Underwater Optical Wireless Communication

HEMANI KAUSHAL, GEORGES KADDOUM

2021.07.15

세종대학교 스마트기기전공
오승현

ANNOUNCEMENT

Military

tactical surveillance

Reason

Why we have to research about underwater communication?

Industry

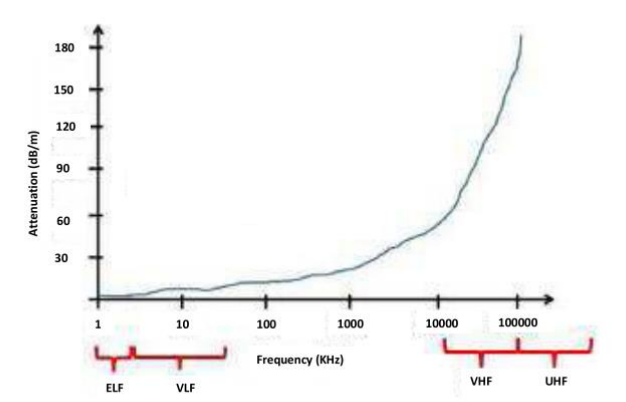
pollution monitoring,
oil control and
maintenance,

Scientific

offshore explorations
climate change monitoring
oceanography research

PHYSICAL ASPECTS OF UNDERWATER WIRELESS COMMUNICATION

Acoustic Wave



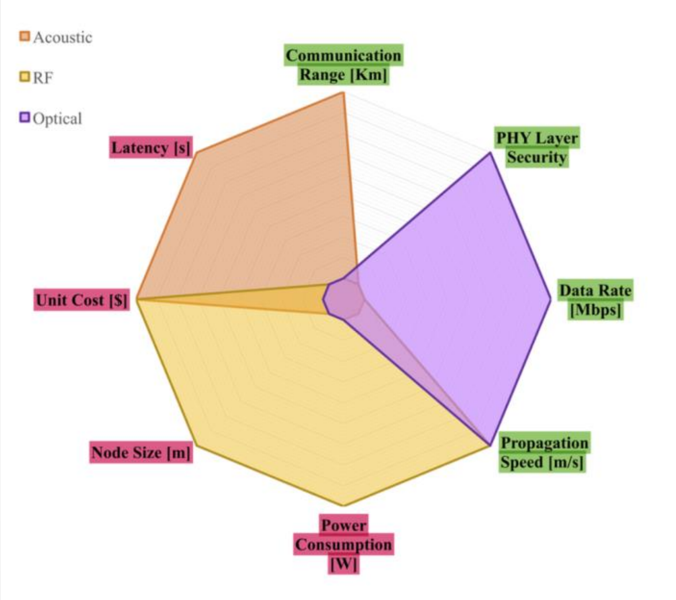
RF Wave

Optical Wave

PHYSICAL ASPECTS OF UNDERWATER WIRELESS COMMUNICATION

Parameters	Acoustic	RF	Optical
Attenuation	Distance and frequency dependent (0.1 - 4 dB/km) [12]	Frequency and conductivity dependent (3.5 - 5 dB/m) [13]	0.39 dB/m (ocean) - 11 dB/m (turbid) [14]
Speed (m/s)	1500 m/s	$\approx 2.255 \times 10^8$	$\approx 2.255 \times 10^8$
Data rate	~ kbps	~ Mbps	~ Gbps
Latency	High	Moderate	Low
Distance	up to kms	up to $\approx$ 10 meters	$\approx$ 10 - 100 meters
Bandwidth	Distance dependent [8]: 1000 km < 1kHz 1 - 10 km $\approx$10 kHz < 100 m $\approx$ 100 kHz	$\approx$ MHz	10 - 150 MHz
Frequency band	10 - 15 kHz	30 - 300 Hz (ELF) (for direct underwater communication system) or MHz (for buoyant communication system)	10^{12} - 10^{15} Hz
Transmission power	tens of Watts (typical value)	few mW to hundreds of Watts (distance dependent)	Few Watts
Antenna size	0.1 m	0.5 m	0.1 m
Efficiency	$\approx$ 100 bits/Joules		$\approx$ 30, 000 bits/Joules
Performance parameters	Temperature, salinity and pressure	Conductivity and permittivity	Absorption, scattering/turbidity, organic matter

