthermore, the expected transmission count (ETC) metric of Optimized Link-State Routing (OLSR) protocol is adopted for determining the quality of the links between access routers in the developed ad-hoc mesh networks.

Table 3. A summary of maritime wireless communication project characteristics [48].

System/Project	Communication Technology	Communication Coverage (km)	Maximum Data Rate (kb/s)	Cost
DSC-1	MF/HF	>463	0.1	Low
DSC-2	VHF	120	1.2	Low
AIS	VHF	120	9.6	Low
NAVDAT	MF	556	18	Low
VDES	VHF	120	307	Low
India Project	Low-rate Wi-Fi	52 (ship-to-shore)	3000	Low
WISEPORT	WiMAX (IEEE 802.16e)	15	5000	Medium
TRION	WiMAX (IEEE 802.16d)	14.2 (ship-to-shore)	6000	Medium
MariComm	LTE (ship-to-shore)	120	7600	Medium
BLUECOM+	IEEE 802.16e (air-to-surface)	30	5500	Medium
Inmarsat C	Geo Satellite	Global, except polar regions	0.6	High
Inmarsat GX	Geo Satellite	Global, except polar regions	50,000	High
VSAT	Geo Satellite	Global, except polar regions	46,000	High
Iridium	Leo Satellite	Global	134	High

Table 4. Overview of satellite communication orbits and characteristics [53].

Satellite Orbit	Height over Equator (km)
LEO: Low Earth Orbit	200–2000
MEO: Medium Earth Orbit	10,000–20,000
GEO: Geostationary Orbit	35,786
HEO: High Elliptical Orbit	500–50,000

A synopsis of research progress in the IIoT is briefly presented in Section 3.1. In this section, the evolution of WSN technology in application to the maritime industry is discussed. To begin with, the works done in [48] investigates the viability of high-speed maritime WSN technology based on LTE, where a testbed is developed for pelagic operations constituting the embedment of propagating oceanic vessels with marine routers so that they can easily communicate with coastal-mounted BSs and operation centres for useful decision-making procedures in the monitoring and control of surrounding marine activities. The projects embarked in this work [48] aims at designing WSN-based seawater networks that are capable of providing large volumes and varieties of data services to marine users at considerably high data rates. More so, the enhancement of the maritime communication capacity, data rate and spectral efficiency can be achieved using LTE technology such that the merits of advanced communication techniques such as MIMO and aggregation are exploited to achieve a communication

coverage of about 100 km from the coastline. As previously mentioned, satellite communication networks are known for their high implementation cost. This stimulates the need for the development of more reliable and affordable coastal communication technologies where the benefits offered by routing protocols can be capitalized on for the operation of marine activities. For this reason, an overview of wireless mesh communication technologies and protocols is documented for maritime communication networks. Additionally, future research directions are outlined for deploying wide-area maritime wireless mesh networks. Interested readers are referred to [51] for more information in these developments in addition to the main multi-hop routing protocols established for marine wireless networks. These nautical wireless networks are designed based on the optimized link-state routing protocol (OLSR), ad-hoc on distance vector (AoDV) and ad-hoc on-demand multipath distance vector (AoMDV) protocols.

4. Emergent Configurations in the IIoT

IoT systems consist of distributed smart objects which are designed to be heterogeneous, effectively communicate with one another, autonomous, distributed, managerially and operationally independent. The concept of EC is presented in [61] for engineering the design of IoT systems. EC can be define as “a set of things with their functionalities and services that connect and cooperate temporarily to achieve a goal” [61,62]. A “thing” on the other hand, is defined as any *smart* connected device (or object) with its functionalities and services or applications. For an EC network to be formed, operated and managed, four components must interact, collaborate and coordinate with one another. These components are *user agent*, *emergent configuration manager (ECM)*, *device manager (DM)* and a *set of things*. The User Agent (UA) is usually an object that enables a user to express his/her goals. The UA makes interaction with the EC at runtime while the duty of an ECM is to form, operate and manage the EC at runtime in order to satisfy the goals of the user. The role of the DM in the EC is to register the smart connected devices/objects so as to ensure their connection to the Internet for enhancement in communication and interaction. Additionally, the DM is also responsible for monitoring the availability of smart connected objects while informing the ECM in situations where the connected objects become faulty or are not reachable. Finally, the *set of things* are connected together so that they can cooperate and interact with one another under the supervision of the ECM for the actualization of the goals of the user through the formation of an EC. Based on the above description of an EC, it can be concluded that the UA, ECM and DM all constitute the logical layer of an EC network where they collaborate with one another to achieve a common user goal. Figure 3 presents a diagrammatic illustration of the physical and logical layer of an EC and the interactions between components that form these layers.

In Section 2, a review of IoT architectures, technologies and applications is presented. It is observed from this Section 2 that IoT technology finds useful applications in industries which may be in manufacturing, transportation, healthcare, agriculture, etc. One pre-eminent manufacturing industry that can exploit the merits of IoT and EC technology to boost production output is the oil and gas sector. In this section, the procedures for the formation of EC in addition to the architectural description of an EC process is highlighted. Furthermore, an overview of maritime operation activities during oil and gas exploration is presented while the applications of EC in IIoT for maritime operation is as well described.

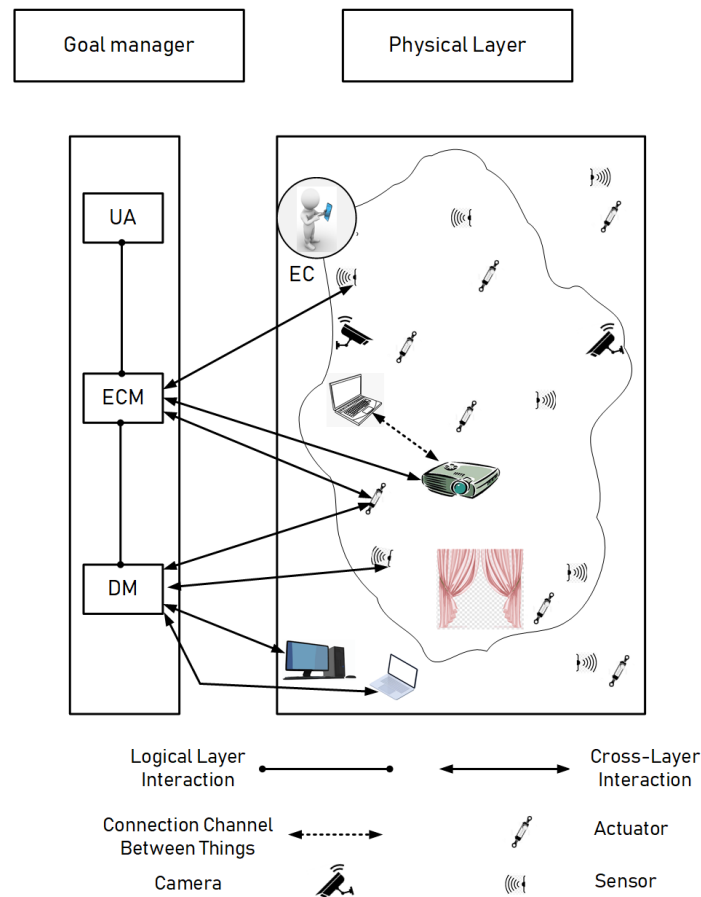


Figure 3. Illustration of the physical and logical layers of an EC.

