The Wireless Communications for Unmanned Surface Vehicle: An Overview

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Abstract. With growing interest in commercial, scientific and environmental issues on oceans, lakes and rivers, there has been a corresponding growth in demand for the development of unmanned surface vehicles (USVs). The wireless communication module is one of the key components of USV because of the data and control information communication with ground control stations and other vehicles to perform cooperative control. This paper presents a survey on the wireless communication techniques that can be used in USVs and a detailed discussion about the advantages and disadvantages of these techniques for data and control information transmission. The paper first provides an overview of both typical and recent wireless communication techniques, along with some principles and parameters. Next, wireless communication techniques used in USVs are outlined and classified according to single USV and multi-USVs. Finally, some advices on choosing wireless communication techniques and some general challenges towards high-speed and swarming USVs are highlighted.

Keywords: Unmanned surface vehicle (USV) · Wireless communication
Multi-USV networks

1 Introduction

Unmanned Surface Vehicle (USV) is an intelligent and unmanned water surface platform, which can navigate autonomously in the marine, lake and river environment and complete various tasks such as environmental perception, target detection. The applications of USV include harbor surveillance, water quality sampling, hydrologic survey, maritime search and rescue, anti-submarine warfare [1–4].

Depending on practical applications, USVs may have a variety of appearances and functionalities. However, the basic elements such as propulsion and power unit, perception and navigation unit, guidance and control unit, communication unit, must be included in every USV. The fundamental architecture of a typical USV is shown in Fig. 1.

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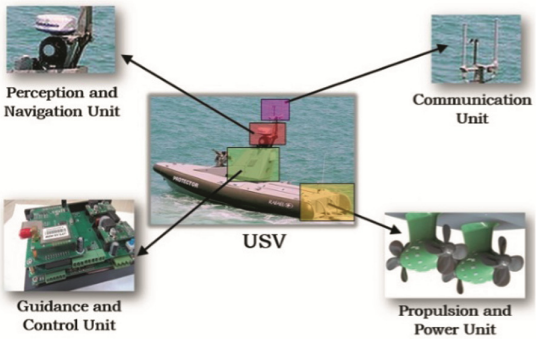


Fig. 1. The fundamental architecture of a typical USV

The propulsion and power unit provides the speed and heading of USV. Most existing USVs use rudder and propeller (or water jet) propulsion systems. The perception and navigation unit concentrates on identifying the USV's current and future states according to its surrounding environment information. The guidance and control unit focuses on determining the proper control forces and moments to be generated with instruction provided by the navigation unit and the control objectives. The communication unit has wireless communication with ground control stations and exchange data including receiving commands from the ground station and reporting the operating status and videos. Reliability of communication systems is therefore of great importance [5–8].

In order to enhance robustness and reliability of USV, improve mission performance, increase their spatiotemporal capacity, and enlarge the coverage of surveillance and measurement, the USVs are clustered into swarm application under cooperative control. Consequently, there are four types of wireless communication for USVs as shown in Fig. 2.

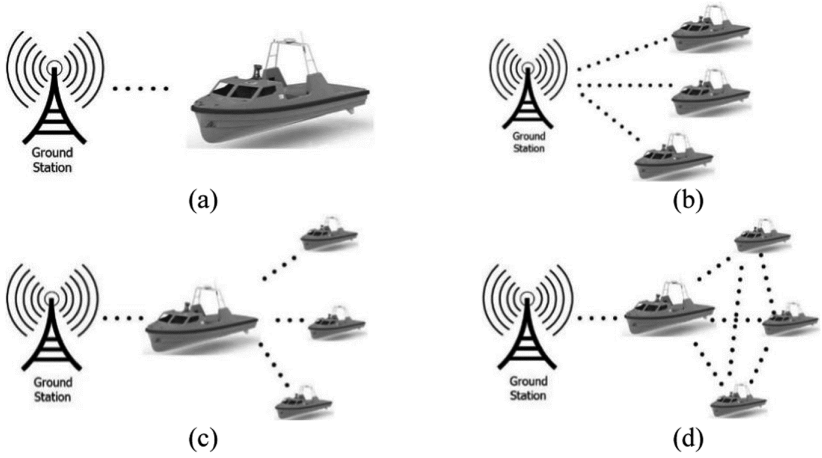


Fig. 2. Four types of wireless communication for USVs

The four types of communication configurations are point-point, point-multipoint, point-point and point-multipoint and mesh network. Different configuration requires different communication performance. Decentralized cooperative control shares information among the USVs, which brings about numerous challenges including limited communication bandwidth, transmission noise, and communication delays, dropouts and failures [1, 9–13].