<Paper : Underwater Optical Wireless Communication - Table 2>



<Paper : Underwater Optical Wireless Communications Networking, and localization: a survey >

Optical Beam Propagation Underwater

Pure Sea Water

Clear Ocean Water

Coastal Ocean Water

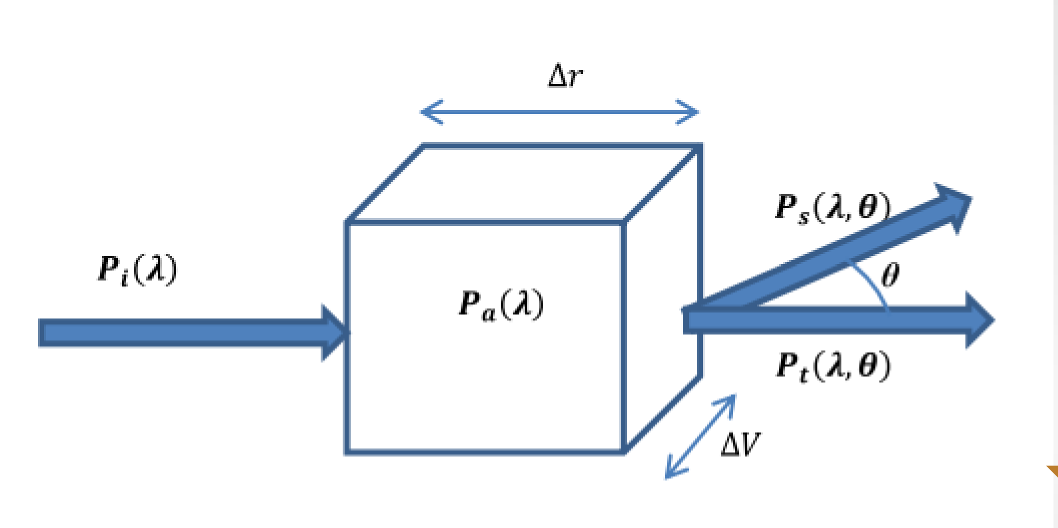
Turbid Harbor

$$\alpha_{sea\,water}(\lambda) < K(\lambda) - \frac{b(\lambda)}{2},$$

Factors that affect UWOC

1. Absorption and scattering
2. Beam Spreading
3. Turbulence
4. Alignment
5. Multipath interference
6. Physical obstruction
7. Background noise

Absorption & scattering and Beam spreading



$$P_i(\lambda) = P_a(\lambda) + P_s(\lambda) + P_t(\lambda)\,.$$

$$A(\lambda) = \frac{P_a(\lambda)}{P_i(\lambda)}, \quad B(\lambda) = \frac{P_s(\lambda)}{P_i(\lambda)}.$$

$$a(\lambda) = \lim_{\Delta r \to 0} \frac{\Delta A(\lambda)}{\Delta r} = \frac{dA(\lambda)}{dr},$$

$$b(\lambda) = \lim_{\Delta r \to 0} \frac{\Delta B(\lambda)}{\Delta r} = \frac{dB(\lambda)}{dr}.$$

$$c(\lambda) = a(\lambda) + b(\lambda)\,,$$

$$L_P(\lambda, z) = exp^{-c(\lambda)z}.$$

Absorption & scattering and Beam spreading

Water Type	$\boldsymbol{a}\ \left(m^{-1}\right)$	$\boldsymbol{b}\left(m^{-1}\right)$	$\boldsymbol{c}\left(m^{-1}\right)$
Clear ocean	0.114	0.037	0.151
Coastal ocean	0.179	0.220	0.339
Turbid harbor	0.366	1.829	2.195

