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Information technology – Underwater acoustic sensor network (UWASN)

Part 1: Overview and requirements

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CONTENTS

FOREWORD 5
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms and definitions 7
4 Abbreviated terms 9
5 UWASN overview and applications 9
5.1 Overview 9
5.2 Application domain of UWASN 11
6 Characteristics of UWASN in terms of the effects of propagation variability 12
6.1 Underwater acoustic communication 12
6.2 Acoustic signal strength attenuation 12
6.3 High propagation delay 12
6.4 Multipath 13
6.5 Propagation loss 13
6.6 Noise 14
7 Differences between UWASN and terrestrial sensor network 14
7.1 Types of underwater communication technologies 14
7.2 Housing case 16
7.3 Costs associated with sensor nodes 16
7.4 Omni-directional and directional transducers for data transmission and reception 16
7.5 Underwater object and event localization and 3D relay node 17
7.6 Energy harvesting technology for UWASN 18
8 Specificities of UWASN and related requirements 18
8.1 Three structural scales of UWASN network 18
8.2 Deployments of 2D and 3D topology 21
8.2.1 General 21
8.2.2 Two-dimensional UWASN architecture 21
8.2.3 Three-dimensional UWASN architecture 22
8.3 Cross layering 24
8.4 Underwater acoustic modem 25
8.5 Doppler spread 25
8.6 Deployment considering water depths 26
8.7 Underwater wired and wireless communication 26
8.8 Time synchronization 27
8.9 Data transmission period for energy saving 28
8.10 Routing 29
8.11 Network coding 31
8.12 Data compression 31
8.13 Delay and disruption tolerant network (DTN) 31
9 UWASN further general requirements 32
9.1 General 32
9.2 General requirements for UWASN – Cross layering 32
9.3 General requirements for the UWASN – Communication technology 32
9.4 General requirements for the UWASN – Other system requirements 33

AVA Documents
Document Sharing Hub

Full document details: BS ISO/IEC 30140-1:2018

Annex A (informative) Selected applications of UWASN 34
A.1 Environmental monitoring – Chemical and biological changes 34
A.1.1 Description 34
A.1.2 Physical entities 35
A.1.3 Normal flow 35
A.1.4 Conditions 35
A.2 Detection of pipeline leakages 35
A.2.1 Description 35
A.2.2 Physical entities 36
A.2.3 Normal flow 36
A.2.4 Conditions 37
A.3 Exploration of natural resources 37
A.3.1 Description 37
A.3.2 Physical entities 38
A.3.3 Normal flow 38
A.3.4 Conditions 39
A.4 Fish farming 39
A.4.1 Description 39
A.4.2 Physical entities 40
A.4.3 Normal flow 40
A.4.4 Conditions 40
A.5 Harbour security 40
A.5.1 Description 40
A.5.2 Physical entities 41
A.5.3 Normal flow 41
A.5.4 Conditions 42
Bibliography 43

Figure 1 – Overview of a UWASN 10
Figure 2 – Omni-directional and directional transducers for data transmission and reception 17
Figure 3 – Underwater cluster network 18
Figure 4 – Underwater ad-hoc network 19
Figure 5 – UWA-UN communication network 19
Figure 6 – UWA-UN communication network using fixed gateway 20
Figure 7 – UWA-EUN communication network 21
Figure 8 – Two-dimensional UWASN architecture 22
Figure 9 – Three-dimensional UWASN architecture 23
Figure 10 – UWA-cross layer protocol stack 25
Figure 11 – Underwater wired and wireless communication 27
Figure 12 – Time synchronization for data transmission 28
Figure 13 – Using active and sleep modes for energy saving 29
Figure 14 – UWASN routing 30
Figure A.1 – Illustration of the environmental monitoring use case 34
Figure A.2 – Oil and gas pipeline leakage monitoring use case 36
Figure A.3 – Flow – Oil and gas pipeline leakage monitoring 37

