Channel Modeling for Underwater Optical Communication

Chadi Gabriel[1,2], Mohammad-Ali Khalighi[1], Salah Bourennane[1], Pierre Leon[2], Vincent Rigaud[2]

Paper Review : 스마트기기전공 오승현(19011847)

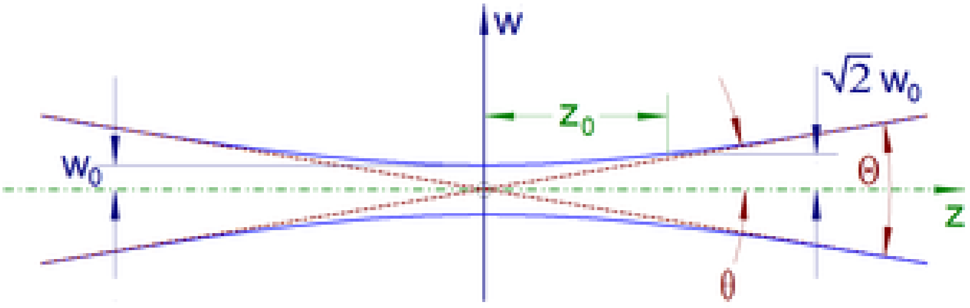
***Abstract*— We consider in this paper channel modeling for underwater optical channels. In particular, we focus on the channel impulse response and quantify the channel time dispersion under different conditions of water type, link distance, and transmitter/receiver parameters. We use the Monte Carlo approach to simulate the trajectories of emitted photons propagating in water towards the receiver. We show that in most practical cases, the time dispersion is negligible and does not induce any inter-symbol interference on the received symbols. Our results can be used to appropriately set different system design parameters.**

Abstract— We consider in this paper channel modeling for underwater optical channels. In particular, we focus on the channel impulse response and quantify the channel time dispersion under different conditions of water type, link distance, and transmitter/receiver parameters. We use the Monte Carlo approach to simulate the trajectories of emitted photons propagating in water towards the receiver. We show that in most practical cases, the time dispersion is negligible and does not induce any inter-symbol interference on the received symbols. Our results can be used to appropriately set different system design parameters.

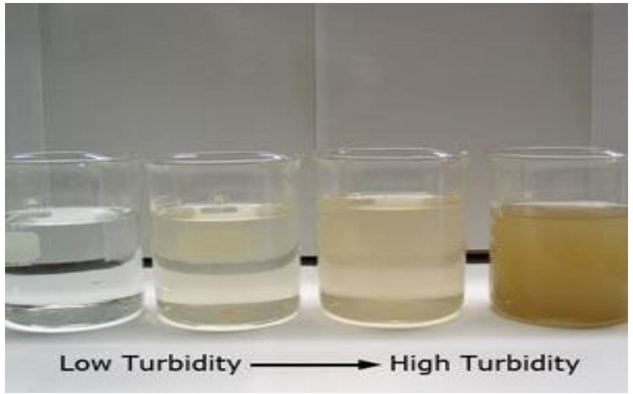
How to Propagate(or model) with Optical Communication and What do we consider about that.

: with RTE, it can provide what we want

Consideration!



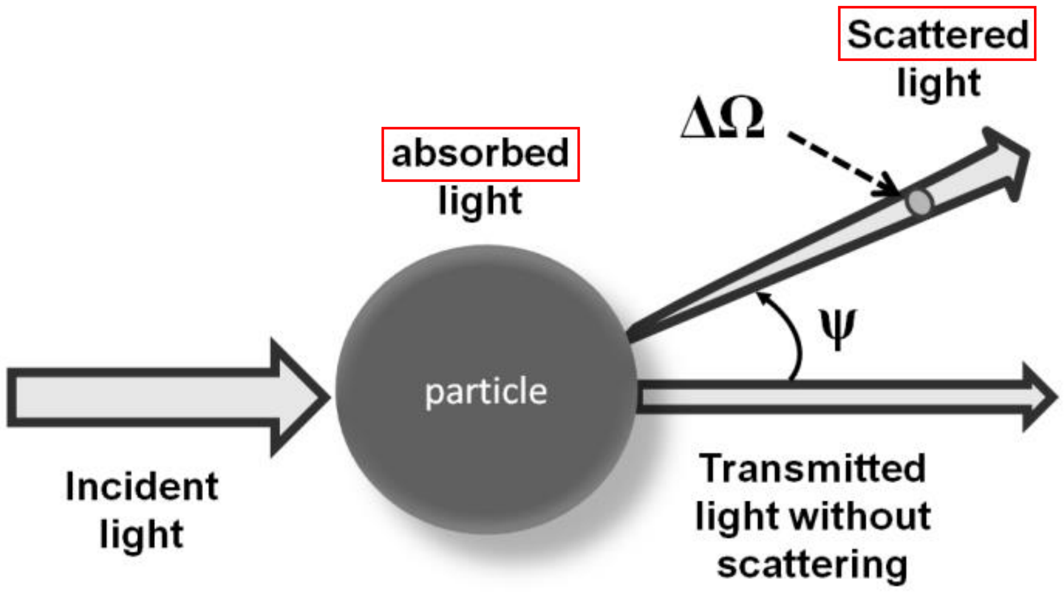
3.

