Intelligent Ocean Convergence Platform Based on IoT Empowered with Edge Computing

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Abstract

The ocean is currently crowded with vessels, including but not limited to commercial ships and submarines used for military operations or scientific investigations. Each of these vessels and their on-board equipment produce a massive amount of data that need to be shared with potential destinations. The current popular Intelligent Ocean Convergence Platform is suggested to support oceanic services by taking advantage of the novel concepts of the Internet of Things and 5G communications. However, the processing activities are not always centrally performed within the cloud but are sometimes shifted to the edge of the network according to edge computing. In this paper, we propose a combination of software-defined networking and edge computing, where software technology is used to support interoperability of heterogeneous network technologies, as well as edge computing enables ultra-reliability, scalability, and low latency in ocean networks. This will meet the rapid growth of marine vessels' demand for rapid computing and communication capabilities. Through the simulation of the average end-to-end delay, the efficiency of the proposed architecture based edge computing is evaluated.

Keywords: Ocean network, Edge computing, SDN, SANET, End-to-end delay

1 Introduction

With the dramatic growth of traffic in current oceanic shipping routes, the traditional use of radio communications is considered obsolete. There is a demand for novel Internet Protocol-based communication capabilities and to have maritime data available among the vessels for better route planning. Moreover, the oceans are characterized by civil, military or research vessels that are involved in commercial, leisure or military activities that generate data that need to be exchanged to endpoints located in the ocean or on the mainland. As done in the management of other transportation means, such as road and air traffic, the data sharing needs are starting to be supported by modern protocols for ocean networking. Recently, the "Ocean Cluster" proposed by Chinese insitute is to realize the simultaneous observation of the active microwave scanning imaging altimeter associated with laser radar water profile. By developing the satellite with independent intellectual property rights, innovative satellite can realize the remote sensing and networking technology. A new system is combined to construct a space-based observing system from the 10km to 100km, and the surface to the deep ocean. Although there are many Land-Ocean-Sky systems supporting satellite links for maritime communications, there still need a faster, more reliable method to adjacent vessels or facilities exchanging data. Despite the availability of satellite links that support maritime communications, there exists a demand for faster and more reliable ways to allow neighboring vessels or installations to exchange data. The Ocean Network (ON) [1] is an important networking abstraction to support maritime communications. Such a network is more than a traditional means to exchange messages but also exhibits the features of complex data processing. Such a vision is currently possible due to the fast growth of the Internet of Things (IoT), Device-to-Device (D2D) [2], cloud/edge computing, big data analytics and 5G communications.

According to relevant studies, the ON has a wide extension and a wide coverage, which needs to reach dozens to hundreds of kilometers under the heterogeneous network mode. The communication environment in the ocean is very complex, and severe sea conditions occur frequently. At the same time, the density of network equipment is uneven geographically and spatially, and the density of service nodes in the offshore area is often higher than that in the offshore area. Moreover, the trajectory of mobile terminals such as ships and undersea robots is difficult to predict, and the establishment of service base stations is limited by the coastline. For terrestrial in-vehicle networks, the

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number of vehicle service nodes is sufficient, the distribution in geospatial space is relatively uniform, and the speed of these vehicle nodes is relatively slow in urban networks, and the durability and continuity of services are greatly improved. Meanwhile, the communication efficiency between nodes is mostly affected by bad weather.

The overall idea of this article is to realize a service-driven intelligent ocean convergence platform (IOCP), similar to other transportation domains such as vehicular networks [3]. Figure 1 provides a concrete example of the possible data sources and kinds of information that may be supported and provided by the IOCP. The intentions are to support maritime transportation and any possible ocean-based leisure activities by integrating the Internet of Underwater Things (IoUT). On the one hand, weather forecasts can be seamlessly shared to all interested destinations, such as the personnel on ships or submarines. Maritime traffic data are also shared so vessels can optimally plan routes. On the other hand, our envisioned data platform may also be used for applications that are less critical than transportation control, such as having "Bob" find attractive underwater dive sites.