AVA Documents
Document Sharing Hub

Full document details: BS ISO/IEC 30140-1:2018

Figure A.4 – Underwater resource exploration use case 38
Figure A.5 – Fish farming and monitoring use case 39
Figure A.6 – Harbour security monitoring use case 41

Table 1 – UWASN market segments and their current and future applications list 11
Table 2 – Summary of the features of acoustic, radio, and optical waves in seawater environments 15
Table 3 – Differences between underwater communication technologies [10][12] 15
Table 4 – Comparison between 2D and 3D UWASNs. 24

Documents
Document Sharing Hub

Full document details: BS ISO/IEC 30140-1:2018

INFORMATION TECHNOLOGY – UNDERWATER ACOUSTIC SENSOR NETWORK (UWASN) –

Part 1: Overview and requirements

FOREWORD

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International Standard ISO/IEC 30140-1 was prepared by subcommittee 41: Internet of Things and related technologies, of ISO/IEC joint technical committee 1: Information technology.

The list of all currently available parts of the ISO/IEC 30140 series, under the general title *Information technology – Underwater acoustic sensor network (UWASN)*, can be found on the IEC and ISO websites.

This International Standard has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the second title page.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

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INTRODUCTION

Water covers approximately 71 % of the surface of the Earth. Modern technologies introduce new methods to monitor the body of water, for example pollution monitoring and detection. Underwater data gathering techniques require exploring the water environment, which can be most effectively performed by underwater acoustic sensor networks (UWASNs). Applications developed for the UWASNs can record underwater climate, detect and control water pollution, monitor marine biology, discover natural resources, detect pipeline leakages, monitor and locate underwater intruders, perform strategic surveillance, and so on.

The ISO/IEC 30140 series provides general requirements, reference architecture (RA) including the entity models and high-level interface guidelines supporting interoperability among UWASNs in order to provide the essential UWASN construction information to help and guide architects, developers and implementers of UWASNs.

Additionally, the ISO/IEC 30140 series provides high-level functional models related to underwater sensor nodes and relationships among the nodes to construct architectural perspective of UWASNs. However, the ISO/IEC 30140 series is an application agnostic standard. Thus, ISO/IEC 30140 series specifies neither any type of communication waveforms for use in UWASNs nor any underwater acoustic communication frequencies. Specifying communication waveforms and/or frequencies are the responsibility of architects, developers and implementers.[1]

Acoustical data communication in sensor networks necessitates the introduction of acoustical signals that overlap biologically important frequency bands into the subject environment. These signals may conflict with regional, national, or international noise exposure regulations. Implementers of acoustical communication networks should consult the relevant regulatory agencies prior to designing and deployment of these systems to ensure compliance with regulations and avoid conflicts with the agencies.

The purpose of the ISO/IEC 30140 series is to provide general requirements, guidance and facilitation in order for the users of the ISO/IEC 30140 series to design and develop the target UWASNs for their applications and services.

The ISO/IEC 30140 series comprises four parts as shown below.

Part 1 provides a general overview and requirements of the UWASN reference architecture.

Part 2 provides reference architecture models for UWASN.

Part 3 provides descriptions for the entities and interfaces of the UWASN reference architecture.

Part 4 provides information on interoperability requirements among the entities within a UWASN and among various UWASNs.

[1] Architects, developers and implementers need to be aware of the submarine emergency frequency band, near and below 12 kHz, and it is recommended to provide a provision for such submarine emergency band in their UWASN design and applications.

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INFORMATION TECHNOLOGY – UNDERWATER ACOUSTIC SENSOR NETWORK (UWASN) –

Part 1: Overview and requirements

1 Scope

This part of ISO/IEC 30140 provides a general overview of underwater acoustic sensor networks (UWASN). It describes their main characteristics in terms of the effects of propagation variability and analyses the main differences with respect to terrestrial networks. It further identifies the specificities of UWASN and derives some specific and general requirements for these networks.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 29182-2, *Information technology – Sensor networks: Sensor Network Reference Architecture (SNRA) – Part 2: Vocabulary and terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 29182-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
ad-hoc node
device in a wireless ad-hoc network

Note 1 to entry: A wireless ad-hoc network is defined in ISO/IEC 27033-6:2016[1],[2] 3.12, as a "decentralized wireless network which does not rely on a pre-existing infrastructure".

