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A Possible Development of Marine Internet: A Large Scale Cooperative Heterogeneous Wireless Network

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Abstract: Today, terrestrial Internet can be easily accessed with various types of terminals almost anytime and anywhere on the land. But this is not yet the case in the ocean mainly due to huge differences between terrestrial and marine environments. Although satellite Internet services are available in marine environments, at the time-being, they are neither cost-effective nor popular due to their inherent weaknesses in construction, launching and operation. Ever-increasing human activities in the ocean require marine Internet to provide handy, reliable and cost-effective high-speed Internet access not only on surface but also underwater in marine environments. This is due to the fact that a huge number of sensors and things have been deployed underwater, and this number is still increasing. How to interconnect them becomes an important issue that is necessarily addressed in order to form large and sophisticated underwater systems. This paper discusses the major available network technologies and new networking approaches that can be used to develop marine Internet, particularly a large scale cooperative heterogeneous wireless network, along with some further research issues.

Key words: Marine Internet, cooperative heterogeneous wireless networks and underwater networking.

1. Introduction

Marine Internet aims to provide Internet services in marine environments for users and applications on water surface and under water [1]. One type of user comes from civil sectors, including seamen, fishermen, cruise/yacht passengers, island habitants etc. These users have to be provided with seamless Internet access and kept connected with the rest of the world during their sea voyages. Another kind of user is from industry sectors, such as maritime transportation and offshore oil industry. Marine Internet can be used for real-time control of product line and remote surveillance. It can also be used to transport large volume of data to terrestrial high-performance computing centers for fast analysis and rapid result feedback. This is typically useful to undersea oil exploration, ecosystem monitoring and scientific research in marine environments.

On the other hand, a large number of underwater sensors and things have been deployed in the ocean, and this number is still increasing fast. But due to many challenges for realizing efficient underwater networking [2-6], a single underwater wireless network can only cover a small area and is often isolated from each other. This is due to the fact that the currently popular underwater communication medium is acoustic wave, which can only provide low transmission rates with large propagation delay [7-10]. Another underwater communication medium is blue/green laser, which can provide much higher transmission rates with shorter propagation delay but can only propagate well over shorter distance [11]. In this case, marine Internet can be used to connect underwater networks in different locations to form a large and sophisticated underwater system, such as the IoUT (Internet of underwater thing) [12].

For the time-being, marine Internet is still one of less developed areas due to huge differences between the terrestrial and marine environments. These differences, mainly residing in geographical environments, climate conditions and user distribution,

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cause that marine Internet cannot be a simple extension of terrestrial Internet. The ocean is a huge water body containing about 1.3 billion cubic kilometer saltwater with a 3,682-meter average depth, and covers about 71% of the earth's surface, which makes it extremely difficult and costly to deploy network infrastructures therein. Special ocean climate conditions of high humidity, various forms of precipitation and frequent extreme weather also cause problems to communication and networking. For example, humidity and precipitation may severely degrade the performance of satellite communication at super high frequencies, and extreme weather may severely destroy network infrastructure to paralyze the network. On the other hand, most marine Internet users are transient and unevenly distributed at a very low density on average. Marine Internet users are much less than terrestrial ones but the former are distributed over a surface about 2.5 times the terrestrial surface. Most areas in the ocean are unpopulated, while a large number of users may just crowd in a very small place such as a cruise ship, whose capacity ranges from hundreds to thousands with an average of 3,000 for ocean liners. These ships often move from one place to another.

This paper discusses the major network technologies available and under development as well as a large scale cooperative heterogeneous wireless network structure for marine Internet in Sections 2, 3 and 4, respectively. The underwater inter-networking in the context of marine Internet is discussed in Section 5. Some issues to be further addressed are discussed in Section 6.

2. Available Network Technologies

This section briefly reviews the major currently available network technologies able to provide marine Internet services, which include maritime radio systems, cellular networks and satellite Internet. The former two are collectively called CLNs (coastline networks), henceforth.