Turbulence

$$\Phi_n(\kappa) = K_3 \kappa^{-11/3},$$

$$K_3 \left(= \chi \epsilon^{-1/3}\right)$$

<안드레이 콜모고로프 난류 모델>

POINTING AND ALIGNMEN

$$
\begin{aligned}
&BSF(L, r) \\
&= E(L, r)exp(-cL) + \int_0^{\infty} E(L, v)exp(-cL) \\
&\quad \times \left\{ exp\left[\int_0^L b\tilde{\beta}(v(L-z))dz \right] - 1 \right\} J_0(vr)vdv,
\end{aligned}
$$

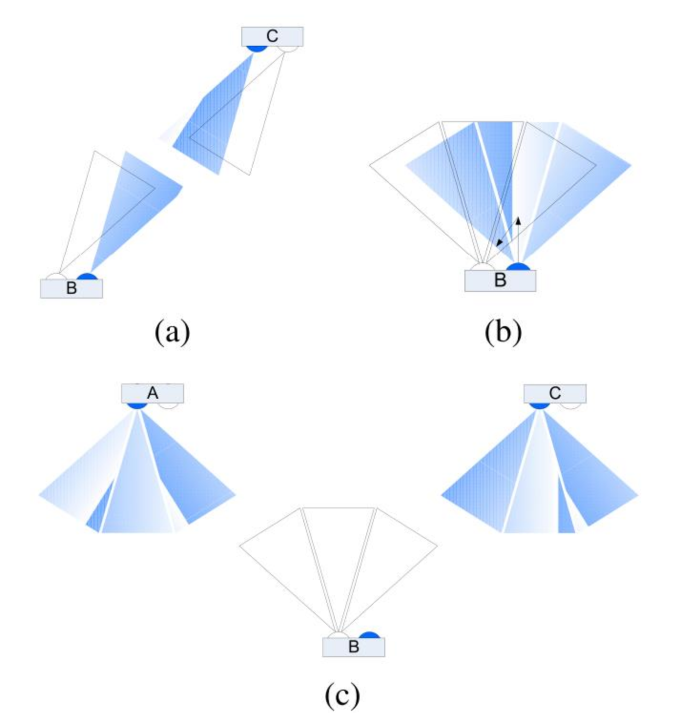
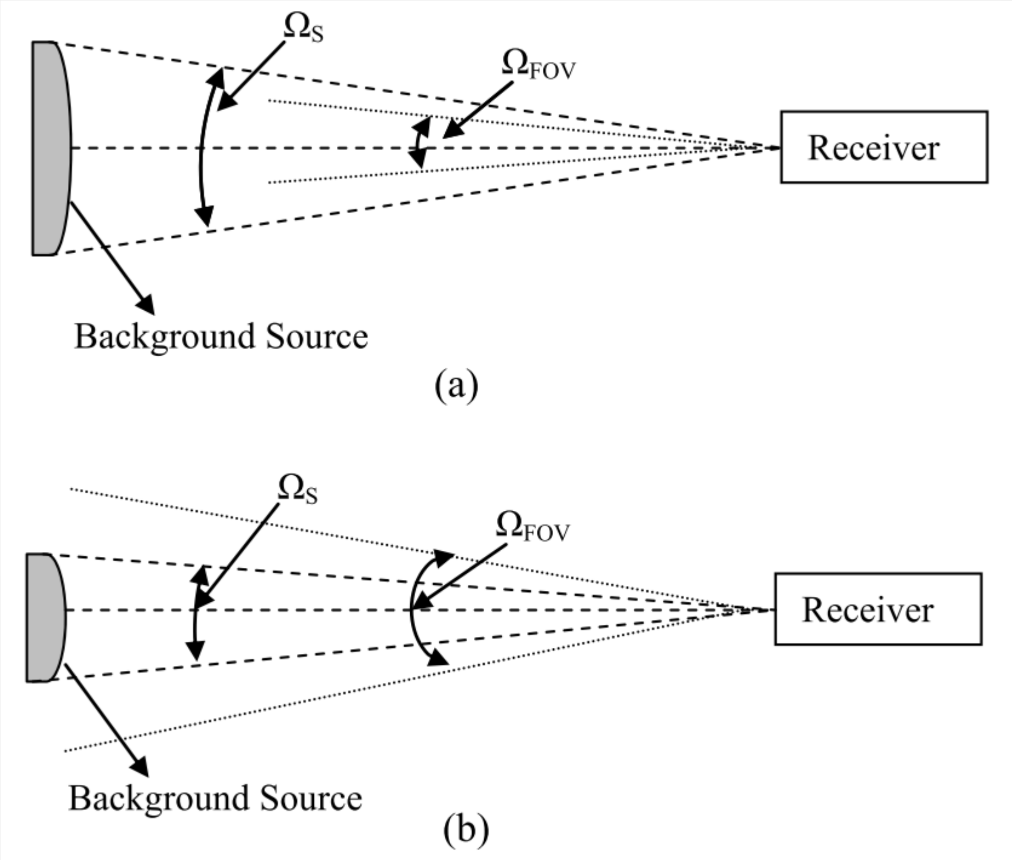