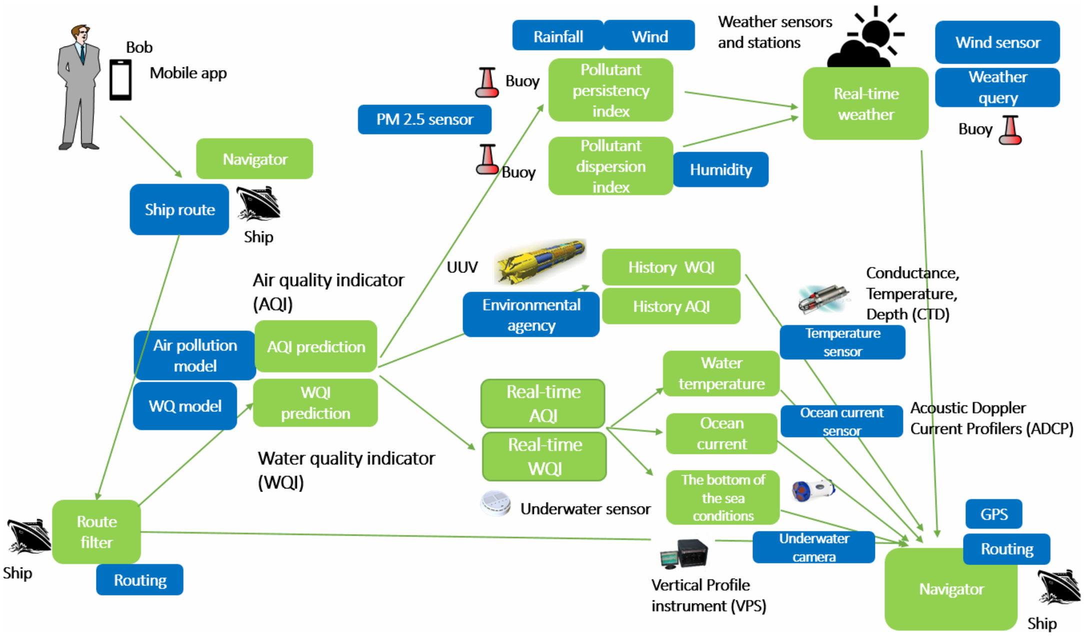

Figure 1. An example of service-driven ON applications supported by the IOCP

In this article, we propose a new ON structure based on an application of the IoT concept in maritime communications. It utilizes software-defined networking (SDN) and edge computing [4] to fulfill the sharp increases in the demand for fast computing and communication capabilities among ocean vessels.

2 Related Works

There is a great demand for improved and effective maritime communications and a solution for the ON architecture. However, the current academic literature and industrial practice on this topic are particularly fragmented, since only a specific portion of ON investigations address the architecture. That is, most of the existing studies may only focus on the coastal-to-offshore, ship-to-ship, and/or underwater communications (such as Underwater sensor network ("UWSN") [5]). To realize the communication under different modes, conventional works, for example, in terms of maritime communication modes, [6] has ensured the communication ability of ships after they leave the shore by studying the characteristics of network links in the communication network of fishing boats at sea. [7] analyzed the communication capacity according to different antenna heights and different distances between transmitter and receiver. [8] introduced the maritime communication solution being developed by BLUECOM project. The scheme USES standard wireless access technologies such as GPRS/UMTS/LTE and Wi-Fi to achieve cost-effective broadband Internet access in remote ocean areas. For the underwater communication mode, [9-10] explored the underwater wireless optical communication technology, and the experiment proved that this method is feasible. [11] analyzed the effects of underwater environmental conditions and different water quality types on the performance of the underwater optical link of the system, so as to build a model of the ocean waterway to develop the power link budget including the effects of absorption and scattering on the real sea water. [12] considered an underwater acoustic network paradigm with an improved butterfly-shaped topology, including surface nodes, access points and nodes in the water surface, and proved the improvement of the performance of underwater acoustic network by implementing network coding algorithm on the underwater acoustic modem that makes up the network.

In addition, great efforts have been devoted to the investigation of the effects of the marine or sub-marine environment on signal propagation [13], the reliability of the communication links [14], resource management [15] or clock synchronization [16]. It is rare to have a holistic approach that links these aspects and provides operational ON protocols. Only recently have researchers started to address the overall problem of maritime communications. In [1], the vision of the next generation ON was presented by applying the concepts of IoT and edge computing to a coastland base station to achieve low transmission delay and routing overhead.