2.1 Maritime Radio Systems

The VHF (very high frequency) refers to frequency bands between 30 and 300 MHz. Particularly, the maritime VHF radio operates in frequency bands between 156 and 162.025 MHz, with a typical channel spacing of 50 and 25 kHz, respectively. Traditionally, it only provides analog voice communication with a maximum communication range of up to about 111 km. Now it has a digital selective calling capability at a rate of up to 1.2 kbps, which can allow a distress signal to be sent by pressing a single button. Some VHF channels have been used to develop VDLs (VHF data links) to provide data communication for AISs (automatic identification systems) at a maximum rate of 9.6 kbps. An AIS is an automatic tracking system used to identify and locate vessels for navigation and vessel collision avoidance. To this end, the position information of a ship is continuously transmitted on AIS VDLs to ensure that all its closest vessels will receive its position report. To improve the safety of maritime navigation and operations especially in adverse conditions, more messages have to be exchanged in real-time, such as weather, ice charts, status of aids to navigation, water level and rapid changes of port status, voyage information, passenger manifest and pre-arrival report etc. [10].

Due to the popularity of AIS applications and increasing demands of ship-to-shore and ship-to-ship data exchange, the capacity of the current AIS VDLs becomes inadequate to satisfy these increasing demands. To handle this problem, two additional 25-kHz channels have been proposed to support ASM (application specific message) communication, and six original VHF channels have been enhanced for the VDES (VHF data enhanced system) [13]. The VDES aims to provide a maximum rate of 302.2 kbps by merging four of the six VHF channels into a 100-khz channel and the other two channels to a 50-kHz channel [14]. Existing wireless communication technologies such as the OFDM (orthogonal frequency division multiplexing) modulation and distributed antenna technologies can be used to enable VDESs. Some results of a VDES channel sounding campaign are reported in Ref. [15]. Similarly, in the UHF (ultra high frequency), which ranges from 300 to 3,000 MHz, six frequencies between 450 and 470 MHz with a 25-kHz channel spacing are also used for on-board communication for maritime operations. To improve spectrum utilization, narrower channel spacings such as 12.5 or 6.25 kHz are suggested so that additional channels can be introduced [16, 17].

Both VHF and UHF are very important for maritime radio communication to support maritime operations, especially for safety and rescue. However, due to the limited VHF/UHF bandwidth allocated for marine communications and ever increasing data communication necessary for improving the safety of maritime navigation and operations, there is no adequate channel capacity available for popular Internet applications in marine environments.

2.2 Cellular Networks

Advanced cellular network technologies such as WiMAX and LTE (the long-term evolution) have been used in harbor areas and busy water channels to provide Internet accesses for residents and ships therein. It was reported by the Wall Street Journal in June 24, 2013 that Verizon Wireless had enhanced its 4G LTE coverage in and around Boothbay Harbor in Maine, USA. These technologies can provide transmission rates up to several hundreds of Mbps with a maximum coverage radius of a hundred kilometer. The Huawei eWBB LTE solution can cover a circle of 100 km radius with a downlink and uplink data rates of up to 100 Mbps and 50 Mbps, respectively [18].

Although the ocean is big, most human activities therein take place in water areas near coastlines. For example, many domestic maritime shipping routes are set close to the coastline, say about 2~20 nautical miles away from the coastline as suggested in the literature. Therefore, it is necessary to consider how to provide handy, reliable and cost-effective high-speed Internet access for marine Internet users in these water areas. Thus, deploying cellular network like systems along coastlines makes sense. This system is mainly composed of certain terrestrial infrastructures like base stations installed near or along coastlines or on islands. This type of infrastructure can act as a bridge between water areas and terrestrial networks.

The benefit of using such system is twofold. First, some existing technologies such as WiMAX and LTE can be used without need of a long R&D period. Internet users covered by this system can have seamless and direct Internet access with their handsets without paying extra cost of specific devices. Second, newly developed technologies for cellular networks can be continuously used to increase the system capacity and reduce system construction cost. For example, the combination of RoF (radio over fiber) and distributed antenna technologies has been considered as a promising technology to increase the capacity of future wireless networks, with which, the base station can be simplified into an antenna system mainly equipped with a tx/rx module that simply relays analog radio signal. Multiple antennas can be linked through optical fibers to a processing center, which conducts further processing for signaling, communication and networking.

Since this system requires deployment of terrestrial infrastructure, which limits its coverage, it is very difficult for the system to cover deep water areas. With the global coastline of about L = 356,000 km, given the maximum radius of a base station's coverage R =50 km (e.g., with WiMax), the overall coverage of the system can be roughly estimated by $L \times R = 1.78 \times 10^7$ km^2, which is only 4.92% of the overall ocean's surface of 3.62×10^8 km^2; if R = 100 km (e.g., with LTE), the coverage ratio is doubled to 9.83%.