3.2
cross-layer
technology that permits communication between different layers by allowing one layer to access data of another layer to exchange information and enable interaction

3.3
management cross-layer
technology that provides a system-level management service to all or selected OSI layers in a wireless network system

[2] Numbers in square brackets refer to the Bibliography.

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Note 1 to entry: Examples of management cross-layer are device management cross-layer, network management cross-layer, QoS management cross-layer, security management cross-layer, localization management cross-layer, power management cross-layer, etc.

3.4
underwater acoustic fundamental network
UWA-FN
wireless communication network that is built either exclusively using one or more cluster networks or exclusively using one or more ad-hoc networks for underwater environment using acoustic modems

Note 1 to entry: Fundamental network consists of only one network type, either cluster network or ad-hoc network.

Note 2 to entry: Wireless acoustic communication and data links are realized using an acoustic modem.

Note 3 to entry: A modem is defined in ISO/IEC 2382:2015[2], 2124386, as a “functional unit that modulates and demodulates signals”.

3.5
underwater acoustic united network
UWA-UN
wireless communication network that is made of two or more underwater acoustic fundamental networks (3.4) and relay nodes

Note 1 to entry: A relay node is, for example, an unmanned underwater vehicle, communication node, beacon, etc.

3.6
underwater acoustic extended united network
UWA-EUN
wireless communication network that is made of two or more underwater acoustic united networks (3.5)

3.7
underwater acoustic sensor node
UWA-SNode
sensor network element that includes at least one sensor and, optionally actuators with communication capabilities and data processing capabilities, which is built for underwater applications using acoustic modem as a communication unit internal to this element

Note 1 to entry: Wireless acoustic communication and data links are realized using an acoustic modem.

Note 2 to entry: A modem is defined in ISO/IEC 2382:2015, 2124386, as a “functional unit that modulates and demodulates signals”.

[SOURCE: ISO/IEC 29182-2:2013, 2.1.8 – modified: the original definition of sensor node is adapted to an underwater acoustics context.]

3.8
underwater acoustic cluster head
UWA-CH
unit that receives data from underwater acoustic sensor nodes (3.7) and transmits the data to one or more relay nodes or a nearby underwater acoustic gateway (3.9)

3.9
underwater acoustic gateway
UWA-GW
unit connecting different underwater networks or parts of one underwater network and performing any necessary protocol translation in underwater environment using acoustic modem

[SOURCE: ISO/IEC TR 29108:2013, 3.1.88.3 – modified: the original definition is adapted to an underwater acoustics context.]

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4 Abbreviated terms

2D	two dimensional
3D	three dimensional
BER	bit error rate
DG	distance group
DTN	delay and disruption tolerant network
EM	electromagnetic wave
EMI	electromagnetic interference
GPS	global positioning system
kbps	kilobits per second
LED	light emitting diode
µPa	Micropascal
Mbps	megabits per second
MCCP	minimum cost clustering protocol
QoS	quality of service
RF	radio frequency
RSS	received signal strength
UUV	unmanned underwater vehicle
UWASN	underwater acoustic sensor network
UWA-CH	underwater acoustic cluster head
UWA-DTN	underwater delay tolerant network
UWA-DTN-GW	underwater DTN gateway
UWA-EUN	underwater acoustic extend united network
UWA-FN	underwater acoustic fundamental network
UWA-GW	underwater acoustic gateway
UWA-SNode	underwater acoustic sensor node
UWA-UN	underwater acoustic united network

5 UWASN overview and applications

5.1 Overview

Figure 1 shows the basic topology of UWASN. In a cluster-based network, the data sensed by underwater acoustic sensor nodes (UWA-SNodes) are transmitted via acoustic communication to an underwater acoustic gateway (UWA-GW) using an underwater acoustic cluster head (UWA-CH), unmanned underwater vehicle (UUV), or relay nodes. Users receive the transmitted data through various externally connected networks (e.g. radio frequency (RF) or satellite communication). During these processes, underwater communication is implemented by acoustic communication. In general, UWA-GWs are either moving nodes or fixed nodes. Topologies and communication configuration models could be adaptively modified according to the application domain's needs at any given time.