4.1. Procedures for the Formation of an Emergent Configuration

Two subprocesses are put into consideration in the formation of an EC in order to meet user goals. The first subprocess involves the collaboration of the three elements of the logical layer (i.e., UA, ECM, and DM) towards actualizing the goals of the user whereas, in the second subprocess, the EC is continuously managed by a monitor, analyses, plan, execute, system knowledge base (KB) update (MAPE-K) loop. In the first subprocess, the user expresses his/her goals over a specified goal location boundary using a smart connected device (i.e., the user agent). Common examples of user agents include *personal computers* such as palmtops, laptops, desktops, electronic notebooks or smart mobile phones, etc. Once the user expresses the user goal through the aid of a user agent, an ECM then interprets the goals and then makes a subsequent analysis of the possibilities of actualizing the goal. For instance, the ECM can then decide if the boundary location intended for use by the user is available or not. If not available, the ECM may then suggest alternative boundary locations for the user in order to help the user to achieve his/her goals. The interaction between the DM and the ECM then takes place, where information of the current state of connected things are made known to the ECM through the aid of the DM. The ECM then analyses the entire system and ensure that all connected things work together to achieve a common goal for the user’s satisfaction. The second subprocess of EC formation (MAPE-K loop) is explained in Section 4.2.

4.2. Architectural Description of an EC Process Management

An architecture for the IoT process management consists of seven core components which can be used to describe the core components of an ECM. These components of an EC architecture include; *goal manager, adaptation manager, context manager, enactment engine, business rules, domain ontology* and *system KB* [61,63–65]. The responsibilities of these components are explained subsequently.

Firstly, the primary role of the goal manager according to Figure 4 is to interpret the goals of the user and then specify suitable goal location boundaries. The goal manager is also responsible for analyzing available IoT objects/services while making efforts to exploit the functionalities of these objects towards the actualization of user goals. Furthermore, the goal manager is responsible for suggesting relevant and alternative services to the user in order to enable the user to achieve his/her goals, while also deriving subgoals for the EC to meet user needs. Moreover, the goal manager is responsible for connecting and coordinating the available IoT connected devices for the actualization of the user's expectations.

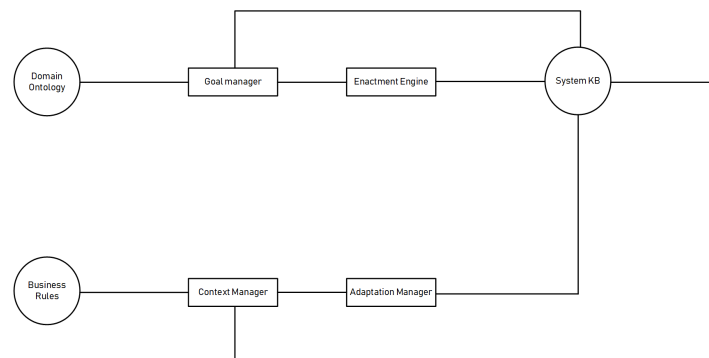


Figure 4. An architecture of an EC management process.

Secondly, the adaption manager is responsible for managing the MAPE-K loop which involves *monitoring* of changes in the context, for instance, discovery of new connected devices and faulty devices by dynamically configuring and updating the EC system to meet the user goals. The adaptation manager also *analyses* the effects of the system changes for the satisfaction of user goals while *planning* all changes to the subgoal model of the EC. Other roles of the adaption manager according to the MAPE-K loop involves *execution* of the planned changes by communicating with the enactment engine as depicted in Figure 4.

The context of the EC such as *system KB update* and *detection of dynamic events* in the environment is managed and maintained by the context manager. The primary context (which is the *raw data*) that made available from sensing is as well maintained by the context manager while inferring new business rules based on the context.

It is attention-worthy to mention that the primary responsibility of the enactment engine is to give instructions to IoT connected devices while coordinating their activities and ensuring effective collaboration between the devices in order to satisfy user needs. The business rules component, on the other hand, is a central location that consists of domain related and theorize rules which are based on the context changes whereas the domain ontology host a classification of Semantic information about domains that are employed for the derivation of the EC subgoals for example, "a smart room". Finally, the system KB is a container that houses information of the EC context.

The architecture of an EC process is refined in [62] as diagrammatically illustrated in Figure 5. A detailed description is as well presented for all components in the refined architecture for realizing EC in the IoT (Eco-IoT), in addition to their interaction with the IoT platform. A first prototype is developed using Java programming language, while performance is evaluated to validate the feasibility of EC in some key components of the refined architecture. Interested readers are referred to [62], for more information on the refined Eco-IoT architecture.

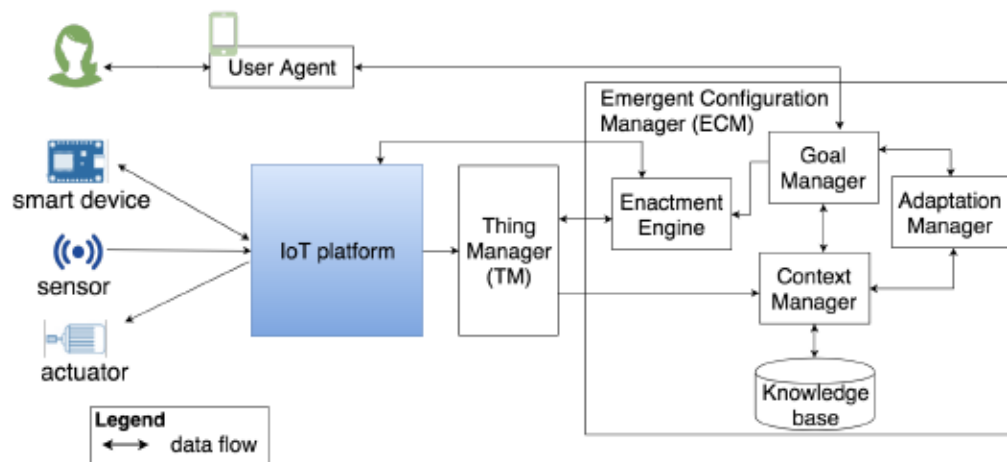


Figure 5. A refined architecture for realizing ECs [62].