2.3 Satellites

A GEO (geostationary earth orbit) satellite runs in an orbit of 35,786 km with an orbit period of 24 hours and seems to be fixed in the sky to a ground observer. Theoretically, three GEO satellites can cover most of the earth's surface except the polar areas. They have been used to provide communication services in marine environments for long time. For example, Inmarsat uses GEO satellites to provide voice, IP data services and access to the GMDSS (global maritime distress and safety system) in sea. The major problem of using GEO satellites for Internet applications is the long round-trip propagation delay between two ground stations via a GEO satellite, which is about 250 ms and almost a double of the end-to-end delay bound of voice application. A much larger latency further contributed by queueing delay and processing time for communication and networking will severely affect the performance of network protocols (e.g., TCP) and QoS (quality of service) provisioning for delay-sensitive applications.

This long propagation delay can be significantly reduced with a MEO (medium earth orbit) satellite (whose orbit ranges from 3,000 to 35,786 km), especially with a LEO (low earth orbit) satellite (whose orbit ranges between 200 and 3,000 km), such as Iridium and Globalstar systems. However, LEO/MEO satellites fly rapidly around the earth while vessels may also move and rock with water. In this case, it is difficult to track a satellite to keep a line of sight between the satellite and directional antennas to maintain high communication quality. If an omni-directional antenna is used instead, wireless communication quality will be degraded severely. On the other hand, satellite communication at the L-band (1~2 GHz), C-band (4~8 GHz), Ku-band (19 GHz) and Ka-band (29 GHz) is also affected by moisture and various forms of precipitation frequently present in marine environments, to which communication at these bands is susceptible.

Another weakness of satellite systems is the high cost of construction, launching, operation and maintenance of satellites. Hardware upgrading or repairing of a satellite already in the orbit almost means a replacement. Furthermore, for high altitude satellites, radio communication suffers high attenuation and large path loss so that some specific bulky terminals with large transmission power are needed, which further financially burdens the user. With such high cost and very low user density, satellite Internet is not cost-effective for marine Internet users. Table 1 lists some recently available marine Internet services provided by satellites, which are still luxury to the ordinary user.

3. Developing Network Technologies

Due to the weaknesses of the existing network technologies discussed above, several new approaches have been studied in the literature, namely, WANETs (wireless ad hoc networks) and HAPs (high altitude platforms).

3.1 WANETs (Wireless Ad Hoc Networks)

Cellular networks and wireless local area networks need infrastructures like base stations or access points to coordinate communication between terminals, which cannot communicate each other directly. This is just opposite in WANETs, where no infrastructure is required and terminals can communicate each other directly. The ability of WANETs in terms of self-organizing and self-curing makes them suitable for dynamic and unstable networking environments.

Table 1 Some available marine Internet services provided by satellites [19].

Service package	Data rate (kbps)	Cost/MB (USD)	Cost/PM (USD)	Equipment's cost (USD)
FleetBroadband G†	≤432	0.40~20.85	0.42~1.15	4, 700~16,914
MCD-4800-BGAN†	448	4.70~6.99	0.98	13,733
FleetPhone Global†	2.4	15~50	0.80~0.95	1,899~2,349
Iridium Pilot Global	134	7.41~10.90	0.65~1.22	4,595

†which is provided by Inmarsat, MB=Megabyte, PM=Phone Minute.

That is, any vessels and facilities on water surface (e.g., buoys) equipped with wireless communication devices can be used to construct WANETs to enable vessel-to-vessel and vessel-to-shore communication. Reference [20] is among the earliest discussing such idea, in which a WiMAX mesh network is used to provide onboard Internet broadband access for vessels in the Mediterranean without using satellites. A systematical study has been carried out by the project TRITON [21], which tries to set up a WiMax-based mesh network for ship-to-ship and ship-to-shore communication at high rates. This kind of WANET consisting of vessels and facilities on water surface is often called NANET (nautical WANET) [22, 23].

A WANET can be used as a complementary technology to the available networking technologies to improve their service coverage and performance with the following extensions. The first one is that any vehicles above water surface such as balloons, airships, helicopters and airplanes can be used to form an AANET (aeronautic WANET) [24] to provide opportunistic networking. Obviously, NANETs plus AANETs can cover much larger water areas and provide more networking opportunities. The second extension is UANETs (underwater WANETs) [25], which can avoid underwater construction of network infrastructure and be used to connect underwater things [12].