This paper presents a survey on the wireless communication techniques that can be used in USVs and a detailed discussion about the performance according to single USV and multi-USVs. Finally, some advices on choosing wireless communication techniques and some general challenges towards high-speed and swarming USVs are presented.

2 The Wireless Communication Techniques

According to the different coverage ability, the wireless communication techniques can be divided into short-range and long-range wireless communication methods. The short-range wireless communication methods contains Bluetooth, Zigbee, Ultra WideBand, Wi-Fi, and Radio Frequency (RF). The long-range wireless communication methods includes High-gain Wi-Fi (Microwave bridge), GPRS, 3G, WiMAX, and LTE [14–18].

Bluetooth is a wireless technology standard for exchanging data over short distances from fixed and mobile devices, and building personal area networks (PANs). Invented by telecom vendor Ericsson in 1994. The IEEE standardized Bluetooth as IEEE 802.15.1, but no longer maintains the standard. The Bluetooth SIG oversees development of the specification, manages the qualification program, and protects the trademarks. The transmission frequency band of Bluetooth is the 2.4 GHz ISM band that is universally available to the public worldwide, providing a transmission rate of 1 Mbps and a transmission distance of 10 m.

Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios. Zigbee is a low-power, low data rate, and close proximity wireless ad hoc network. The technology defined by the Zigbee specification is intended to be simpler and less expensive than other wireless personal area networks (WPANs), such as Bluetooth or more general wireless networking such as Wi-Fi. Applications include home energy monitors, traffic management systems, and other consumer and industrial equipment that requires short-range low-rate wireless data transfer.

Ultra-wideband (also known as UWB, ultra-wide band and ultraband) is a radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. UWB has traditional applications in non-cooperative radar imaging. Most recent applications target sensor data collection, precision locating and tracking applications. UWB can achieve data transfer rates of hundreds of Mbit/s to several Gbit/s in a range of about 10 m.

Wi-Fi or WiFi is a technology for wireless local area networking with devices based on the IEEE 802.11 standards. Wi-Fi most commonly uses the 2.4 GHz UHF and 5.8 GHz SHF ISM radio bands. Wi-Fi also allows communications directly from one device to another without an access point intermediary. This is called ad hoc Wi-Fi

transmission which can be used for multi-USV communication. The Wi-Fi signal range depends on the frequency band, radio power output, antenna gain and antenna type as well as the modulation technique. An access point compliant with either 802.11b or 802.11g, using the stock antenna might have a range of 100 m. The same radio with an external semi parabolic antenna (15 dB gain) might have a range over 20 miles, which is also called high-gain Wi-Fi. The newest 802.11ac can achieve the Gigabit throughput.

RF communications incorporate a transmitter and a receiver. They are of various types and ranges. Several carrier frequencies are commonly used in commercially available RF modules, including those in the industrial, scientific and medical (ISM) radio bands such as 433.92 MHz, 915 MHz, and 2400 MHz. These frequencies are used because of national and international regulations governing the use of radio for communication.

GPRS (General Packet Radio Service) is a packet oriented mobile data service on the 2G and 3G cellular communication system's global system for mobile communications (GSM). In 2G systems, GPRS provides data rates of 56–114 Kbit/second. 2G cellular technology combined with GPRS is sometimes described as 2.5G, that is, a technology between the second (2G) and third (3G) generations of mobile telephony. It provides moderate-speed data transfer, by using unused time division multiple access (TDMA) channels.

3G, short for third generation, is the third generation of wireless mobile telecommunications technology. It is the upgrade for 2G and 2.5G GPRS networks, for faster internet speed. 3G telecommunication networks support services that provide an information transfer rate of at least 0.2 Mbit/s. Later 3G releases, often denoted 3.5G and 3.75G, also provide mobile broadband access of several Mbit/s. It is expected that 3G will provide transmission rates at a minimum data rate of 2 Mbit/s for stationary or walking users, and 348 Kbit/s in a moving vehicle.

WiMAX (Worldwide Interoperability for Microwave Access) is a family of wireless communication standards based on the IEEE 802.16 set of standards. WiMAX was initially designed to provide 30 to 40 megabit-per-second data rates, with the 2011 update providing up to 1 Gbit/s for fixed stations. WiMAX is a long range system, covering many kilometers that uses licensed or unlicensed spectrum to deliver connection to a network, in most cases the Internet.

