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An environment-friendly spectrum decision strategy for underwater acoustic networks

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ABSTRACT

As the expansion of marine exploration, an increasing number of scholars have turned to the research of underwater acoustic networks (UANs). Recently, much attention was focused on enabling acoustic communication in UANs, a single network. However, in the ocean exist not only UANs, artificial networks, but also natural networks including marine mammals. Thus, how to use spectrum efficiently, especially when marine mammals are present around the communication area, is easily neglected. To achieve the goal of protecting marine mammals and improving spectrum efficiency simultaneously, an environment-friendly spectrum decision strategy was proposed in the paper. The strategy features a position prediction method for marine mammals and an environment-friendly channel allocation scheme. The goal of position prediction is achieved through the combination of localization and speed measurement for marine mammals. Based on results of position prediction, the allocation scheme maximizes total network capacity on the condition of avoiding marine mammals' normal lives. Simulation results show that the localization method has a success rate of localization around 92% and a relatively small average localization error less than 10 m; speed measurement method also has a relatively small average velocity error compared with velocity of marine mammals; environment-friendly channel allocation scheme can work effectively as the locations of marine mammals change.

1. Introduction

Over the past decade, increasing attention has been paid to underwater acoustic networks (UANs) due to its numerous applications such as underwater resource exploration and disaster-prevention (Heidemann et al., 2012; Davis and Chang, 2012). However, most of the research efforts concentrate on coping with challenges from long propagation delay, high packet error rate and mobility in a single network scenario (Caruso et al., 2008; Mirza et al., 2013), which causes two problems. First, researches in a single network may neglect influence of UANs on marine mammals. In fact, artificial acoustic system like UANs and natural acoustic system like marine mammals coexist in underwater environment. Usually, marine mammals vocalize for navigation, foraging and communication at frequency mainly ranging from 30 Hz to 40 kHz (Luo et al., 2014) and UANs usually operate on the frequencies from 20 kHz to 50 kHz (Liu et al., 2008a), which means marine mammals and UANs share the scarce spectrum resources. Recently, the significant development of marine undertaking including constructing UANs is affecting marine mammals' normal lives. For example, in 2000, a mass stranding of 17 cetaceans was discovered in the Northeast and Northwest Providence Channels of the Bahamas islands, which was believed to be caused by sonar use (Evans and England, 2001). For marine mammals, all sensors in UANs are invaders who make a lot of noise and disturb their normal communication. Second, since almost all researches pay attention to how to enable acoustic communication, efficient use of the scarce spectrum resources is usually ignored, especially under the requirement of protecting marine mammals. Therefore, there is a great need of constructing a smart network to achieve an environment-friendly and spectrum-efficient acoustic communication over underwater channels.

In the smart network, we regard marine mammals as the primary users of spectrum resources, since they are the real owners of the sea and their lives are under great threat from artificial systems. In the network, primary users have top priority of communication. In this case, all sensors are required to exploit cognitive acoustic (CA) techniques (Baldo et al., 2008) for data transmission. We call these sensors CA users.

As a base of the smart network, we propose an environment-friendly spectrum decision strategy for CA users to make a proper allocation of spectrum in this paper. First of all, the strategy achieves the goal of environment-friendly transmission by two basic rules. One is that data transmission is prohibited from

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utilizing the channel which is being occupied by marine mammals. Another one is that transmitted power on the available channels is controlled based on the distance between sensors and marine mammals. Thus, it is necessary to get where marine mammals are when data transmission begins. Since marine mammals swim in the sea, their locations must be re-estimated at every turn of allocation, which leads to the requirement of a localization algorithm. In previous work (Yao et al., 2015), we have proposed a localization algorithm for marine mammals. However, due to possible movement of marine mammals during the gap between localization and data transmission, it is necessary to estimate velocity of marine mammals, which helps further predict the position of marine mammals. The combination of localization algorithm and speed measurement algorithm is called location prediction method. Second, the target of spectrum-efficient communication is obtained through joint allocation of transmitted power and channel, which aims at getting maximum total network capacity on condition of avoiding interference with marine mammals. Therefore, the environment-friendly spectrum decision strategy we designed in the paper features not only a channel allocation scheme but also a location prediction method for marine mammals.