The major weaknesses of this WANET-based approach include small network coverage, unstable network connectivity and unreliable network performance due to its dynamic network topology. The end-to-end network performance degrades quickly as the number of hops along a network route increases. It can provide high-speed network connection occasionally at low cost, but the performance largely depends on the density and distribution of network nodes, both of which are highly dynamic in marine environments. Hence, WANETs cannot provide always-on connectivity or service guarantee.

3.2 High Altitude Platforms

A HAP is a quasi-stationary aerial platform in the stratosphere located at an altitude of 17~22 km above the earth's surface. The radius of a HAP's footprint can be up to 100 kilometers, depending on its altitude and elevation angle. With a 50-MHz bandwidth at 28-GHz frequency, a HAP at a height of 10 km above the ground can provide downlink date rates up to 320 Mbps [26]. HAPs are particularly suitable for large water areas near a coastline such as 200-nautical-mile exclusive economic zones, and can be used in the following scenarios to provide marine Internet services:

(1) An instant demand for a short time period: For example, when the number of users goes beyond the normal situation due to some occasional events such as a gathering, a HAP can be set up shortly and removed afterwards;

(2) A short-term solution where neither CLNs nor NANETs are available. An HAP can be in the place for duration of several months and even longer with solar energy supply, and are particularly useful for some events with special networking requirements for months, such as scientific exploration;

(3) A fundamental part of marine Internet networks in the places where it is difficult to deploy CLNs. This HAP can consist of solar-powered unmanned airships, which can stay in the stratosphere for a very long period.

Actually, there are several projects of HAPs under going. For example, the vulture program of USA's DAPRA aims to develop a single high-altitude unmanned airplane to operate continuously on-station for five years [27]. Google's Loon project (see http://www.google.com/loon/) tries to use balloons to provide Internet access for everyone in the world, and was tested in 2013.

The major advantages of HAPs over satellites include easy and fast deployment, low cost and large capacity with shorter propagation delay [26]. In comparison with a WANET, an HAP can cover much larger areas with more reliable network performance; but their deployment and power supply are more difficult to handle. As discussed in Ref. [26], one major challenge is the overall long-term power balance. Relatively mild wind and turbulence in the stratosphere need power for propulsion and station-keeping. Particularly for a balloon platform, the HAP requires wind compensation to stay still in the sky, and for an aircraft platform, the HAP has to fly on a circle to maintain services to some area. Power is also required for the payload, communication and networking. Unlike satellites which can be re-charged by solar power frequently, for HAPs, enough power has to be stored in cells during the day in order to maintain the normal operation throughout the whole night. Thus, a large capacity cell is required, resulting in more payloads and more power consumption. Hence, the ageing of cells is a major factor determining the achievable mission duration of an HAP. A possible solution to this problem is to bring an HAP back to the ground for service, which however will cause service disruption and increase deployment cost.

4. A Hybrid Networking Structure

Table 2 summarizes the suitability for marine Internet (the upper part) and characteristics (the lower part) of the major network technologies discussed above, where strengths are spelt in the bold italic font. This table shows that none of them alone can provide a cost-effective solution for marine Internet, hence that a hybrid networking structure able to make use of their good features is necessary [1]. With such a structure as depicted in Fig. 1, CLNs are deployed along coastlines to cover water areas in which the majority of marine Internet users will present. Typical CLNs include the maritime radio systems and cellular systems discussed in Section 2.2. To reduce interference to terrestrial wireless networks, directional antennas should be used to focus the signal coverage to the corresponding water areas. These types of antennas can also allow larger transmission power to be used to expand transmission distance and signal coverage when necessary. A CLN also functions as a gateway between water areas and terrestrial networks. It is expected that marine Internet users covered by a CLN can enjoy terrestrial Internet access with acceptable cost and QoS.

To improve QoS in a water area and expand the coverage of a CLN, WANETs can be used jointly to provide low cost and short-term network connections. For example, vessels close to each other can form a NANET, which can further involve buoys and small boats nearby. This kind of NANET can link nodes therein to a CLN for terrestrial Internet access, or be used to support intra-NANET communication. For delay-tolerant applications, an AANET can also be exploited if any to provide opportunistic network connectivity with a store-and-forward transfer mode. When a node is out of the service coverage of the CLNs or NANETs, this kind of AANET may become

Table 2 Characteristics of networking technologies for marine Internet.