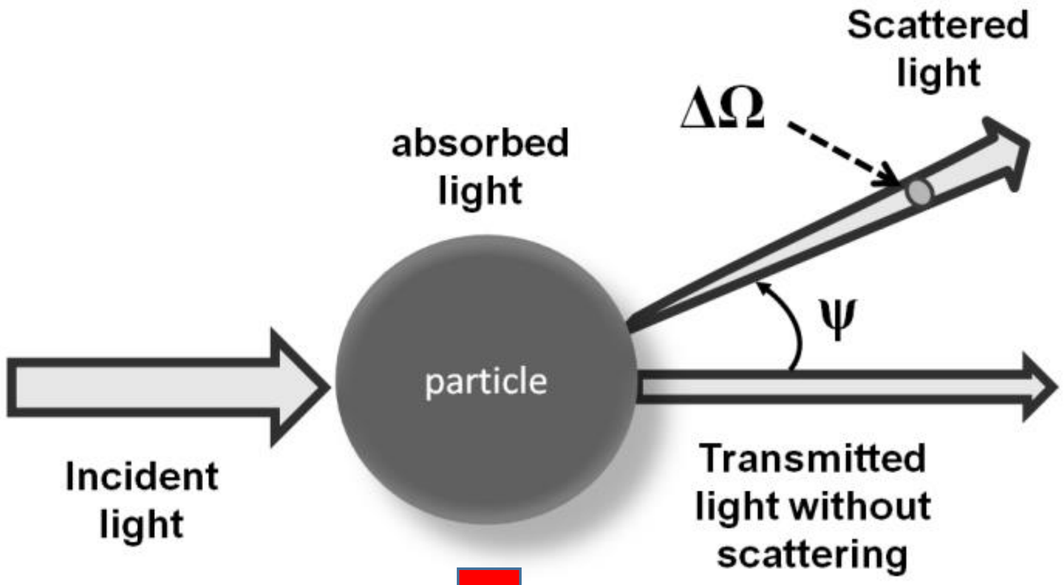


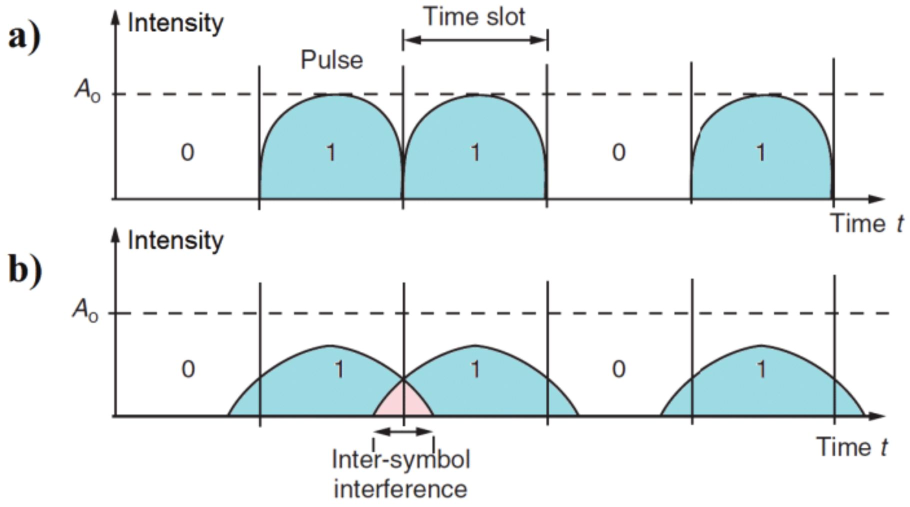
1. Transmitter Beam Divergence

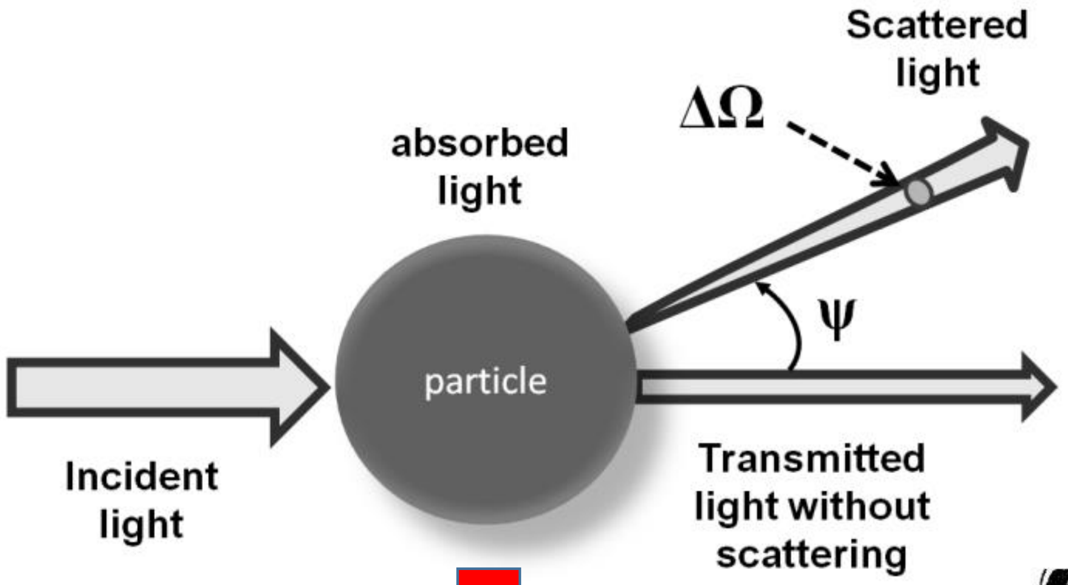
2. Link Distance