4.3. Overview of Maritime Operations in Oil and Gas Extraction

Drilling of reservoir rocks is considered as a major objective of maritime operations with a goal of finding trapped hydrocarbons that are buried in the rocks, for several years. The processes of oil and gas explorations begin by building the *oil rig* in an exact and location with the aid of a satellite so that trapped hydrocarbons can be optimally explored using a vessel. A *drill bit* is connected to the sea floor (to a depth ranging between 2 to 11 km) through the aid of a *conductor pipe*, where the bit rotates to drills the rocks and sediments formed below the seabed. *Drill pipes* are then connected to a conductor pipe which runs down to sea floor after which the conductor pipe is installed into the rock. A *casing pipe* (with approx. diameter of 50 cm) is inserted into the hole through the conductor pipe to ensure installation firmness. A *cement* is then poured in between the drilled hole and the inserted casing pipe in order to strengthen and firmly position the casing pipe. During drilling operations, a special *mud* is injected through the drill pipes to cool the drill bit and for mitigating the gushing of oil and gas from the drilled layers by stabilizing the pressure. The mud is a mixture of clay (for thickness) and fine ground rocks (for weight). This mud is also used for cleaning the bottom of the well by carrying rock fragments to the water surface as it travels through the pipes. When hydrocarbons are found, the oil and gas flow to the surface of the water through the calibrated hole at high pressure and are collected and stored in vessels, where they are subsequently transported onshore for further refining in the petrochemical refineries.

During oil drilling operations and transportation, there is a possibility of *oil spillage* occurring. The spillage constitutes a significant challenge for marine engineers during maritime operations [66]. Oil spillage in the context of maritime oil and gas extraction is described as an accidental release of the drilled petroleum hydrocarbons into the marine ecosystem which consequently pollutes the marine environment. Simple plankton organisms such as bacteria, plants, and animals are adversely affected by oil and gas spillages in the marine environment. Fishes, seabirds, marine mammals (such as dolphins and whales), marine reptiles, sea grasses, and mangroves are organisms that greatly suffer the harmful consequences of oil pollution. These organisms end up losing their habitat/shelter. Toxic chemicals released into seawater from marine oil spillages may cause impairment of cellular functions in these marine organisms which can result into a catastrophic mortality rate of marine lives [67].

Oil spillages are caused by two principal actions that may arise naturally or from anthropogenic activities. The spillage is naturally caused from oil and gas leakages that spring up from the bottom of seawater (or oceans). On the other hand, oil spillages may arise from human (anthropogenic) related activities such as accidental oil spills during oil drilling and refining processes including oil collection, storage and transportation. It can also be caused from intentional anthropogenic activities such as oil

discharges through drains to the marine environment in a sewer system as well as through burning of fuels.

Oil on water locator (OWL) is a device that is adopted for sensing and detecting oil spillages in both seawater surfaces and sea depth [68]. Hyperspectral laser-induced fluorescence light detection and ranging (HLIF LIDAR) is the technology that is adopted by the OWL for detecting oil leakages in seawaters and oceans [68,69]. Several remote oil sensing techniques such as radio detection and ranging (Radar), ultraviolet (UV)/infrared (IR) scanners and spectral imaging can be employed for detecting oil spillages. The HLIF LIDAR technology detects oil leakages in water by using the intrinsic fluorescence of polycyclic aromatic hydrocarbons (PAH) present in the oil [68]. It receives the re-emitted light using an inbuilt telescope which is diffracted and thus detected by a 500 channel hyper-spectral detector which detects UV and visible light. To mitigate the deterioration of aquatic environments and to save the lives of marine animals as well as other living marine organisms as a result of oil spillages, the concept of EC can be deployed for the maritime IIoT. An application of the concept of EC is proposed in Section 4.6 for the maritime IIoT.

4.4. Administration of SDN-Based Ubiquitous Computing-Aided EC in Oil and Gas Explorations

The maritime networks deployed for oil and gas deracination need to be carefully designed to deliver smarter, reliable, scalable and faster services in order to increase the output of ocean-going extractions. The merits of ubiquitous computing technology which is an embodiment of IoT networks can be adopted in cooperation with SDN technique in order to meet the above-stated needs of naval networks. In this section, we present a succinct overview of SDN technology and successively propose a ubiquitous computing enabled SDN-based architecture for enhancing the production outputs (or throughputs) of nautical explorations.

4.4.1. Overview of SDN Architecture in Wireless Network Applications

As a result of the resource-constrained limitations of existing traditional network infrastructures due to pre-programmed application-specific integrated circuits, there is need to develop flexible network architectures that will efficiently adapt to changes in network conditions and operations in order to perform a dedicated task. Consequently, the SDN architecture is proposed in [70] where network control is decoupled from the conventional hardware devices [4]. In other words, the data plane (also known as forwarding plane) which is responsible for forwarding packets/frames from a given interface to another is separated from the control plane that is usually designed to manage network operations for decision-making procedures on traffic directions. The SDN technology is designed to consist of three distinct layers including infrastructure, control and application layers, where all the information housed in the data plane (infrastructure layer) are centrally managed and directed by the control plane.

The application layer consists of network applications that are deployed for managing the technical configuration of network devices while the control layer (control plane) fundamentally consist of one or a given combination of SDN controllers that may otherwise be described as the wholistic brain of the entire SDN architectural system. Application program interfaces (API) are often used for interfacing (or interacting) between the layers of the SDN structure and may be classified into four groups including northbound API, southbound API, east and westbound API respectively. The communication between the application and control layer is interfaced by the northbound API while the southbound API is required for communication between the control and infrastructure layers as depicted in Figure 6. Network communication protocols such as OpenFlow protocol are good examples of southbound API which is often conventionally deployed in SDN-based networks for interaction between the control plane and the infrastructure layer. Finally, the east and westbound API are used as network interfaces between controllers especially when multiple controllers are engaged for enhancing communication performance in the software-defined network. A few examples of

open-source controllers for enabling SDN include OpenDaylight, Nox/PoX, Cherry, ONOS, OpenKilda and RUNOS etc.