<table>
<tr><th></th><th>Satellite</th><th>HAP</th><th>Cellular</th><th>WANET</th><th>VHF/UHF</th></tr>
<tr><td>Wide water surface</td><td>Suitable</td><td colspan="4">Unsuitable</td></tr>
<tr><td>Underwater network</td><td colspan="3">Unsuitable</td><td>Suitable</td><td>Unsuitable</td></tr>
<tr><td>Channel quality</td><td>Vulnerable</td><td colspan="4">Invulnerable to humidity & precipitation</td></tr>
<tr><td>Infrastructure</td><td colspan="2">Safe</td><td colspan="3">Unsafe in extreme weathers</td></tr>
<tr><td>Power supply</td><td colspan="2">Limited</td><td colspan="3">Unlimited (except UANETs)</td></tr>
<tr><td>Service capacity</td><td>Small</td><td colspan="3">Large</td><td>Too small</td></tr>
<tr><td>Service guarantee</td><td colspan="3">Yes</td><td>No</td><td>Yes</td></tr>
<tr><td>Cost-effectiveness</td><td>Low</td><td colspan="4">High</td></tr>
<tr><td>Direct user access</td><td>Difficult</td><td colspan="4">Easy</td></tr>
</table>

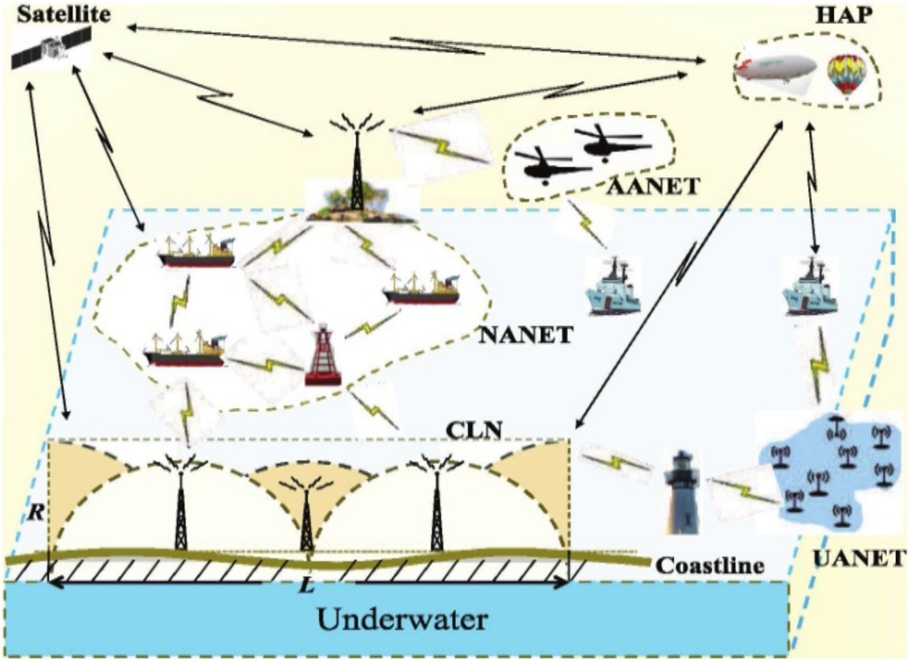

Fig. 1 A hybrid networking structure for marine Internet.

the only chance for nodes therein to communicate with the outside. Another important application of WANETs is to construct underwater networks at lower cost with more flexibility in comparison with wired underwater networks, which will be discussed more in Section 5.

An HAP can be developed on-demand for occasional marine Internet users, especially when neither CLNs nor WANETs are available. If the problems of HAPs mentioned in Section 3.2 can be effectively resolved for dense deployments, HAPs can even become a replacement of terrestrial base stations to cover large water areas, with the satellite being used as a backhaul to terrestrial networks. Different from the current situation in which the satellite usually is the only option available for marine Internet, the hybrid networking structure tries to make the satellite to be the last option. For example, the satellite is just used as a backup solution for emergency situations when none of the above-mentioned networks are available.

It is expected that the hybrid structure can provide a cost-effective network service following application requirements by exploiting any networking opportunity as much as possible with the following preference: CLNs are always selected first if any, then WANETs and/or HAPs can be exploited with the backup of satellites. Actually, if each network in this hybrid structure is treated as a special networking node, this structure itself can be regarded as a super-scale hybrid WANET. One challenge is how this super-scale network can be smart enough to select the most cost-effective network service to satisfy application requirements without requiring user's involvement in real-time. Since this part is still under study, here we only provide a simple simulation to demonstrate the effect of the availability of various types of networks on network performance and coverage.