FIGURE 7. **Smart transmitters and receiver for UOWC system (a) electronic switched pointing and tracking (b) optical back scatter estimation (c) segmented FOV for duplex multi-platform system [112].**

BackGround Noise



diffused extended background noise

background noise from the Sun or other stellar (point) objects

scattered light collected by the receiver.

BackGround Noise

$$P_{BG} = P_{BG\_sol} + P_{BG\_blackbody}.$$

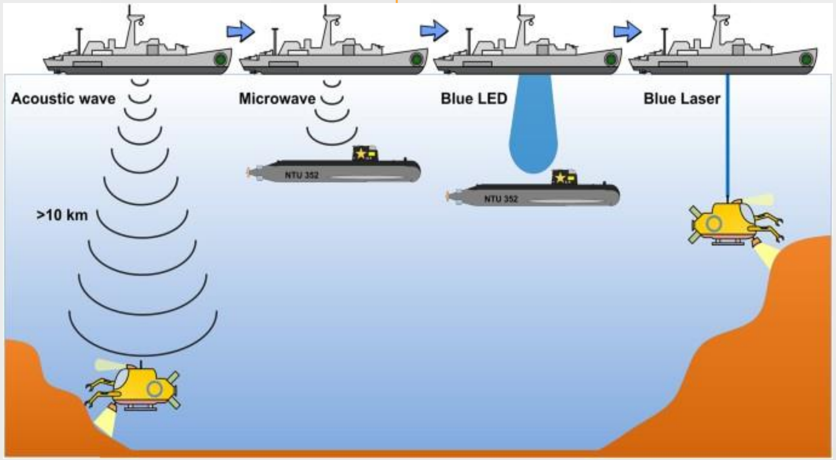
$$P_{BG\_blackbody} = \frac{2hc^2 \gamma A_R (\pi FOV)^2 \Delta\lambda T_A T_F}{\lambda^5 \left[e^{(hc/\lambda kT)} - 1\right]},$$

$$P_{BG\_solar} = A_R (\pi FOV)^2 \Delta\lambda T_F L_{sol},$$

$$L_{sol} = \frac{ERL_f e^{-Kd}}{\pi},$$

Left Aspect

MULTIPATH INTERFERENCE AND DISPERSION



PHYSICAL OBSTRUCTIONS

ARQ(Automatic Repeat Request)

FEC(Forward Error Correction)