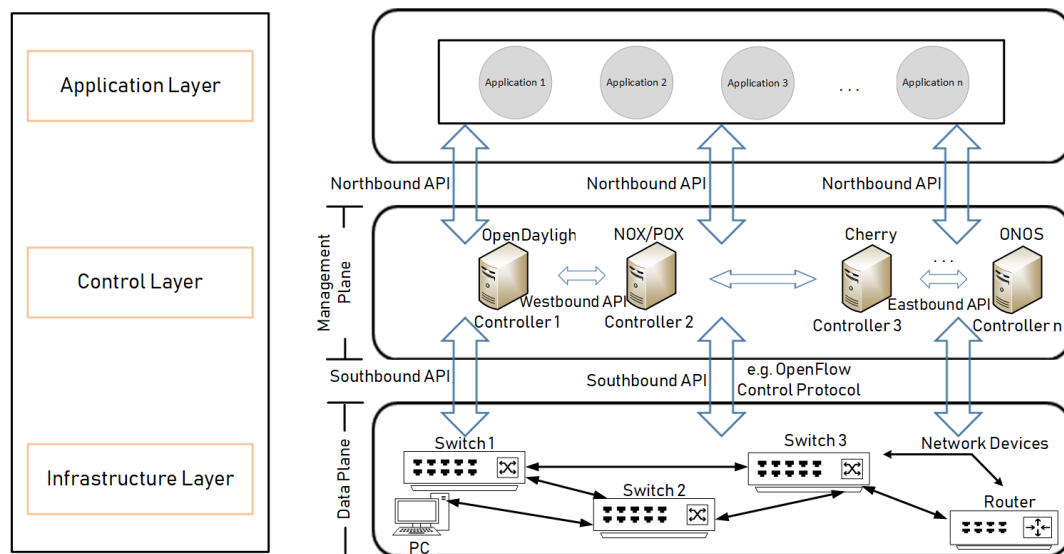


Figure 6. Diagrammatic illustration of an SDN architecture.

4.4.2. Description of Ubiquitous Computing-enabled SDN-based Architecture of EC for Maritime Operations

Ubiquitous computing (or simply “Ubicom”) is simply described as a paradigm where computing can be made by various device users in any given location and at any given time. The user in this context is described to interact with the computer which could either be desktop computers, laptops, electronic hardware, and terminals that are incorporated into everyday objects such as a pair of eye glasses, curtains, windows, doors and fridges. etc. This paradigm also known as *ambient intelligence* or *pervasive computing* is supported by some fundamental IoT enabling technologies such as sensors, actuators, microprocessors, internet connectivity and numerous specialised application layer protocols. Motivated by the works done in [62,71], we propose an EC architecture for monitoring the operations of nautical explorations as illustrated in Figure 7 in such a way that the onshore marine users exploit the benefits of ubiquitous computing and SDN technology in order to satisfy user standards. In this architecture, the interaction between the seashore located marine user (i.e., UA) and an ECM is managed by an efficient *ubiquitous computing service system* (UCSS) that is based on *matchmaking* and *rule-based* algorithms, where the UA of the EC network tries to exchange dynamic information to perform network diagnosis and high-quality evaluations for the improving the communication efficiency and throughput of the entire marine networks.

In the development of our proposed naval communication architecture, a littoral-based marine user expresses his/her desire to monitor the conditions and operations of the entire seafaring explorations then, the ECM tries to ensure meaningful and seamless communication between all ocean-embedded network devices and the seashore-located marine BS. The user can express his desire to request performance information through a UA that is made available through any electronic object that forms a part of any ubiquitous computing system. The goal manager then takes control of the request and makes communication with other components of the EC process in order to meet the user requirements. Assuming an underwater-embedded sensor becomes faulty and the user intends to find out the faults in the nautical network after receiving some signals in the control room, the thing manager that is managed by the ECM and primarily configured to control all connected wireless devices of the network will then identify the faulty sensors and send the information to a knowledge database that is mounted on the ocean oil-rig substation. The communication interface between all aggregated sensor information through the cluster head (CH) and the control layer is managed

by an SDN controller using the OpenFlow communication control protocol. Thus, the transmitted information which is stored in the marine cloud/universal description, discovery, and integration (UDDI) registry is then managed by the context manager whose general responsibility is to manage data within the maritime network. Imminently, the ECM retrieves the storage information through the context manager and contacts the matchmaking engine. The matchmaking engine consists of an extended defense advanced research projects agency (DARPA), agent markup language (DAML)/UDDI translator whose responsibility is to construct an interpretation based on the information retrieved from the context manager as described by a DAML-S profile. More over, the reasoner contained in the matchmaking engine ranks the aggregated CH information retrieved from the context manager using a matchmaking algorithm and subsequently computes a match level to meet the user demand in accordance with the network architecture of a matchmaking engine represented in Figure 8.

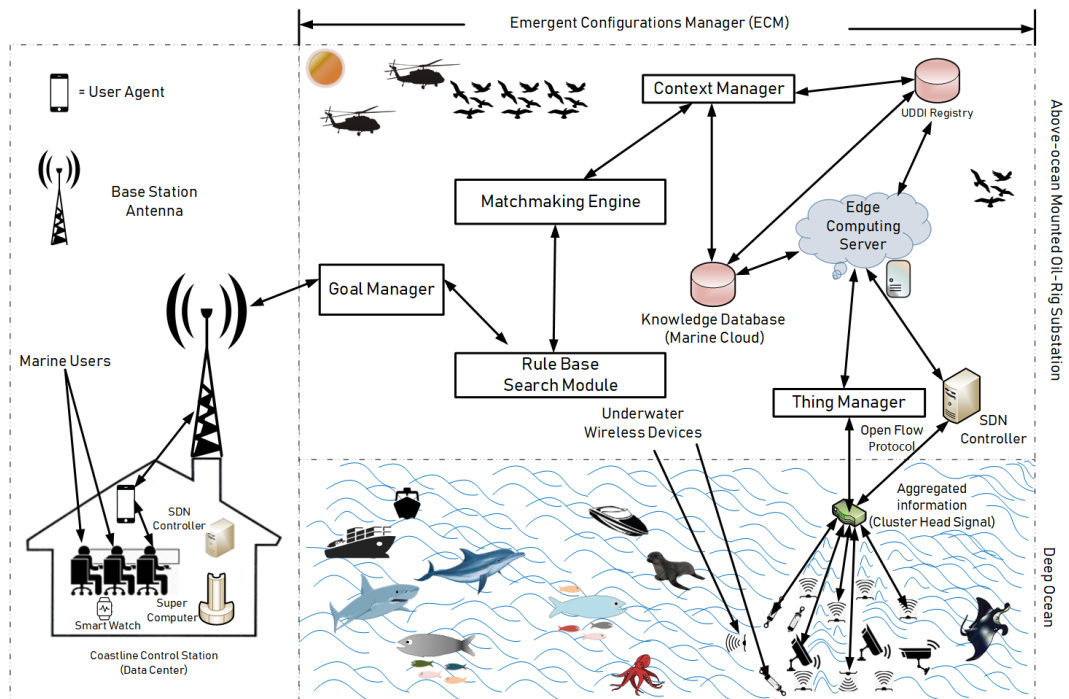


Figure 7. Proposed ubiquitous computing-aided SDN-based EC architecture for maritime explorations.