The recent trend in the research of short-range communications within the ocean is to transfer the vision of the Vehicular Ad hoc NETworks (VANETs) to maritime communications, leading to Ship Ad hoc NETworks (SANETs). The VANETs implemented using 5G networking are recognized as a significant application of the concept of IoT to intelligent transportation systems [17]. One of VANET's features is defined in an unmanned and autonomous manner, by allowing the links between vehicles to be autonomously determined without any previous configuration [18]. These networks must comply with the Ultra-Reliable and Low Latency Circumstance (URLLC). Due to its scale in terms of the number of interconnected devices and the volume of exchanged data, it is unfeasible to have a centralized data processing node, even if clouds or other virtualization infrastructures are adopted. Such processing capabilities are moved from the core of the network to the edges [19] when possible. SDN and edge computing have realized the vision to provide efficient maritime computing and communicating capabilities [20]. While SANET [14, 16, 21-22] represents a marine counterpart of VANET, it has yet to attract significant attention in the literature.

3 Edge Computing-based Ocean Network Architecture

ONs have a more complicated architecture than VANETs. Not only ships and coastland access points but also buoys, underwater robots and sensors, and unmanned underwater vehicles (UUV) should be considered as instances of edge computing nodes (ECNs) within the context of edge computing. To provide a clear view of such a network, Figure 2 illustrates the physical architectural paradigm of the proposed ON by highlighting the network component to be incorporated within a realistic deployment of the overall system.

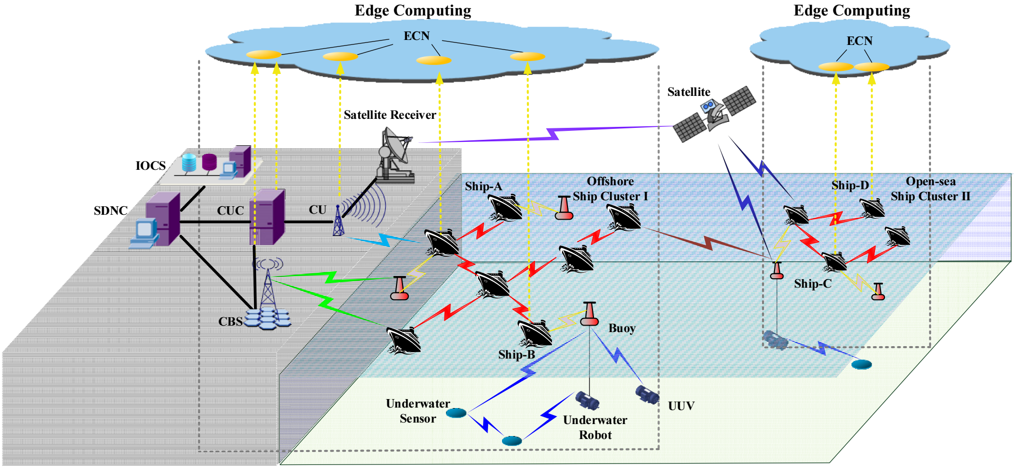

Figure 2. Physical architecture of an ON that combines SANETs and edge computing

Specifically, the ON is characterized by the interconnection of multiple types of physical nodes as follows.

Intelligent ocean cloud server (IOCS). An IOCS hosts virtual machines running a service-driven IOCP to provide the centralized data-processing capabilities. It receives all the current and up-to-date marine information from other nodes that needs to be properly processed and stored.

SDN controller (SDNC). An SDNC node offers the networked intelligence of the ON to manage the communications within the IOCP. This includes network virtualization, customized services, resources allocation for each unit, quality of service (QoS) provisioning and others. SDNC is the pivotal virtualization component to support an IOCP, enabling services at the edge of the network to have a set of processing capabilities closer to and faster for the users.