As illustrated in Fig. 2, a hybrid network consisting of a CLN, NANETs and a satellite (SAT) is simulated with the Exata simulation package [28] in an 85×85 km^2 area, one part of Shanghai Harbor in China. The CLN has two IEEE 802.16 base stations located at points A and D in the figure, whose maximum transmission distance is about 50 km. NANETs are randomly formed by 105 boats, which are distributed according to the statistic pattern of real boat traffic and

Fig. 2 A simulation scenario for hybrid networking structure (nodes located in areas between the dashed lines and edges are called edge nodes).

Table 3 Effective throughput (kbps) versus available networks and mobility.

Boat's speed ranges	0~6 km/s		6~13 km/s	
Networks turned on	Edge nodes	Overall	Edge nodes	Overall
Only CLN	0	896.6	0	97.153
CLN, NANETs	3.741	872.531	2.914	99.196
CLN, NANETs, SAT	7.851	876.641	7.024	103.306

move according to a random way point model at one direction with a uniform distributed speed. Boats try to communicate with a server located on the land (point B in the figure) through a gateway (point C in the figure) at a constant bit rate. The CLN, NANET and the SAT are turned on one by one in order.

Table 3 lists some simulation results on effective throughput, which is the ratio of the total received packets to the simulation time. The first performance indicator is the effective throughput for edge nodes. We can find that since these nodes are far away from the coastline, the CLN cannot cover them so that they cannot communicate with the server on the land. When the NANET and satellite join in, these nodes get opportunities for communication with the server. Accordingly, the overall effective throughput (i.e., the sum of the effective throughput of every node in the network) increases too. The large column on the right show the effective throughput for larger speed ranges, which show the effect of boat's mobility on the performance. In this case, more boats will move away from the coastline and cannot be covered by the CLN, while the performance of NANETs also degrades.

5. Underwater Inter-networking

Terrestrial Internet usually need not consider underground networking. However underwater networking has to be taken into account by marine Internet to support the IoUT (Internet of underwater thing) [12], for example. This is due to the fact that a huge number of sensors, vehicles and other underwater things have been deployed, and this number is still increasing. The network technologies and approaches except WANETs discussed in above sections are not suitable for underwater networks due to difficulties in deploying the required network infrastructure.

Table 4 summarizes the transmission rates, distance and propagation speeds of the major media when they are used for underwater communication. It shows that electromagnetic wave cannot propagate well in seawater, while acoustic wave can propagate over a long distance but at a very slow speed, which will cause long end-to-end latency. The kbps-level capacity of acoustic media is in—sufficient to support many Internet applications. For example, the audio codec bandwidth is 11.8~128 kbps and 0.25~4 Mbps for video, both of which exclude the network protocol overhead ranging from 12.5~55.5% of the original one for audio if only the IP header is counted. Blue/green laser can provide high transmission rates with very short propagation delay but cannot propagate over long distance due to scattering and the precise point-to-point transmission requirement [4]. The transmission rates in VLF (very low frequency) and ELF (extremely low frequency) bands are just too small.

To maintain acceptable transmission rates with the current underwater communication technologies, the size of an underwater wireless network should be constrained. The WANET is a reasonable option to avoid underwater infrastructure construction, with which underwater nodes close to each other can automatically form a UANET (underwater ad hoc network). To cover a large underwater area in this case, underwater inter-networking technologies should be used to link different underwater networks.

Basically, there are two underwater inter-networking methods. The first one is to use cables deployed on the sea floor to link underwater things and provide energy to them. This method has been used in some underwater observation systems such as the MARS (Monterey accelerated research system). Its major advantages include high-speed reliable network connections and sustainable power supply. The major challenge arises from the difficulty in and the cost of dense infrastructure deployment for covering wide underwater areas.

The other method is to use surface gateways floating on water to link UANETs especially underwater sensor networks [29] through acoustic wave or green/blue lasers. The marine Internet above water surface can be used to inter-network different UANETs by connecting their surface gateways as illustrated in Fig. 3. Particularly with a star-topology, which is more common than other topologies for underwater networks [3], each UANET has one surface gateway, which collects data from the UANET

Table 4 Characteristics of underwater communication media.