Long-Term Evolution (LTE) is a standard for high-speed wireless communication for mobile devices and data terminals, based on the GSM/EDGE and UMTS/HSPA technologies. It increases the capacity and speed using a different radio interface together with core network improvements. LTE is commonly marketed as 4G LTE and can provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s and QoS provisions permitting a transfer latency of less than 5 ms in the radio access network. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams.

The current typical communication techniques can be summarized in the Table 1. The methods can be used in USV are listed too. All the available methods are proper for Multi-USV communication using point-multipoint mode, especially, the Zigbee, Wi-Fi and RF can be used to set up the ad hoc network for swarm control.

Table 1. The typical wireless communication techniques

ID	Name	Range type	Range	Speed	Network structure	Can be used by USV
1	Bluetooth	Short	10 m	1 Mbps	Direct	No
2	Zigbee	Short	100 m	250 kbps	Direct/Ad hoc	Yes
3	Ultra WideBand	Short	10 m	100 Mbps	Direct	No
4	Wi-Fi	Short	100 m	600 Mbps	Direct/Ad hoc	Yes
5	RF	Short	1 km	2k–2 Mbps	Direct	Yes
6	High-gain Wi-Fi	Long	5 km	600 Mbps	Direct/Ad hoc	Yes
7	RF	Long	5 km	20 Mbps	Direct/Ad hoc	Yes
8	GPRS	Long	10 km	100 kbps	Direct	Yes
9	3G	Long	10 km	2 Mbps	Direct	Yes
10	WiMAX	Long	10 km	1 Gbps	Direct	Yes
11	4G	Long	10 km	300 Mbps	Direct	Yes

3 The Wireless Communication in USV

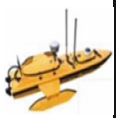
If the USV adopts a real-time data transmission scheme, its operating range will be limited by the distance of wireless data communication. Generally, a point-to-point communication method can transmit up to several km, and a 4G network can cover about 10 km of the coastline, which is the maximum operating range of the scheme. If non-real-time data transmission and artificial intelligence obstacle avoidance schemes are used, the scope of operation is theoretically limited by the power supply of USV.

The performance of the USVs in domestic market is listed in Table 2. Most domestic USVs choose 2.4G Wi-Fi or RF for short-range communication and 4G for long range communication.

For short-range communication, we can use the 2.4G Wi-Fi modules. Each USV is connected to the Wi-Fi access point in the same local area network. The Wi-Fi access point can be installed on the shore or on the leader USV. This ensures that each USV can use the TCP/IP protocol to transfer data.

For long-distance communications, we can use 4G modules. USVs send data to the ground control center or cloud server for data storing through 4G modules. The cloud server can forward the data to the ground control center. After that, the USV receives the information from the ground control center forwarded by the cloud server to autonomously navigate, and sends the real-time heading, speed, and location data to the ground control center during the sailing process.

Table 2. The performance of the USVs in domestic market

Name		TianXing NO.1	JingHai NO.3	M75	Huawei NO.5
Picture					
Company		Harbin Engineering University	Shanghai University	Zhuhai Yunzhou	Hua Ce
Parameters	Type	Monomer	Monomer	Monomer	Three-body
	Length	13m	6.28m	5m	1.6m
	Max speed	⩾ 50 knots	⩾ 10 knots	⩾ 30 knots	⩾ 10 knots
	Propulsion	Double surface slurry	Unknown	Jet Pump	Propeller
	Distance	1000km	200 nautical miles	150 nautical mile	Unknown
Short-range Comm.		2.4G	Unknown	2.4G	Radio / Network Bridge
Long-range Comm.		Unknown	4G/ Satellite	Unknown	Unknown

4 Conclusions

This paper presents a survey on the wireless communication techniques that can be used in USVs and the discussion about the advantages and disadvantages of these techniques for data and control information transmission. The Zigbee, Wi-Fi and Radio Frequency (RF) can be used for short-range wireless communication. The high-gain Wi-Fi (Microwave bridge), RF, GPRS, 3G, WiMAX, and LTE can be used in long-range wireless communication for single or multiple USV networks. The Zigbee, Wi-Fi and RF can also be used to form the ad hoc USV networks.

With the rapid development of 5G wireless communication techniques [19], USVs can transmit video and control or status information through faster broadband channel and more convenient narrow band techniques such as LoRa and NB-IoT with acceptable delay. At that moment, the wireless communication challenges in USV swarm may not be in the way.

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