Hybrid ARQ

Direct LOS links

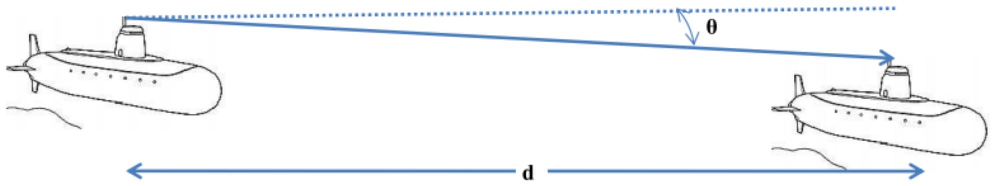


FIGURE 10. **LOS configuration.**

$$P_{R\_LOS} = P_T \eta_T \eta_R L_P \left(\lambda, \frac{d}{\cos\theta}\right) \frac{A_R \cos\theta}{2\pi d^2 \left(1 - \cos\theta_d\right)}, \tag{30}$$

NLOS LINKS

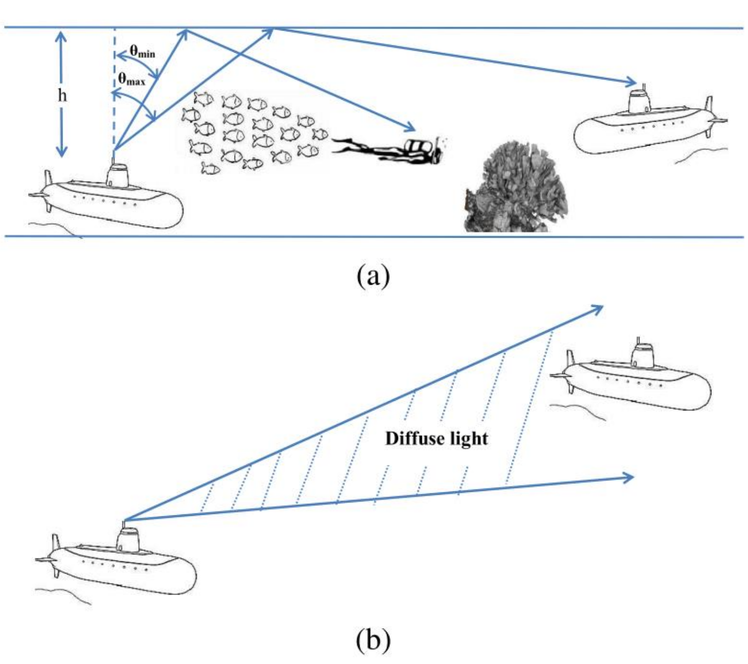


FIGURE 11. NLOS configuration: (a) reflective (b) diffuse.

RETRO-REFLECTOR LINKS

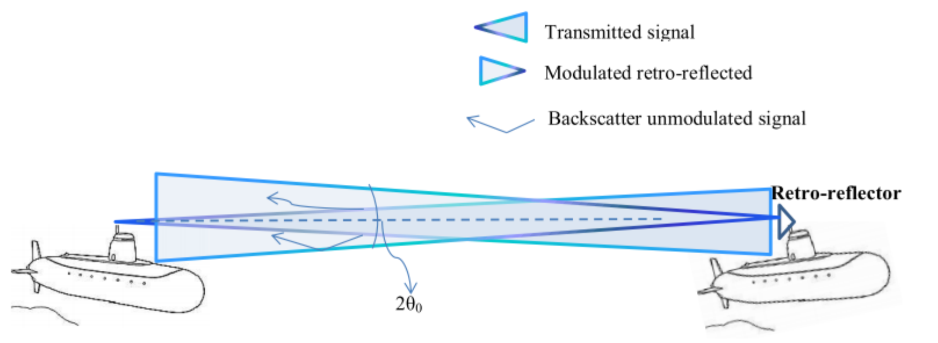


FIGURE 12. **Modulating retro-reflector configuration.**

Scenario

i) Photon Limited

ii) Contrast Limited

Conclusion

Historical approach

Kind of Aspect

Kind of Links

THANKS