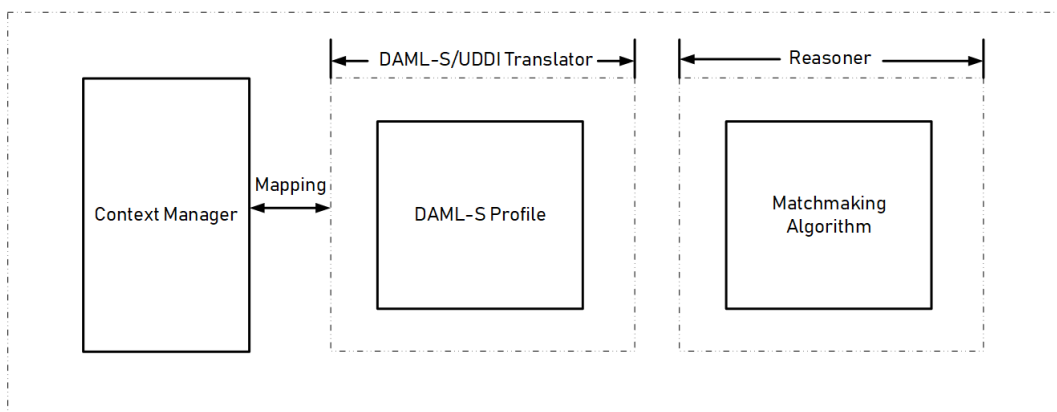


Figure 8. System architecture of a matchmaking engine.

After the computation and ranking of data is performed in the matchmaking engine, the required information is eventually sent for verification procedures through a rule-based module using appropriate QoS measurement algorithm to the goal manager who then interprets the information and

conveys the requested message to the marine user for appropriate action procedures. The rule-based engine verifies the ranked information by comparing the computed data received from the matchmaking engine with that of the context managed UDDI profile registry. A system architecture of the rule-based engine is represented as depicted in Figure 9. In this architecture, the search for rule-based information from the ECM can be implemented using SweetJess [72] which is then converted into Jess's rule language through an extensible stylesheet language transformer (XSLT). The Jess engine then converts the rules and information to form usable by a reasoner after which the results are subsequently concluded using the Jess engine for further actions by the goal manager.

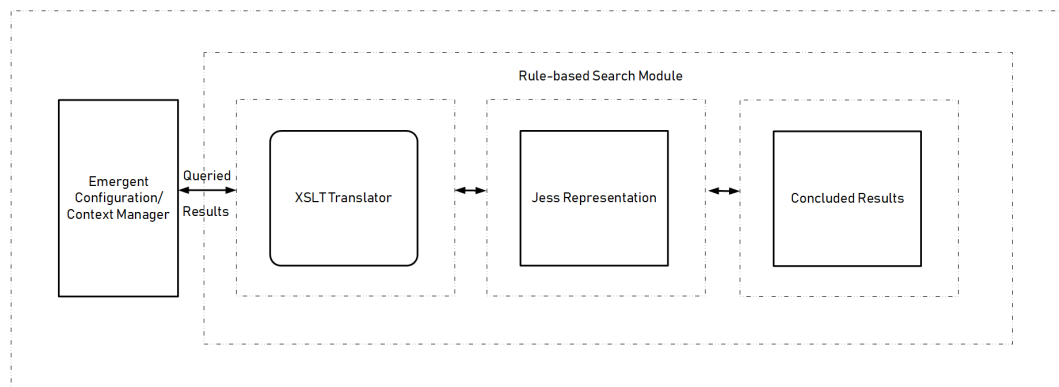


Figure 9. System architecture of a Rule base engine.

4.5. Revolutionary Communication Technologies for Facilitating EC in Oil and Gas Explorations

The traditional IoT architecture consists of three layers that include the perception, application, and network layers. Information that is obtained from the physical world is converted into electrical signals in the perception layer where the converted information is subsequently transmitted through the network layer to the application layer for exploitation and adequate use (by the IoT users) in order to enable meaningful decision makings. Several technologies can be deployed for assisting the performance and efficiencies of various layers of the propounded SDN-based EC architecture for oil and gas extractions according to Figure 7. These technologies and communication routing protocols are discussed subsequently.

4.5.1. Data Acquisition Technologies for Enabling EC in Oil and Gas Extractions

The technologies adopted in the perception layer are mostly data acquisition technologies because this layer is responsible for obtaining information from surrounding objects/environmental conditions. Data acquisition devices such as quick response (QR) code, Radio Frequency IDentification (RFID), sensors and actuators are employed in this layer of the oil exploration phase. The obtained information is then converted into electrical signals, where the propagating information is transmitted from the perception (or infrastructure) layer through the network layer to the application layer. *Networking technologies* aid the transmission of information from one layer to another. These technologies that are capable of enabling EC in marine networks, whose properties are summarized and compared in Table 5 include; low-rate wireless personal area networks (LR-WPANS) e.g., ZigBee [73–75], wireless personal area networks (WPAN) e.g., Bluetooth, IPv6 over low-power wireless personal area networks (6LoWPAN), wireless local area networks (WLAN) e.g., wireless fidelity (WiFi), wireless metropolitan area network (WMAN) e.g., WiMAX and mobile communication technologies such as the current fourth generation (4G)—long-term evolution (LTE)-based cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) technologies.

Table 5. A comparison of existing IoT communication technologies for EC in Oil and Gas extractions.

Communication Technology	Transmission Range	IEEE Standard	Data Rate	Power Consumption	Cost
WPAN (Bluetooth)	8–10 m	802.15.1	1–24 mb/s	Low	Low
LR-WPAN (ZigBee)	10–100 m	802.15.4	40–250 kb/s	Low	Low
WiFi	20–100 m	802.11a/b/g/n/ac	1 Mb/s–6.75 Gb/s	High	High
WiMAX	Less than 50 km	802.16	1 Mb/s–1 Gb/s (fixed)	Medium	High
Mobile Communication	Entire Cellular Region	4G-LTE based on CP-OFDM	100 Mb/s–1 Gb/s	Medium	Medium