For the ON uplink, the services may include fishing, salvage, and surveillance. For example, in these services, the ship equipped with underwater ROV may be preferred for video or sonar data collection. Collected data are cached and shared among the ships and buoys, where the first level of processing may be performed, and then are forwarded back to IOCS. Under such a circumstance, the SDNC runs the widely known OpenFlow protocol [23], which enables the SDN. It separates the control from the forwarding and can achieve more sophisticated traffic management. Specifically, it is used for controlling and optimizing the uplink resources among buoys, ships, coastland base stations (explained later), and satellites according to node buffer spaces and customized services. For the ON downlink, the OpenFlow protocol mainly optimizes caching and routing among nodes for the cooperative services and also reduces the traffic payload from IOCS, enhancing the quality of experience (QoE).

Coastland-unit (CU). The CU is an access point located along the coastline for offshore ships or buoys. It can run the OpenFlow protocols and is controlled by the SDNC.

Coastland-unit controller (CUC). The CUC is an OpenFlow-enabled unit under the control of the SDNC. It acts as the head node for many CUs and is connected to a CUC via broadband connections before accessing SDNC. It does not only forward data but also stores them and provides emergency services.

Coastland-base-station (CBS). The CBS is a local server in the proposed ON, rather than a voice and data conveying unit. The CBS is more sophisticated than the CUC and is under the control of the SDNC, runs the OpenFlow protocols, and can deliver edge services.

Ship and buoy nodes. Ship and buoy nodes have sensing and communicating abilities. They are capable of computing, acting as edge units, and running the OpenFlow protocols controlled by the SDNC. However, buoys are instances of a situationally aware edge unit that has limited computing capabilities and constrained battery power.

Underwater robot, sensor, and unmanned underwater vehicle (UUV). they are nodes with sensing, communicating, and limited computing abilities, likewise buoys. The underwater data sharing capabilities are provided by means of acoustic communications, and some of them can be contacted with buoys by wired cable, as illustrated in Figure 2.

Satellite system. Without the loss of generality, the satellite system is used as a backup communication means to cover large distances among certain nodes within the open sea. Since using such a system still implies high expenses, in our system model, we only consider the satellite system in the extreme case where nodes are not reachable with 5G networking technologies.

Among these physical nodes, the ON must establish an overlay network, as depicted in Figure 3. It is worth noting that the proposed ON has two degrees of heterogeneity. On the one hand, we have the communications that are conveyed by several different wireless technologies, such as Long-Term Evolution Advanced (LTE-A), Wi-Fi, satellites, and acoustic communications. On the other hand, these nodes are geographical distributed among the different contexts of coastal, offshore, open-sea, or underwater communication endpoints. OpenFlow can cope with this heterogeneity due to its characteristic features. Therefore, the physical nodes have respective counterparts within the overlay architecture at the logic layer of our solution, as presented in Figure 3.

The CBS in Figure 2 is represented by the logical unit of eNB in Figure 3, which maintains the LTE's up/down links with offshore ships or buoys. The ship nodes in the open sea can maintain the up/down link with nearby buoys by Wi-Fi links, due to its simple deployment. The actuator in Figure 3 is the logical unit denoting a node with sensing and communications abilities.