Compared with our previous paper (Yao et al., 2015), we have added a speed measurement algorithm for marine mammals and proposed a position prediction method by combining it with previously proposed localization algorithm. Based on this, we have renewed our network model and specified communication process of the spectrum decision scheme. Also, we re-conducted position prediction method experiment in replace of previous localization algorithm experiment. The rest of this paper is organized as follows. In Section 2, we give a brief introduction on work related to characteristics of voice from marine mammals and localization algorithms. In Section 3, we give an overview of the environment-friendly spectrum decision strategy including its mechanism, network model and communication procedure. In Sections 4 and 5, the two components of the strategy: position prediction method and environment-friendly channel allocation scheme are discussed respectively. Then, the performance of these two schemes is analyzed in Section 6. Finally, Section 7 concludes this paper.

2. Related work

In this section, we present the work related to characteristics of vocal signals from marine mammals and localization algorithm to illustrate the significance of localizing marine mammals and the necessity of designing a new localization algorithm.

As mentioned above, dominant components of calls of most marine mammals are within frequency range from 30 Hz to 40 kHz, which overlap most frequency band of man-made signals in UANs. In order to judge whether their lives will be influenced, we need to understand marine mammals' hearing abilities first. Hearing threshold audiograms, which represent the lowest levels of sound detectable in a quiet environment, are usually exploited to show sensitivities of marine mammals to sounds of different frequencies. Fig. 1 is an audiogram of five common marine mammals. As illustrated in Fig. 1, marine mammals have similar curves of hearing threshold and the range of most sensitive hearing corresponds to frequency from 10 kHz to 100 kHz, which covers most of frequency band used in UANs. According to this, we can get that most common marine mammals have sensitive hearing and it is inevitable for them to hear man-made signals, most of which are above the threshold. Thus, response threshold, a limitation of power under which marine mammals will not respond to man-made signals, plays an extreme important role in guaranteeing normal lives of marine mammals. In Thomson (1995), response threshold of marine mammals is 120 dB re μPa, which is relatively small compared with signal power in UANs.

According to the discussions above, it is important to estimate and limit man-made signal power heard by marine mammals through power control at sender, which makes it necessary to localize marine mammals. Generally, localization algorithms for underwater acoustic networks can be classified into two categories (Tan et al., 2011): range-based localization and range-free localization. Range-free localization can only estimate a possible area where a certain node is located with information on connectivity between nodes. Considering the goal of reducing influence of artificial signals as much as possible, accurate position estimation is preferred, which means it is advisable to utilize range-based localization. Range-based localization estimates distance between reference nodes and ordinary nodes first and then calculates the location based on the estimated distance. Recently, basic methods of distance estimation are received signal strength indicator (RSSI), time difference of arrival (TDoA) and time of arrival (ToA).

Dive and Rise (DNR) (Erol et al., 2007b) is a range-based localization algorithm using ToA. In the algorithm, beacons are utilized to localize unknown nodes. DNR beacons get their coordinates through GPS while floating above water. While sinking and rising, they broadcast their coordinates. Unknown nodes conduct range measurement by using the time of arrival of these messages. After receiving messages from several beacons, unknown nodes can finally estimate their positions. In order to enlarge the localization coverage of DNR positioning, a Multi-Stage DNR (MS-DNR) positioning scheme was proposed in Erol et al. (2008).

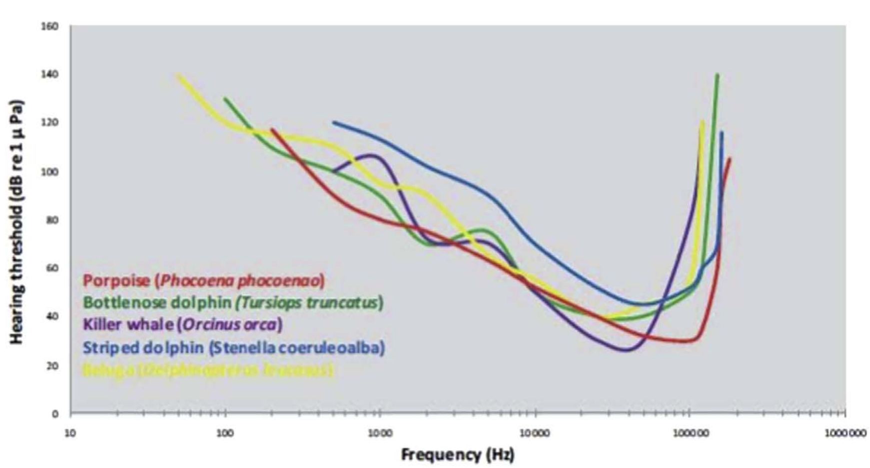

Fig. 1. Hearing threshold of marine mammals (Doksæter, 2011).