4.5.2. Communication Routing Protocols for Realising EC in Oil and Gas Explorations

Application layer messaging protocols such as message queue telemetry transport (MQTT), constrained application protocol (CoAP), advanced message queuing protocol (AMQP) and extensible messaging and presence protocol (XMPP) can be adopted to aid the transportation of the sensed data across the marine communication network for meaningful decision making. Communication protocols constitute the backbone of IoT systems as they enable the coupling and connectivity of IoT networks to the ubiquitous computing-assisted SDN-based EC network architecture and its applications while allowing data devices to exchange information over the communication network. Data exchange formats and encoding are defined using communication protocols including routing of packets from the transmitter to the receiver. In addition, flow control, sequence control, and lost packet re-transmission are other functions performed by communication protocols. Table 6 presents a brief comparison of the aforementioned application layer protocols for IoT including CoAP, MQTT, XMPP, XMPP and WebSocket which are further discussed and classified in [25,76] and may be deployed for communication in any suitable application of the propounded EC architecture. The security provided by these protocols are presented in [77,78]. These protocols are deployed in constrained environments such as the described smart oceanic domains where the devices operate under constrained conditions including low memory and processing power situations. In [3], a classification of low-end (constrained) IoT devices is presented. CoAP on the other hand is an alternative application layer protocol to the hypertext transfer protocol (HTTP) [79] which is not suitable in resource-constrained environments. The CoAP uses the efficient extensible markup language interchange binary data format while supporting features such as automatic configuration, asynchronous message exchanges, congestion control and support for multicast message [1]. More so, four kinds of messages make up the CoAP namely; confirmable, nonconfirmable, reset and acknowledgment message [1,76]. MQTT is a lightweight international business machines (IBM) created publish-subscribe message protocol that uses transmission control protocol/internet protocol (TCP/IP) in constrained environments such as low memory devices with limited processing capabilities. According to [76,77], three QoS modes namely *fire and forget mode*, *acknowledge delivery (or at least once)* and *assured delivery (or exactly once)* are provided for message delivery according to the MQTT specification. It is documented in [79] that MQTT protocol outperforms CoAP in situations of high traffic networks. It is note worthy to mention that some sets of open technologies deployed for instant messaging, chat and voice calls as standardized by the Internet engineering task force (IETF) is the XMPP where the exchange of data is made possible by the use of small pieces of extensible markup language (XML) structured data named *XML stanzas* [77] whose architecture is based on the client-server concept. Abstract layering of the XMPP is based on TCP, transport later security (TSLs) and simple authentication and application layer (SASL) [77]. Other application layer protocols are data distribution service (which is a publish-subscribe) protocol adopted to enhance the operation of high-performance device-to-device (D2D) communication), advanced message queuing protocol (AMQP) and WebSocket. In [80], the performance of three application layer protocols namely CoAP, WebSocket and MQTT is documented in a LAN and IoT scenario using simple and affordable devices. The performance is evaluated in terms of protocol efficiency and average round trip time (RTT) in LAN and IoT scenario. Results obtained show that the protocol's efficiency does not change as the network changes; however, RTT increases by a factor of two to three times in an IoT scenario as compared to LAN scenario. The results obtained also demonstrate that CoAP offers

the highest efficiency in comparison to MQTT and WebSocket while MQTT offers the highest RTT as a result of the presence of both application layer acknowledgements and transport.

Table 6. Comparison of adaptable application layer protocols for marine communication networks.

Application Protocol	Key Features (Benefits)	Originator (Creator)	Message Transition Technique	Underlying Transport Layer Protocol
MQTT	Efficient routing for small, cheap, low-power and memory devices	IBM and Circus Link	Publish/Subscribe	TCP/IP
COAP	Automatic configuration, multicast messaging, congestion control,	IETF	Request/Response	UDP
AMQP	Provides flow controlled message-oriented communications.	JPMorgan Chase	Publish/Subscribe	TCP
XMPP	Secure and spam-free instant messaging, chat, video and voice calls.	IETF	Publish/Subscribe	TCP
WebSocket	Full-duplex communication for encrypted and unencrypted connections.	IETF	Request/Response	TCP

Network layer communication protocols such as OLSR, AoMDV, dynamic source routing (DSR), and a AoDV were proposed for configuring maritime wireless communication systems. However, none of these protocols was found to be efficient [51] since they cannot provide optimal communication capability, sustained interoperability and guaranteed reliable communications. Because the sea-embedded network devices are not stationary and the underwater signal coverage is limited, there is a need to develop energy-efficient and energy balanced protocols that can be used as communication interfaces between submerged network devices. This is required because permanently installed under-sea sensors may be difficult to replace thus, prolonging the battery life of such nodes is necessary for the extremely harsh under-water atmospheric conditions which can be achieved either through clustering or load-balancing techniques. In such scenarios, load balancing schemes require multihop configuration approaches whereas, single-hop methods are adopted for implementing the clustering procedures. Thus, we propose the use of an energy-efficient and energy balanced routing protocol that attempts to balance the energy dissipation of the marine user equipment (MUE) during the formation of cluster networks in the aquatic communication system according to [29] named mobile sink selective-path priority table (MSPT). In this technique, a priority table is developed, where the two shortest paths to the CH are prioritised using some simple rules. The aforementioned rules are formulated to improve marine explorations by combining routing metrics including the transmission power and range of each sensor node in addition to the residual energy of each sensor. Likewise, two phases are involved in the formation of the MSPT routing protocol for maritime communication networks and these consist of the set-up and steady phases respectively. The former phase involves the election of CH nodes for the marine communication networks whereas, the latter phase primarily consists of the development of the data identification and transmission paths in order to optimise the seafaring network performance while considering the energy maximization of network devices.

4.6. Application of EC in the IIoT for Maritime Operation

The underlying concepts of EC is presented in Section 4 of this paper, whereas, an overview of maritime operations with specific application to oil and gas extractions is presented in Section 4.3. The propounded application of EC in combating oil and gas leakages during maritime oil and gas explorations is further highlighted in this section. For this application, it is assumed that a *ground station* is positioned at some remote onshore location, where the entire oil and gas exploration processes are monitored as depicted in Figure 10. The control station consists of display management systems such as computer monitors and projectors, lighting systems including numerous shared IoT objects such as sensors and actuators. The *oil rig* (which is a platform that is built over the oil well) is designed to consist of a substation that receives instructions from the onshore control station. The oil exploration set up, and procedures is described as presented in Section 4.3. Stationed around the derrick are sensor objects, for instance, a helium-filled balloon (aerostat) carrying OWL IoT sensors. Positioned at the onshore control station are emergency mechanical devices built with OWL sensors such as helicopters and other unmanned aircraft systems for instance, remotely piloted aircraft systems (RPAS). *Platform supply vessels* (PSVs) are offshore kind of vessels that are adopted for transiting required equipment as well as additional manpower for oil explorations. Another name for PSVs is *offshore supply vessels* (OSV)

and they are also useful during oil spillage cleaning operations. Other kinds of unmanned surface sensor carrying vessels are also well positioned onshore in preparation for oil spillage emergencies. At a depth of the sea are stationed *unmanned underwater vehicles* which are designed for monitoring the activities of the oil drilling and explorations. For instance, *autonomous underwater vehicles* (AUV) are robots that do not require human operations to monitor drilling operations several kilometers beneath the sea. Mobile *non-autonomous underwater vehicles* that require human control can also be employed for motoring/surveying drilling activities beneath the sea. A good example is the *remotely operated underwater vehicle* (ROV) that is linked through a *tether* to a host vessel on the water surface.