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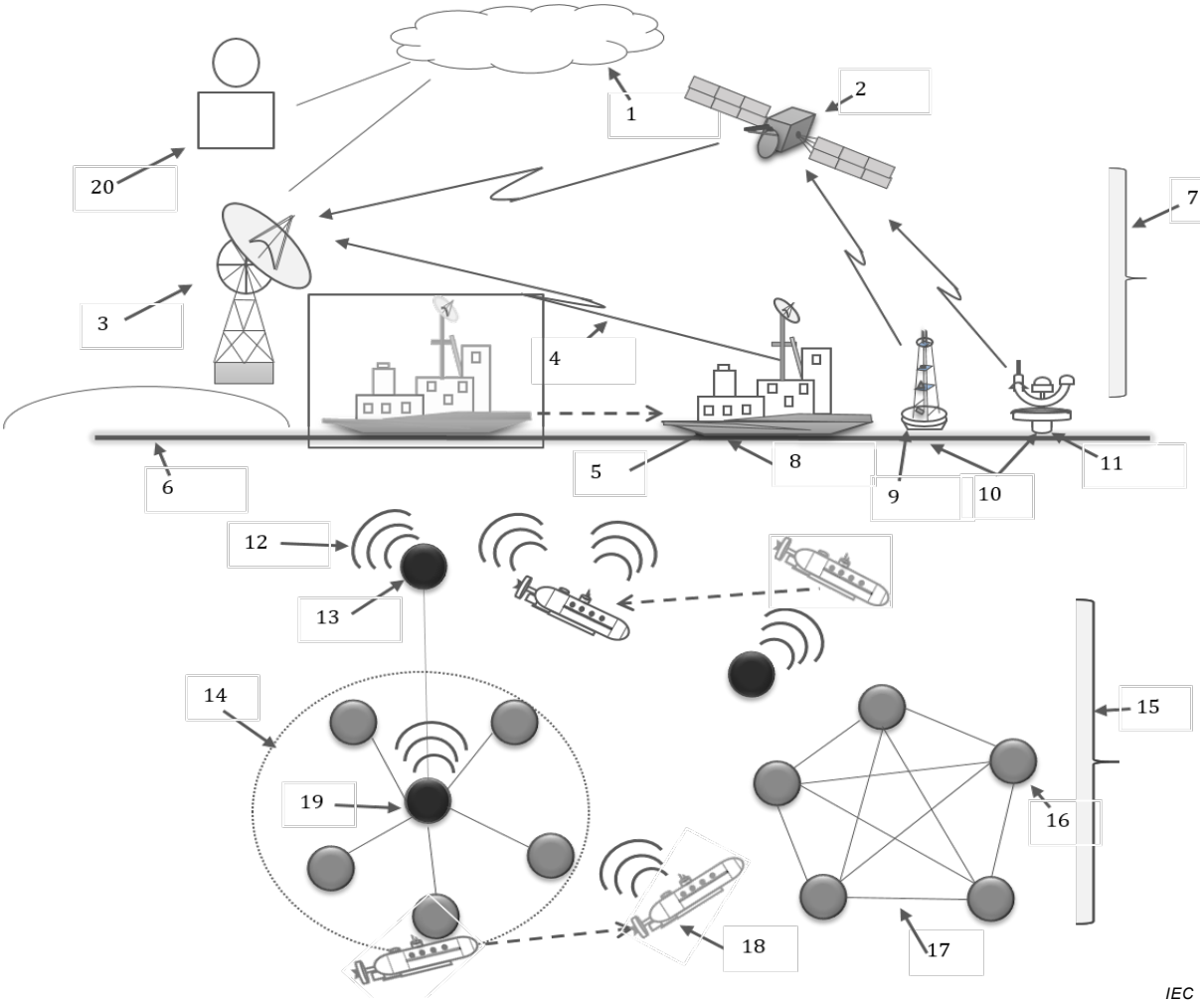