Maximum transmission distance (km)						Speed in seawater
Transmission rates	0.05	0.1	1	10	100	
Acoustic waves (kbps)	300	-	30	15.36	0.5	1.5 km/s
Blue/green laser (Mbps)	10	20	-			33,333 km/s
VLF(ELF (bps)	300	-	3	Negligible		

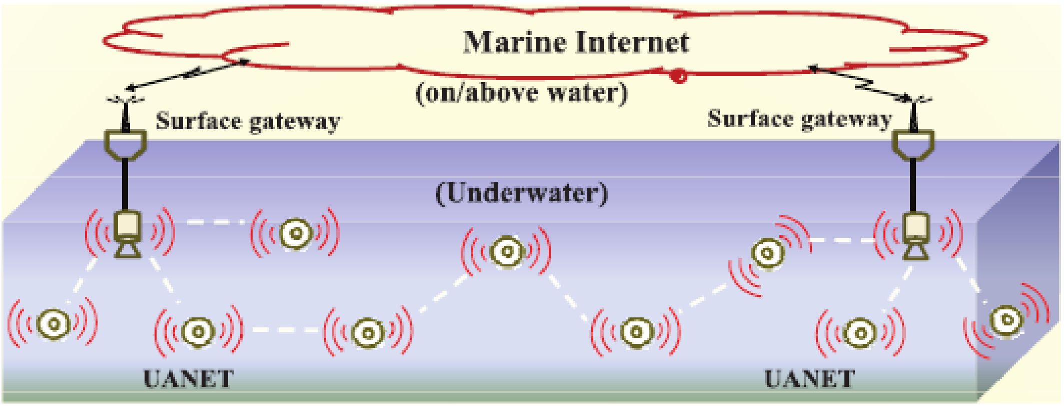

Fig. 3 Underwater inter-networking with marine Internet.

and sends it to marine Internet. This gateway can also broadcast the data coming from marine Internet to the UANET under its control. The underwater nodes covered by a surface gateway can communicate with it directly, while those out of its coverage need the relay of other nodes to connect the gateway. A set of surface gateways close to each other and equipped with the same type of air interface can also form a wireless mesh network, but those with different types of air interfaces or far away from each other have to use marine Internet for inter-networking. This method can avoid severe performance degradation problem in WANETs as the number of hops along a route increases, and allow many small-sized UANETs to be connected to cover a large underwater area. This method is more flexible, easier and cheaper than the first one but cannot provide power supply to underwater things.

6. Further Research Issues

This section briefly discusses some major research issues necessarily to be further addressed in order to foster the development of marine Internet.

6.1 CLNs and Satellite Internet

Although CLNs are relatively mature, there are still some issues necessarily to be further addressed to overcome their weaknesses discussed earlier. Particularly for the VHF/UHF maritime radio systems, it is important to improve the utilization of the allocated spectrum bands to support ever-increasing data communication dedicated for safe and rescue as well as maritime operation, while using available bandwidth for general data communications. This may be achieved by using advanced modulation and distributed antenna technologies such as OFDM, MIMO (multi-input-multi-output) and even their combination. OFDM can reduce channel spacing, and MIMO allows the same carrier to be reused multiple times simultaneously at the same site. The efficiency of the spectrum reuse is subject to the number of transmission and reception antenna-pairs available. In addition, some UHF frequencies allocated to maritime radio overlap with those allocated to IMT (international mobile telecommunication) or satellite systems in some countries (e.g., 420-470 MHz). Thus a cognition ability of communication systems on vessels is necessary for a global inter-operability. To this end, cognitive communication and networking need to be addressed. Although 3G and beyond-3G cellular networks are very popular in terrestrial environments, their applications in marine environments still need to be investigated since radio signals can be easily absorbed by seawater and also due to special user distribution in marine environments mentioned earlier.

To increase communication capacity at low cost for satellite Internet, deploying more small satellites into low orbits seems to be promising since the cost for both construction and launching of satellites can be reduced significantly in this case. However, keeping the communication quality of the wireless link between a flying satellite and a moving terminal in progress of communication and dealing with rapid handoff between a satellite's coverage and terminals on the vessels are two challenging issues to be addressed. On the other hand, to enable satellite Internet to attract more terrestrial users is also important to improve investment efficiency so as to further reduce the cost for users in marine environments.