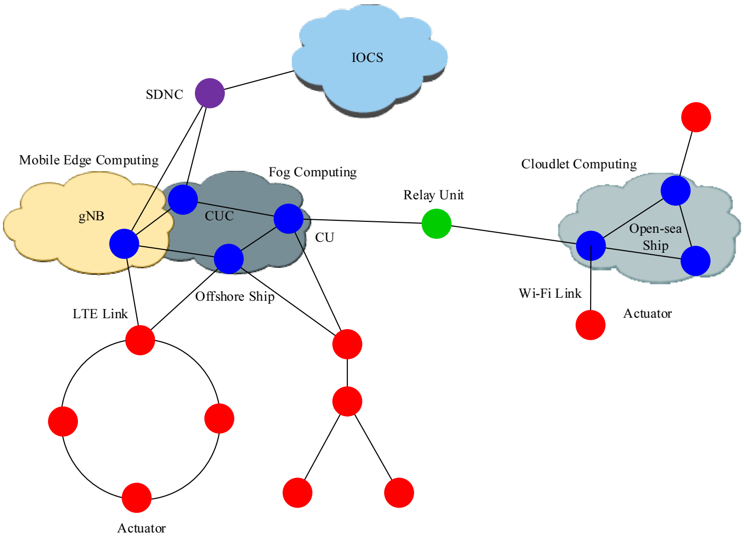

Figure 3. Overlay architecture of an ON

According to Figure 3, the SDNC will establish a global connectivity graph of the entire network and only obtain necessary knowledge for various pivotal services. CUC and eNB receive the ships/buoys traffic data from a local cluster of CUs and ships. Thus, CUC and eNB can run local processing services, such as local water-environment surveillance, without needing the entire network's knowledge from the SDNC. Under edge computing orchestration, CUC and eNB will offer local intelligence and location situation awareness with low latency. They are coordinated with each other by the SDNC. In edge computing, both central data centers and pervasive edge devices share their heterogeneous resources to support services, with the ability to migrate data and services among themselves as needed. Therefore, CUC and eNB both interact with the cloud through SDNC and share their resources for controlling ships.

4 Ocean Network Implementation

The proposed ON solutions are dedicated to civilian, commercial, and military uses. Therefore, IOCS mainly supports customers with the creation, expansion and upgrading of proprietary ONs, while the SDNC is a logical abstract of the underlying services that controls network policy and schedules tasks. Customers can create a private logical ON using IOCS and can logically isolate their businesses. In the rest of this section, we present our considerations and strategy to practically apply our vision.

Virtual private network (VPN) gateways. When a customer accesses ON, he/she needs access through VPN gateways. We include VPNs in ONs to both guarantee security and privacy and save public network IP addresses. A VPN can simultaneously build several fully isolated logical sub-ONs by using the same logical IP addresses. The ON application layer encrypts data by moving beyond a VPN, and only the units within a logical VPN can decrypt such data.

IOCS and SDNC. The X86, a family of backward-compatible instruction sets, is selected as the hardware facility for the IOCS and SDNC. It is better suited for a hybrid structure where enterprise customers provide data storage servers for IOAP, while the SDNC addresses logic tasks. The cryptography primitives for different services and applications may diverge. The keys for encryption and decryption can be stored on the customer side if he/she is willing to privately save them.

CBS and CU. They realize a flexible and distributed deployment of base stations and access points, respectively. Enterprise customers can lease a CBS from service providers and purchase data traffic to build VPNs based on a public network for data forwarding. On the other hand, enterprise customers can build their own private ON by owning ICT equipment and installations. The main advantage offered by such an independent and flexible deployment is the ability to physically isolate a network, while the possible disadvantages may include high costs for the network setup and maintenance.

Ship node. Ship node is an important cloudlet unit constructed by local X86 servers. A ship node could be a cluster of small computers that are able to connect with the rest of the nodes by means of satellite links when located in an open-sea area to forward the IOCS data resulting from local-run sensing and processing activities. We assume that each ship node is equipped with LTE, Wi-Fi, and satellite interfaces for control and data channels. The ship nodes should support a fallback mechanism that is able to revert to conventional communications once the SDNC connection is lost.

Buoy and underwater robot nodes. Similar to a ship node, a buoy node is assumed to be equipped with LTE, Wi-Fi, and satellite interfaces for control and data channels. At an offshore area, the buoy can communicate with both CBS and nearby ships through the LTE interface. While in an open-sea area, it communicates with ships using Wi-Fi links if buoys are located near ships, generally within the 300 meters that represents the maximum radius of the Wi-Fi range. A small on-board X86 computer module can be embedded within a buoy to cache and compress the data gathered from underwater nodes.

An underwater robot, such as a remote-operated vehicle (ROV), is assumed to be connected to a buoy by a wired cable. It may also be possible to have the underwater wireless technologies based on acoustic waves over data carriers. Similarly, it is equipped with a small on-board X86 computer module that senses the environment and compresses the data before the next forwarding.

Let us consider a scenario where a buoy and an ROV monitor activities using a local computer model. The ROV films the underwater environment and compresses the obtained multimedia data according to a given algorithm and then forwards the compressed data to the buoy. Simultaneously, the buoy caches the received data and shares them with the surrounding ships by running a reliable content-sharing protocol. If complex operations need to be performed on the video recorded by the ROV, the task can be passed over from the ROV or the buoy to the ships, since ROVs and buoys are resource-constrained. As a concrete example, this kind of video can be used for an automatic driving mechanism for the ROV by using a machine learning solution trained with a large amount of underwater environmental samples. If necessary, the processed data is forwarded to the IOCS through backhaul links to share the data with other interested nodes within the ON.

