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Underwater acoustic communication and the general performance evaluation criteria

Key words: Underwater acoustic communication; Underwater acoustic channels; High data rate; Communication range; Bandwidth efficiency; General evaluation criterion

Corresponding author: Han WANG
E-mail: whan@mail.nwpu.edu.cn
ORCID: https://orcid.org/0000-0001-6213-2082

Motivation

1. Driven by the huge demand to explore oceans, underwater wireless communications have been rapidly developed in the past few decades. Underwater acoustic communication (UAC) is the major research field in underwater wireless communication.

2. Compared with terrestrial radio frequency communication channels, underwater acoustic channels are affected by several disadvantages, which make the underwater acoustic channel one of the most difficult channels to use.

3. The limited bandwidth for long-range underwater communication restricts data rate increases. On the contrary, the relatively larger available bandwidth for short- and medium-range communications systems makes it possible to investigate high data-rate schemes.

4. Although much research has pushed the performance limits of underwater acoustic communication systems, little of it clearly states the corresponding evaluation criterion.

Methods

1. Characteristics of underwater acoustic channels are first introduced and compared with terrestrial communication to demonstrate the difficulties in UAC research.

2. To give a general impression of UAC, current important research areas are mentioned.

3. Different principal modulation-based schemes for short- and medium-range communication with high data-rate are investigated and summarized.

4. To evaluate the performance of UAC systems in general, three criteria are presented based on the research publications and our years of experience in high-rate short- to medium-range communication.

Major results

1. Underwater acoustic channels are commonly regarded as one of the most challenging channels for communication. Compared with terrestrial radio channels, underwater acoustic channels have severe transmission loss, limited and distance-dependent bandwidth, time-varying multi-path propagation, and severe Doppler spread. Although acoustic channel models are needed for developing and evaluating UAC techniques, there is not a widely accepted underwater acoustic channel model at present due to the complexity and variety of realistic acoustic channels.

Major results

2. At present, most UAC research focuses on the high data-rate UAC for short- and medium-range communication ranges, whose experimental verification is relatively easy to implement. The UAC network has become a popular research area in recent years because many UAC applications have extended from point-to-point communication to networks. In addition, UAC applications have always been a very active research area and have produced lots of new research topics.

Major results

3. High data-rate UAC systems for short- and medium-range communications have been an active major research area in UAC. Currently, there are mainly four high data-rate modulation schemes that are widely applied in UAC systems. Based on the number of carriers, they can be categorized as single- and multi-carrier systems. Based on equalization schemes, they can be classified as frequency- and time-domain equalization systems. With the improvement on UAC technologies, MIMO techniques have been applied to UAC systems to further increase the data rate.

Major results

4. Based on our years of research and data collected from the research, three general performance evaluation criteria for high-rate UAC systems in short- and medium-range communications are statistically presented. The three criteria are:

(1) P: BER versus SNR

(2) I: the product of the data rate and the corresponding communication range

(3) E_s: the product of bandwidth efficiency and communication range

Major results

4.1. A new threshold of *I*=100 km·kb/s for UAC systems is statistically posted based on recent experimental results.

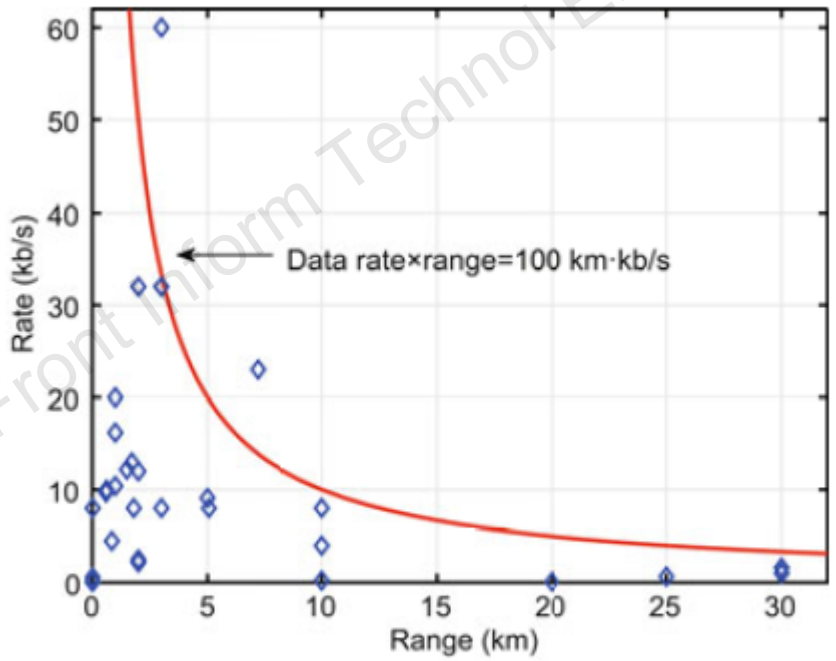

Fig. 12 Performance of short- and medium-range UAC systems after year 2000

Major results

4.2. A modified threshold for optimized systems is posted by the combination of E_s (40 km·kb/Hz, for range≥10 km) and E (4 bit/Hz, for range<10 km)