Key

1	Internet	6	Surface	11	UWA-DTN-GW	16	UWA-SNode
2	Satellite	7	RF	12	Acoustic link	17	Ad-hoc network
3	Base station	8	UWA-GW	13	Relay node	18	UUV
4	RF link	9	Buoy	14	Cluster	19	UWA-CH
5	Moving gateway	10	Fixed gateways	15	Underwater	20	User

Figure 1 – Overview of a UWASN

RF communication systems are used in terrestrial sensor networks. The reasons for this are their high efficiency and low cost. Underwater RF communication is very difficult due to limited wave propagation characteristics that arise from the high attenuation due to the conductivity of water. Underwater communications can also be achieved by optical links employing lasers or LED light sources. Optical waves are still affected by attenuation, but can typically operate over longer ranges than RF.

Diode laser beams and low cost light sources such as LEDs can also be utilized. A light source for an underwater communications system is practicable using LEDs with an optical wavelength between 400 nm and 550 nm.[3]

Presently, underwater acoustic communication is the primary method for establishing wireless communication among UWA-SNodes, UUVs and UWA-GWs. This is because sound travels much further in water than RF radio signals. A UWASN consists of different types of

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UWA-SNodes and UUVs positioned so as to perform collective underwater monitoring. UWA-SNodes and UUVs are organized autonomously into a network that should adapt to changing ocean environments over time.[4]

UWA-SNodes are applicable to pollution monitoring, oceanographic information gathering, strategic observation, assisted navigation, offshore examination, and disaster prevention. Several UUVs with equipped sensors explore underwater resources and gather precise location information. To make this possible, reliable underwater communication between UWA-SNodes and UUVs is required.

UWA-SNodes and UUVs should have self-configuration capabilities that allow them to network themselves. They should manage the operations by sharing location information, configurations, and movements, in order to send monitored data to an on-shore location.

5.2 Application domain of UWASN

A UWASN can realize unexplored underwater applications, increasing the capacity for detecting and forecasting changes in time-varying oceanic environments. Table 1 shows the UWASN market segments and their current and future potential applications.

Annex A provides a description of the selected application of UWASN.

Table 1 – UWASN market segments and their current and future applications list

Market segment	Description
Scientific applications	Early warning system for detection of disasters and tsunami, and providing warnings Studying the effects of oceanic earthquakes (seaquakes) Climate recording Pollution control Oil/gas fields exploration Detecting climate change Improving weather forecasting Studying marine biology Ocean circulation studies
Business applications	Discovery of natural resources Temperature monitoring in runtime Chemical and biological changes Detection of pipeline leakages Seismic monitoring allowing reservoir management approaches
Civilian applications	Assisted navigation Identifying hazards in the seabed Identifying submerged wrecks Identify the mooring positions Underwater hazard avoidance Defining seabed pipeline routes Identifying underwater oilfields Defining paths for the layering of underwater cables
Aqua applications	Aquaculture and farming Remote control-monitoring of costly devices

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Market segment	Description
Military applications	Strategic surveillance Monitoring port facilities Securing foreign harbours Mine countermeasures Submarine monitoring Intruder detection Ocean bottom imaging and mapping

6 Characteristics of UWASN in terms of the effects of propagation variability

6.1 Underwater acoustic communication

Underwater acoustic communication method is used for underwater data transfer. It can establish acoustic communication with the help of transducers. Due to time variations of the channel, limited bandwidth, multipath propagation, and strong signal attenuation, underwater communication is difficult. Because of the high conductivity of seawater, acoustic communication works far better than the RF communication.