Figure 4 demonstrates how such an example can be implemented by having an ROV commanded by a personal smart device used by a human operator located in a neighboring ship. In this case, the smart device can be a cloudlet unit to process the obtained and distributed video images. At present, the chips of smart phones are qualified for image processing and have a processing rate of over 2000 frames per second. Therefore, they can perform real-time processing and target recognition from the local images. Large training data require more powerful computing devices within ship nodes or outsourcing the complex processing to even more powerful nodes within the ON under the support of the IOCS.

Figure 4. ROV operated by a smart device with a control panel

Underwater sensor and UUV: Within an offshore area, it is possible to have underwater sensors installed on the seabed that communicate with buoys or UUVs through the acoustical channels to deliver water quality and ocean current information (among other data). In an open-sea area, underwater sensors installed on ROVs ensure environmental protection and save costs. Moreover, the sensed underwater information can be reliably and quickly processed and returned via a wired cable or future underwater wireless technology.

Satellite relay system: A satellite cluster is a series of satellite transceiver terminals. After it is constructed in the SDNC, it can quickly forward messages. A satellite transceiver cluster, deployed on the coast near the CUC, eNB, and CU, aims to efficiently schedule the satellite communication links by supporting a rapid horizontal expansion of the overall network.

5 End-to-end Delay Improved Due to Edge Computing

In this article, we focus on the average end-to-end delay to assess the efficiency of the proposed edge computing-based ON architecture. We have considered two widely known routing protocols, mainly the Ad hoc On-Demand Distance Vector (AODV) and Destination-Sequenced Distance Vector (DSDV). We compared them both with and without the introduction of the proposed edge computing. We used a simulation approach for the assessment and adopted the simulator NS 2.35. We considered an overwater offshore ship-to-ship communication environment with an area of 30 square kilometers. The adopted propagation model is a one-path Rican fading channel with a 9 dB K-factor and an isotropic antenna deployed on each ship. The traffic type is uplink only with a constant bit rate under 2000 seconds, while the mobility model is random way-point data forwarding to the IOCS. In addition, the number of ships is fixed at 50, and each ship has a speed of 20 knots.

Figure 5 illustrates the efficiency of edge computing to lower the delay performance. The curve of the AODV protocol and the DSDV protocol without edge calculation support is very steep. They have a high initial delay of 0.00045 seconds and 0.00015 seconds in the case of transmission traffic of 300 seconds and 200 seconds, respectively. When the edge calculation is added, it can be seen from the simulation diagram that their delay curves change relatively slowly, and their delays are stable at 0.00012 seconds and 0.00005 seconds, respectively. In the case of the two-edge computing-based protocols, both the AODV and DSDV performances are dramatically lower due to the shorter routing paths. For example, the DSDV is a table-driven protocol that maintains route tables to minimize the time required for route discovery. Due to edge computing, the route tables are optimized so that some messages no longer need to be forwarded to the IOCS. Instead, they can be processed by the decentralized edge computing centers. This simulation has been empirically proven as one of the edge computing advantages, i.e., diminishing transmission delay to support real-time services.

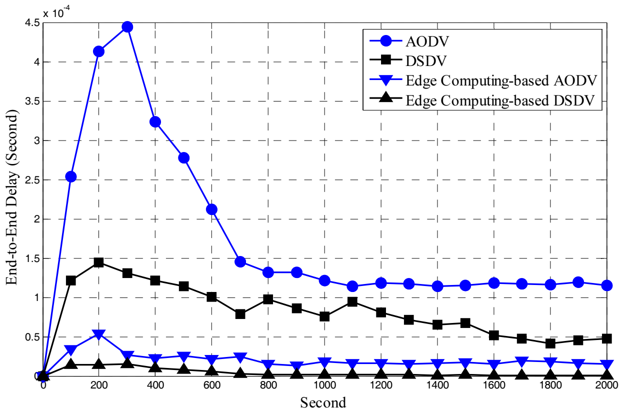

Figure 5. End-to-end delay performance under the edge computing-based ON

6 Ocean Network Challenges and Potential Solutions

In the previous sections, we described a new type of ON that employs ships and underwater devices as overlay nodes to optimize the maritime communications without relying only on satellite communications. Since this is a novel idea, many challenges and open problems exist that require further investigation. In this section, we present and discuss these challenges and open problems.