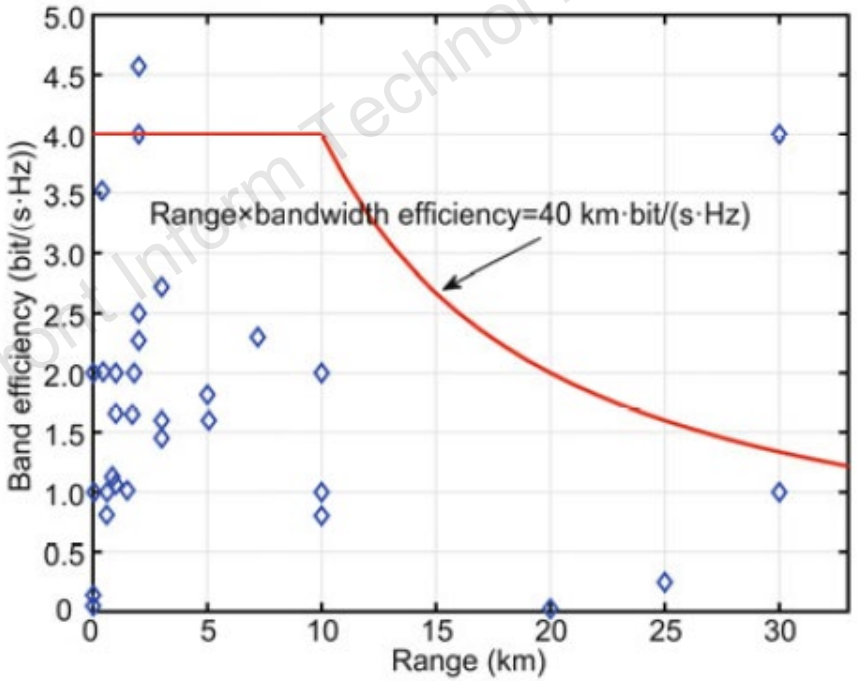

Fig. 13 Bandwidth efficiency at different ranges

Major results

4.3.The three criteria, *P*, *I*, E_s, are not only an evaluation tool for general UAC performance, but also an indicator for UAC system design and optimization.

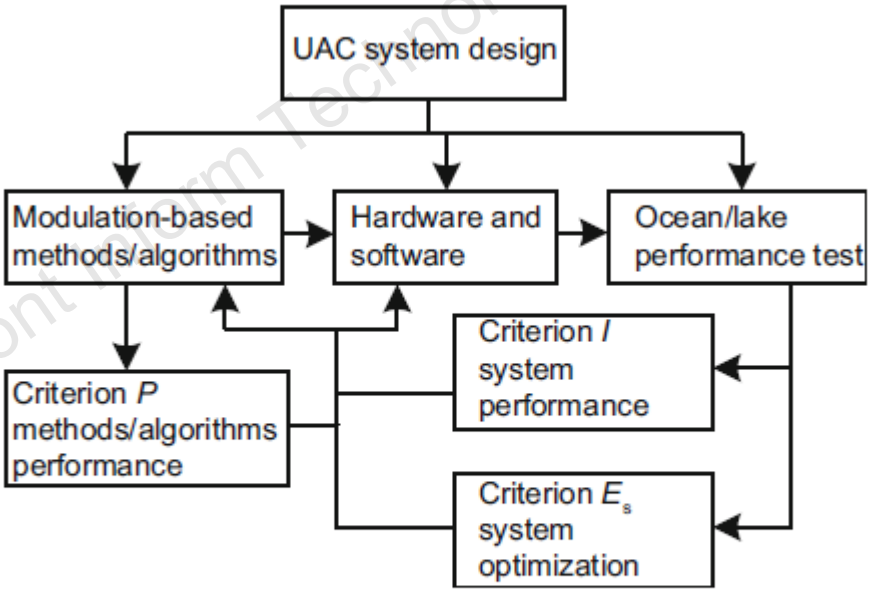

Fig. 14 Relationship between underwater acoustic communication system design and general performance evaluation criteria P, I, and E_s

Conclusions

1. Compared with the terrestrial radio frequency communication, underwater acoustic channels suffer from severe difficulties. These difficulties are obstacles to the development of UAC systems. Major research areas in UAC varies from the physical layer to the network layer.

2. SC-TDE, SC-FDE, and OFDM are the three principal modulations applied in short- and medium-range UAC systems. Besides, OSDM is a new technology providing high-rate transmission in underwater communication.

3. The P, I, and E_s criteria are statistically proposed as a tool to evaluate the general performance and assist the design of UAC systems from the perspective of system designers. These three criteria support the design and optimization from the modulation-based algorithms to the systems including hardware and software.