Concerns that should be examined while planning UWASN system are:

– attenuation of water limits sound's propagation distance;
– path dependent, low propagation speeds of the sound, varying in the interval of (1 500 ± 120) m/s;
– echoes and interferences caused by multipath(s) due to sea bottom and sea surface reflections, as well as between the layers of water body with different densities;
– acoustic signal disturbed by different characteristics of underwater channel and Doppler's effect not only from motion of transmitter and receiver but also from time-variability of the surface and water column [5];
– noise level in underwater can corrupt or block parts of signal.

Sound is produced when an object vibrates and transmits motion to the surrounding physical medium. This results in the propagation of vibrations, where the particles in the medium oscillate in the same direction as the propagation.

6.2 Acoustic signal strength attenuation

A sound's intensity is reduced with distance through the medium in which it travels. In idealized materials, a sound's signal amplitude weakness because of wave spreading. Attenuation is another reason for weakening of sound.

a) Absorption

Converting sound energy into some other form is called absorption. Acoustic waves are converted to heat due to absorption [6].

b) Sound speed profiles

The speed of sound in water depends on several parameters such as temperature, salinity and pressure [7]. In general, sound speed in water increases with increasing water temperature, salinity and pressure.

6.3 High propagation delay

Sound's slow underwater propagation speed can be differentiated from electromagnetic propagation. Sound's underwater speed is influenced by underwater properties such as pressure, salinity, and temperature, which are openly associated with depth. The salinity and

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shallow seawater associated with rivers, and some seawater with ice in the Antarctic or Arctic, can change. Near the sea surface, sound's underwater speed is more than four times faster than its speed in air.

The bending of a sound signal is caused by underwater inhomogeneity characteristics. This commonly occurs in the vertical way because of three factors: (1) water temperature changes due to the non-uniform heating by the sun's rays, (2) salt concentration changes, and (3) hydrostatic pressure changes due to depth. The sound curvature direction is influenced by the sound velocity distribution of the medium. Sound signals are bent downward in summer because the upper layers of water are warmer than lower layers. Sound signals are bent upward in winter because the temperature of lower water is retained. Therefore, the range of sound propagation is greater in winter than in summer.

6.4 Multipath

In underwater environment, the signal propagates from the transmitter to the receiver via either direct or multipath propagation. Additionally, the mechanisms of the multipath formation in the ocean depend on channel geometry, signal frequency, sound speed profile, range of transmission, and depth of water.

Owing to reflection or refraction of the acoustic waves, there would likely be underwater multipath(s) of acoustic waves. As acoustic waves bounce, either at the surface or bottom of the sea or from water turbulence, and reach the receiver, reflections of the acoustic waves occur, resulting in multipath propagation of the acoustic waves. This kind of reflection is common in shallow water. Acoustic wave refractions usually occur in deep water environment, where the speed of sound changes with depth.

Since horizontal communication takes place in underwater, multipath propagation should be considered. Water surface reflections, bottom reflections, and water turbulence reflections can generate the multipath. To reduce multipath effects, directional remote transducers can be used. However, if there are obstacles nearby, the modem will experience dynamic multi-pathing that is rapidly fluctuating due to reflections, and the performance of the modem drops dramatically. Therefore, the multipath powers a constant trade-off between a modem's cost and its reliability [8].

6.5 Propagation loss

Propagation loss is collective impact of attenuation, absorption loss, and geometric spreading. In water, sound travels more than four times quicker than in air. Sounds are transmitted as a pressure wave in water, like in open air. Sound pressure is measured in decibels (dB) with reference to one micropascal (μPa). The noise sources in UWASN channels are separated into ambient noise and man-made noise.

– Attenuation

  Attenuation is created through absorption while transforming acoustic energy to heat. It is increased by frequency and distance. At a rough ocean bottom and surface, attenuation is initiated by scattering. Attenuation is also started by refraction and is also influenced by water depth.

– Geometric spreading

  This is the spreading of sound energy by waves. It is frequency independent and increases with propagation distance. The common geometric spreading approximations are cylindrical spreading and spherical spreading.

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