6.1 Security

Since ON can support huge communication and computational demands, more complex services and applications than the current one will be able to be designed and implemented in the near future. For these reasons, security and privacy are extremely important issues. In the study of [12, 24], communication devices are susceptible to the influence of a series of security problems, such as many IoT devices which do not have enough memory, and CPU performing cryptographic operations need for authentication protocol. It leads to the shortage problem of identity authentication, rogue IoT nodes may abuse of user data or provide malicious data for neighboring nodes and undermine its behavior. Resource-constrained IoT devices lack of encryption or decryption ability to generate the data, which makes it vulnerable to attackers that requests to deal with the increasing number of resources. IoT devices have to send the data to the cloud, while preserving data integrity during and after the processing phase becomes a security concern. Customers may face danger from information theft, hostile attacks, and computer viruses. In this article, we have already suggested several methods to ensure the internal and external security for the ON, including employing a VPN and the IOCS hybrid structure, which can physically and logically isolate the ON.

6.2 ECN Cooperation

The services running within the virtual machine (VM) hosted at the SDNC, CUC and CBS need an orchestration mechanism to forward data and change services. The orchestration is also in charge of service instantiation, replication and migration. A service may require a different number of CUCs and CBSs based on the number of users, the volume of managed data and the necessary amount of computations, resulting in the autonomic adaptation of demanded VMs and their replication or migration. This can be performed by an edge computing controller incorporated within the SDNC that can automatically update service hosting and data forwarding rules. That is the benefit of integrating the SDN with edge computing. However, the reconfiguration of service hosting, instantiation, migration, replication and data flow rules is costly, resulting in increased latency and worsened QoE. A good solution is to operate a hybrid control mode, in which a SDNC does not take full control of the system but shares the work with the CUC and CBS. For instance, instead of sending specific flow rules, the SDNC will send an abstract policy in which a specific behavior will be decided by the CUC or CBS depending on their own local knowledge. The data hosted by the CUC and CBS are then sent to the data center through the SDNC for the IOCS with long-term purposes if necessary.

6.3 Resource Management

To achieve an efficient cooperation and integration among all ON units, we need to design an appreciated resource-management scheme because the utilization of computing capabilities can be promoted by managing resources in a way that minimizes relative costs. A service-oriented resource-sharing architecture and mathematical model for the SDNC, CUC, and CSB could be used as a prospective solution. Instead of a task-oriented approach, this model is based on the key idea of service-oriented utility functions. Suppose that the SDNC, CUC and CSB host services throughout applications are installed within them. They request resources for a service, where each service is composed of multiple tasks. Some tasks are processed using local resources, but other tasks need to use resources from other ECNs.

6.4 Reliability Enhancement

The maritime communications occur in a very hostile environment that results in multiple interferences and attenuation of the signals. Moreover, the communication nodes are mostly moving, causing temporary or permanent disconnections due to being out of range of each other. At the application level, all these cases are seen as message losses or corruptions, necessitating a proper means to assure the reliability of the communications.

ITU-R M.184-1 [6] was released as a recommendation for data exchange within the context of maritime mobile services. In its Annex-5, data link protocols are described along with a time division multiple access (TDMA) frame structure. In [14], transmission resource blocks for marine networks along with the positioning of training sequences that refer to Terrestrial Trunked Radio (TETRA) specifications [25] are introduced, in which 72 pilot symbols are arranged within a TRB to provide a reasonable sampling of channel time-frequency response without incurring considerable lost efficiency. In [15], a multiple-input multiple-output system is considered to guarantee maritime link reliability. In [9], a multi-hop clock synchronization based on robust reference node selection is proposed to reduce the logical clock drifts among ship nodes by incorporating a beacon contention window.