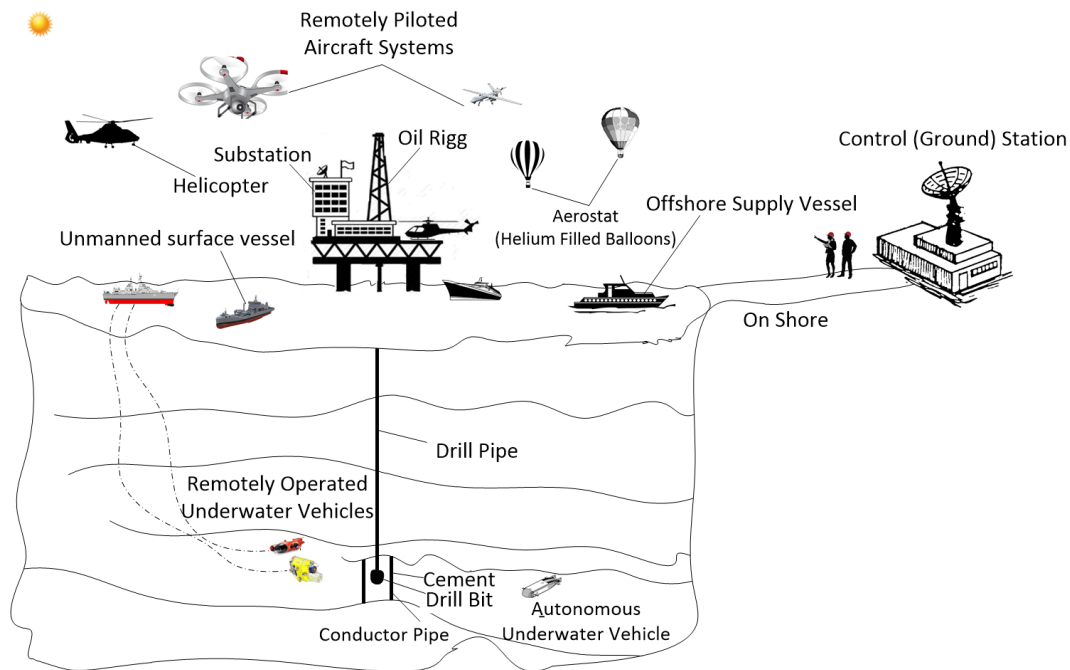


Figure 10. Application of EC in Oil and Gas explorations.

Marine environments can be polluted from accidental oil spillages. The pollution may occur from the depth of the sea or on the water surface. It can arise from the bottom of the seawater as a result of improper drilling operations that may result from human errors. For instance, the ground rocks not being cemented appropriately when drilling operation commences as a result of the drilled ground rock diameter been greater than the diameter of the cemented conductor pipe. This may cause leakage of high-pressure hydrocarbons from the sides of the cemented conductor pipe consequently posing great environmental hazards to marine organisms. On the other hand, seawater pollution can also occur from the surface of the ocean especially during collection and storage of the drilled hydrocarbon as well as offshore to onshore oil transportation. Hydrocarbon transportation vessels with badly damaged tanks can be a chief reason for this kind of oil and gas spillages.

An onshore control system is built for monitoring and managing the installed surveillance devices as well as the drilling process taking place from the onshore station to the offshore ground rocks. An ECM is set up to handle the control processes during emergency operations such as oil leakages as well as during clean up operations. For instance, the ECM triggers an alarm to notify the users of an emergency. A simple application example is given as follows. It is assumed that the maritime control engineers together leave the control room of the onshore station for a quick lunch a few meters away. Suddenly, they hear an alarm indicating an emergency. The curious engineers move to the dark control room to find knowledge of the current emergency situation. Using a user agent (for instance, any ubiquitous computing enabling object), the engineers express their goal to "monitor the entire drilling process". An EC is set up which interprets the goals of the users and collaborates with selected resources to achieve this goal. The installed light sensors in the control room detect that the room

is dark and the lights are automatically put on for improved visibility. Projectors, relevant sleeping monitors and other potential display media comes up to enable the users to monitor the entire drilling process. Suddenly, excessive sunlight comes into the room which makes it impossible for the screens to be viewed appropriately. The light sensors figure it out that there is too much light in the control room and the smart curtains are triggered to close automatically, and the perfect lighting is maintained in the room. The engineers can now visualize the cause of the alarm as it displays on the media that there is oil spillage occurring in the oil well. In the process, the temperature of the room is increased due to the incoming sun rays and the ECM triggers an actuator that puts on the air conditioners. This is a brief application of EC in the control room working in collaboration with IoT devices to meet the user goal. For the engineers to appropriately visualize the cause of the emergency, they need to have accurate knowledge of the ongoing processes in the oil rig as well as on the sea floor. The ECM contacts the EC set up in the oil rig substation. The setup oil rig EC subsequently contacts the device manager so as to obtain first-hand information of the current state of seawater surface and submerged surveillance devices. Unmanned underwater vehicles carrying OWL in addition to ROVs detects an oil leakage gushing from the bottom of the sea floor. The substation ECM is notified which sends the information to the onshore ground station. IoT sensor objects positioned on the sea surface such as the aerostats become more vigilant in sensing for oil spillages while the ECM instructs sensor carrying mechanical devices such as helicopters and RPAS to patrol and survey the oil exploration area. The PSVs are notified, and they move towards the oil rig platform in preparation for cleaning processes. The onshore control engineers monitor and analyze the entire process while making efforts to minimize the detrimental effects of the oil pollution to the marine environment. They could see that the cause of the oil spillage is due to improper installation of conductor pipes beneath the sea floor and they express their goal of sending more cement and mud through the conductor pipes to firmly seal the drilled hole beneath the seafloor. The ECM instructs the substation which automatically sends cement and mud to appropriately seal of the drilled well beneath the sea floor, while oil that floats to the sea surface is cleaned using the PSVs.