6.2 WANETs, HAPs and Hybrid Networking Structure

Regarding the newly developing network approaches, more research is still needed to improve the performance of WANETs, which can be achieved by exploiting some favorable features uniquely present in NANETs. For example, one feature of NANETs is the availability of information on positions and speeds of vessels, which can be provided by AIS or GPS. This information can be used to improve routing performance especially for opportunistic networking. Research is also required to reduce the cost of HAP deployment in marine environments. To this end, the optimization of power allocation should be used to allow an HAP to stay in the sky for longer time period and to support more communication loads, while guaranteeing successful return of HAPs to the ground for recycle usage.

An open networking structure that enables cooperative communication and networking is necessary to support the hybrid networking discussed above. It has to accommodate various types of networks and make them cooperatively provide cost-effective service to marine Internet users. One challenge is to handle the heterogeneity of air interfaces, communication capacities, networking capabilities and various requirements for QoS (quality of service) as well as network security. Most of Internet users in marine environments are transient and come from different places through vessels, which may have various communication facilities and radio interfaces following different technical standards. It is also important to enable an efficient collaboration between CLNs, various types of WANETs, HAPs and satellites to maximize network connectivity at low cost. Another challenge is to provide networking services on-demand since it is costly and even impossible to maintain an always-on connection between any nodes in marine environments. For opportunistic connection, all kinds of nodes should be considered to maximize connectivity especially in emergency situations when no other options are available. In this case, how to ensure end-to-end networking security is an important and difficult issue.

6.3 Underwater Inter-networking

If there is no breakthrough for underwater communication technologies to enable large underwater coverage at high transmission rates, a major performance improvement for a single underwater wireless network is the optimization of the data link layer and network layer, especially from MAC (medium access control) and routing protocols. Particularly with acoustic underwater communication, it is necessary to minimize the use of handshake to avoid long latencies caused by slow signal propagation speed and low transmission rates as discussed below.

The ratio of the time used to transmit a packet (T) to the time used to obtain transmission opportunity (t, which is the interval between when a packet arrives at a node and when the node starts the transmission), $\frac{t}{T}$, is often used to evaluate a protocol's efficiency. It can be estimated below for once packet transmission:

$$\frac{t}{T} \approx \frac{x \times \frac{\gamma}{r} + y \times \frac{d}{v}}{\frac{l}{r}} = x \times \frac{\gamma}{l} + y \times \frac{r}{l} \times \frac{d}{v} \qquad (1)$$

where, r is transmission rate, γ is protocol overhead, l is packet length, d is the distance between the sender and the receiver, v is signal propagation speed. Both x and y are a positive coefficients, and their settings depend on protocol design. For a terrestrial wireless network, v =300, 000 *km/ s* in the air, so that $\Delta = y \times \frac{r}{l} \times \frac{d}{v}$ in (1) can be very small and even negligible so that $\frac{\gamma}{l}$ is a dominant factor of $\frac{t}{T}$. However, for acoustic wave in seawater, v= 1.5 *km/s*, Δ becomes too large to be negligible, resulting in a significant increase in $\frac{t}{T}$. When handshaking schemes are used, such as the RTS/CTS adopted by IEEE 802.11 and the RREQ/RREP used by the AODV (ad hoc on-demand distance vector) routing protocol, both x and y will be increased, causing increase in $\frac{t}{T}$ too.

Particularly for a star-topology underwater wireless network as illustrated in Fig. 3, the CDMA (code division multiple access) can avoid using a handshaking scheme in MAC protocols. With CDMA, each node can send simultaneously in the same frequency band if an orthogonal code is pre-assigned to each node with proper power control. This objective can also be achieved by using the logical MIMO approach [30, 31], which can allow multiple nodes to share the same uplink simultaneously. The number of such nodes depends on the number of receive antennas installed in the surface gateway. Regarding the underwater network routing with this topology, actually the major work can be carried out by the surface gateways rather than by underwater nodes, which can minimize transmission of handshaking message between underwater nodes.

7. Conclusions

It is believed that marine Internet will become more and more important in the future for people to expand their activities in marine environments, while there is not yet a cost-effective solution ready for it. This paper carries out an evaluation of the major state-of-the-art network technologies available and under development that can be used to develop marine Internet, particularly a possible solution using a large scale cooperative heterogeneous wireless network consisting of various types of wireless networks. The challenging issues discussed in the paper also show that marine Internet is still in its enfant stage, and more research is required to foster its development.

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