Based on this literature, our envisioned system can embody some enhancements to provide more reliable communications. The first is to extend the cyclic prefix length to improve the robustness of multi-path propagation, but this results in inevitable decreases in the system spectrum efficiency. The second is to employ the robust channel equalizer (decision feedback equalizer) [26], which can remove both inter-symbol interference in the time domain and inter-carrier interferences in the frequency domain of multi-carrier systems. The third method is to employ redundant ECNs for the same services along with the diversity in the processing operations. These solutions have been designed in consideration of the normal environmental conditions, but the oceans are frequently affected by heavy weather conditions or other types of more severe disasters that can seriously compromise our system. Disaster-resistant communication means are needed to cope with such phenomena.

6.5 Capability Analysis Considering the ON Topology

It is important to analyze the capacity of an ON deployment to support the previously described features and deal with customer demands. Unfortunately, there are no real deployments or simulations for these kinds of networks that can provide us more insights. To this aim, we propose a multi-layer structure, where each ECN is considered different based on its key peculiarities. Therefore, we can divide the ECNs into three layers according to the three possible deployment contexts. Layer 1 includes coastland ECNs that have the strongest computing abilities and highest power consumption. Layer 2 includes maritime ECNs, including ship/buoy nodes, which have lower computational capabilities and power consumption than layer-1 nodes but are higher than the layer-3 ECNs (which are underwater nodes). Such a hierarchical modeling of the ECNs can help us build an accurate model for the ON based on different optimization strategies.

The ships' distribution can be traced throughout an Automatic Identification System (AIS) [27]. An example of our study is presented with a trace taken over a week in Oct. 2017. Figure 6 depicts an example of the capacity analysis supported by the described multi-layer model. In this example, we have simulated the capacity distribution for the moving nodes along the coasts of Hong Kong and Shanghai. In the simulation, we assume that each ship is coupled with three underwater devices. As shown in the figure, the capacity at the offshore area is larger than that of the open-sea area, which is caused by more active movements near the coastline. The figure also demonstrates that the computation capacity distribution is relevant to physiognomy. For example, there is a "Yangtze River"-shape strong computation area in Shanghai. The SDN orchestration logic and the data forwarding rules must consider such models to improve their behavior and the experienced QoS and QoE.

7 Conclusions

In this paper, we propose a combination of software-defined network and edge computing technology for the intelligent ocean convergence platform, and describe the design of the ON architecture in this case. The average end-to-end delay problem is studied through simulation, and it is concluded that the ON architecture combined with edge calculation has a small transmission delay advantage. Also, we have discussed the challenges and potential solutions of the ON architecture.

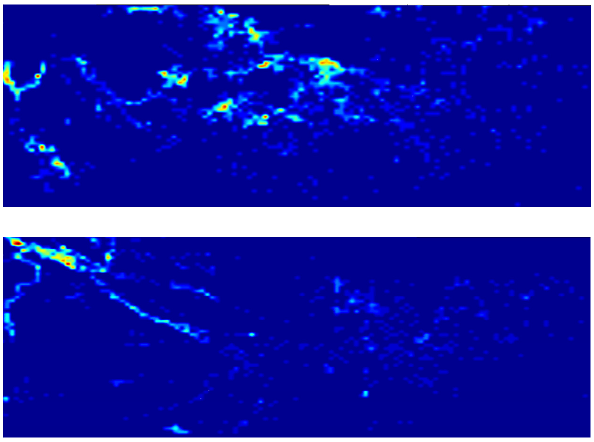

Figure 6. Overview of the computation capacity distribution for ECNs at the ocean areas of Hong Kong and Shanghai

In the future works, we will implement the intelligent platform as mentioned in the article. This is to solve the challenges of the proposed architecture, optimize the service platform, and improve the practicality and stability of the architecture. We would like to share our proposed ON architecture with other academic and industrial groups and expect this architecture to be of assistance to the current maritime communications research community. This will promote and drive progress beyond current state of the art and the most effective methods to meet current needs.

Acknowledgements

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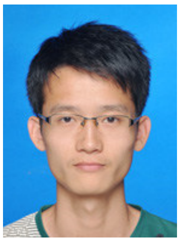
Biographies



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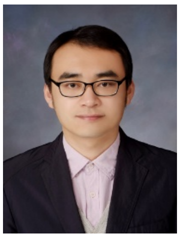

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