4.7. Limitations of IoT for Maritime Operation Enhancement and Possible Research Directions

The effective implementation of EC and IoT technologies for the operation and management of maritime activities is encountered by numerous limitations including data management challenges, resource constraints, security and privacy challenges, mobility management, and cost-effective communication systems. Firstly, the sensor-based MUE embedded to marine devices can generate large volumes of data which needs to be processed and stored for accurate maritime decision-making procedures. The generated data during the processes of EC needs to be accurately processed in order to guarantee high system performance, efficiency and scalability. Hence, it is required that certain preprocessing procedures be performed where the collected information can be arranged to form clusters by splitting the collected data into smaller groups for more reliable transmission and data processing actions. The development of clustering evolutionary algorithms for the collection and processing of the transmitted IoT-enhanced data for maritime decision-making processes is still an open research area. Secondly, it is worthy to mention that the sensor nodes deployed for EC activities during oil and gas explorations are usually resource-constrained by energy, memory and processing resources. As such, the optimal allocation of network resources for marine oil and gas explorations is still an open research issue. Additionally, developing traffic engineering techniques and energy-efficient protocols for monitoring the EC procedures in oil and gas explorations is still required for the optimal exchange of data during maritime communications. Furthermore, scalable and dynamic SDN and NFV-based architectures/frameworks can still be developed to further guarantee the efficient management of limited cloud memory in addition to mobility management procedures and optimal use of system energy for seamless operation of maritime activities. Thirdly, another challenge of realizing IoT technologies for the explorations of oil and gas in the marine environment as mentioned earlier is data security and privacy. This is because the integrity, authentication and confidentiality

of the MUE collected data during EC-based oil and gas explorations requires to be given priority as the wireless interactions of different devices can result in unwanted third user activities such as network tapping, tampering and forgery since most network components will be left unattended due to self-configurations. As such, developing novel security enhancement techniques that will prevent denial of service (DOS) and distributed DOS challenges in order to achieve oceanic exploration confidentiality and privacy in an attempt to avoid system attacks such as false data and malicious code injection, eavesdropping and interference, spoofing, base station and routing information attacks, malicious scripts and worms attacks likewise unauthorised network access etc, is still an open research problem for the IIoT applications of pelagic communication systems. Finally, a significant challenge of maritime operations is cost-effective communications. Satellite communication technologies are usually deployed for the operation of marine activities [51]. Nonetheless, these technologies are known for their high cost despite their rapid developments. To minimize the high communication cost of satellite systems in addition to achieving high-datarate, reliable and lower latency QoS requirements in maritime IoT-based communication technologies, alternative communication techniques such as EC, SDN, NFV, mobile and cloud computing as well as use of multiple directional coastline-mounted directional antennas can be further deployed and connected together for monitoring and improving the operation of seashore maritime activities. Hence, the development of novel frameworks and models that are in line with the above-mentioned communication techniques for the extraction of oceanic oil and gas explorations is an open research area awaiting contributions from researchers and practitioners in this field for meaningful decision-making procedures based on application requirements.

5. Conclusions

In this paper, a comprehensive review of the concept of IoT is presented. A general overview of the concept of IoT is reviewed as applicable to the industrial environment. The concept of SDN-assisted EC is propounded for managing emergency situations as applicable to the maritime IIoT, in order to mitigate the detrimental effects of oil and gas spillages onto marine environments for higher throughput and gain maximization in offshore oil and gas explorations. Marine ecosystems can also be preserved from safe offshore oil and gas exploration which can be enhance by the technology of ubiquitous computing assisted SDN-based EC in the IIoT for maritime operations. The concept of EC can also be deployed to preserve lives in maritime environments during explorations of hydrocarbons from quick responses to emergency situations. This novel concept (EC) can be extended in future research works to other industrial applications of IoT technologies such as manufacturing, health care, transportation, smart energy and agriculture etc. In addition, WSN-based technologies such as SDN and routing protocols etc., can be further developed to enhance the drilling of marine operations. The benefits of EC technology can also be exploited for onshore oil and gas production. Thus, keeping in view the coverage of this review paper, it is presumed that this paper will spring up possible research directions in improving the autonomous extraction procedures of oil and gas across deep waters using contemporary IoT-based communication technologies. For future works, we consider to present a detailed comparative data analysis that compares the output performance of an SDN-aided EC-enabled oil and gas extraction technology in comparison to exploration scenarios where the EC process is not aided. A comparative analysis of existing maritime routing protocols such as the MAC-based routing protocol for TRITON (MRPT), OLSR, AoDV, and AoMDV protocols etc in comparison with our MSPT routing protocol for oil and gas explorations will be elaborately provided. Finally, we intend to also develop energy balanced protocols that would mitigate the energy-hole problem of marine sensor networks.

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Abbreviations

The following abbreviations are used in this manuscript:

3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
xG	Next Generation
6LoWPAN	IPv6 over LoW-Power Wireless Personal Area Networks
AE	Authenticated Encryption
AIS	Automatic Identification System
AoDV	Ad-hoc on-demand Distance Vector
AoMDV	Ad-hoc on-demand Multipath Distance Vector
AMI	Advance Metering Infrastructure
AMQP	Advanced Message Queuing Protocol
AUV	Autonomous Underwater Vehicles
BYOD	Bring Your Own Device
BYOK	Bring Your Own Key
CoAP	Constrained Application Protocol
CP-OFDM	Cyclic Prefix Orthogonal Frequency Division Multiplexing
CPSS	Cyber-Physical-Social Systems
D2D	Device-to-Device
DARPA	Defense Advanced Research Projects Agency
DM	Device Manager
DRS	Demand Response Systems
DSC	Digital Selective Calling
EC	Emergent Configuration
ECM	Emergent Configuration Manager
ETC	Expected Transmission Count
GEO	GEostationary Orbit
MariComm	MARitime broadband COMMunication
MIMO	Multiple Input Multiple Output
MQTT	Message Queue Telemetry Transport
MUE	Marine User Equipment
NAVDAT	NAVigation DATa
NFC	Near Field Communication
NFV	Network Function Virtualization
OLSR	Optimized Link-state Routing Protocol
OSV	Offshore Supply Vessel
OWL	Oil on Water Locator
PBS	Pair Broadcast Synchronization
PSV	Platform Supply Vessel
QoE	Quality of Experience
QoS	Quality of Service
RFID	Radio Frequency IDentification
ROV	Remotely Operated Underwater Vehicle
RPAS	Remotely Piloted Aircraft System

R-sync	Robust SYN Chronization
SDN	Software Define Networking
SINR	Signal Interference to Noise Ratio
SNR	Signal to Noise Ratio
SoA	Service-oriented Architecture
STETS	Spanning Tree-based Energy-efficient Time Synchronization
TBR	Ticket-Based Routing
TCP/IP	Transmission Control Protocol/Internet Protocol
UA	User Agent
UAV	Unmanned Aerial Vehicle
UCSS	Ubiquitous Computing Service System
UDDI	Universal Description Discovery and Integration
VB-RA	Voyage-Based cooperative Resource Allocation
VDES	Very high-frequency Data Exchange System
VSAT	Very Small Aperture Terminal
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
XML	eXtensible Markup Language
XMPP	eXtensible Messaging and Presence Protocol

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