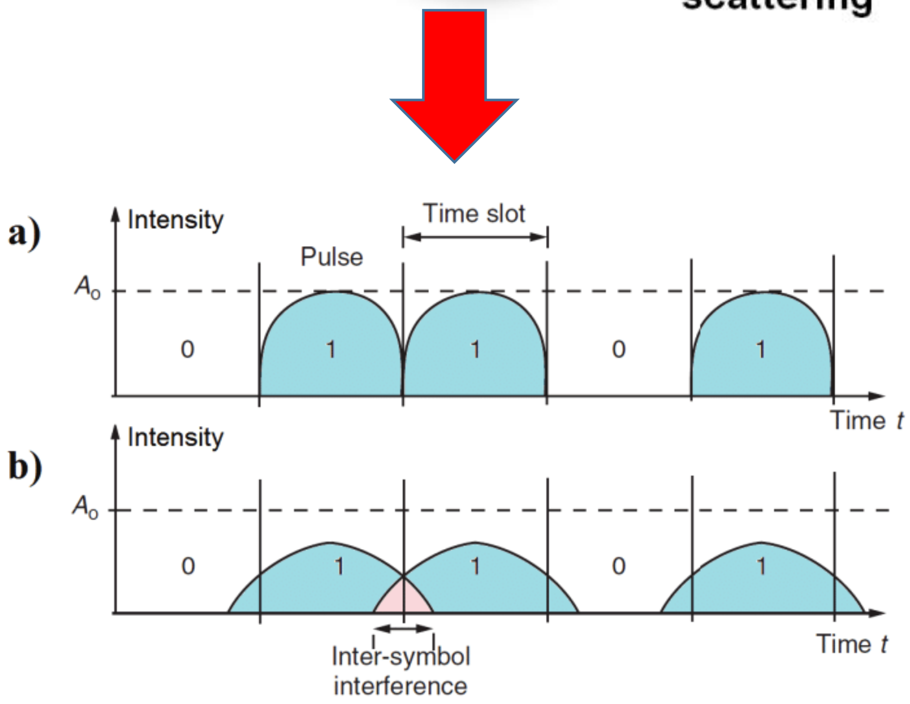
They effect on the Channel Impulse Response!


Scattered
light
ΔΩ
absorbed
light
ψ
particle
Incident
light
Transmitted
light without
scattering

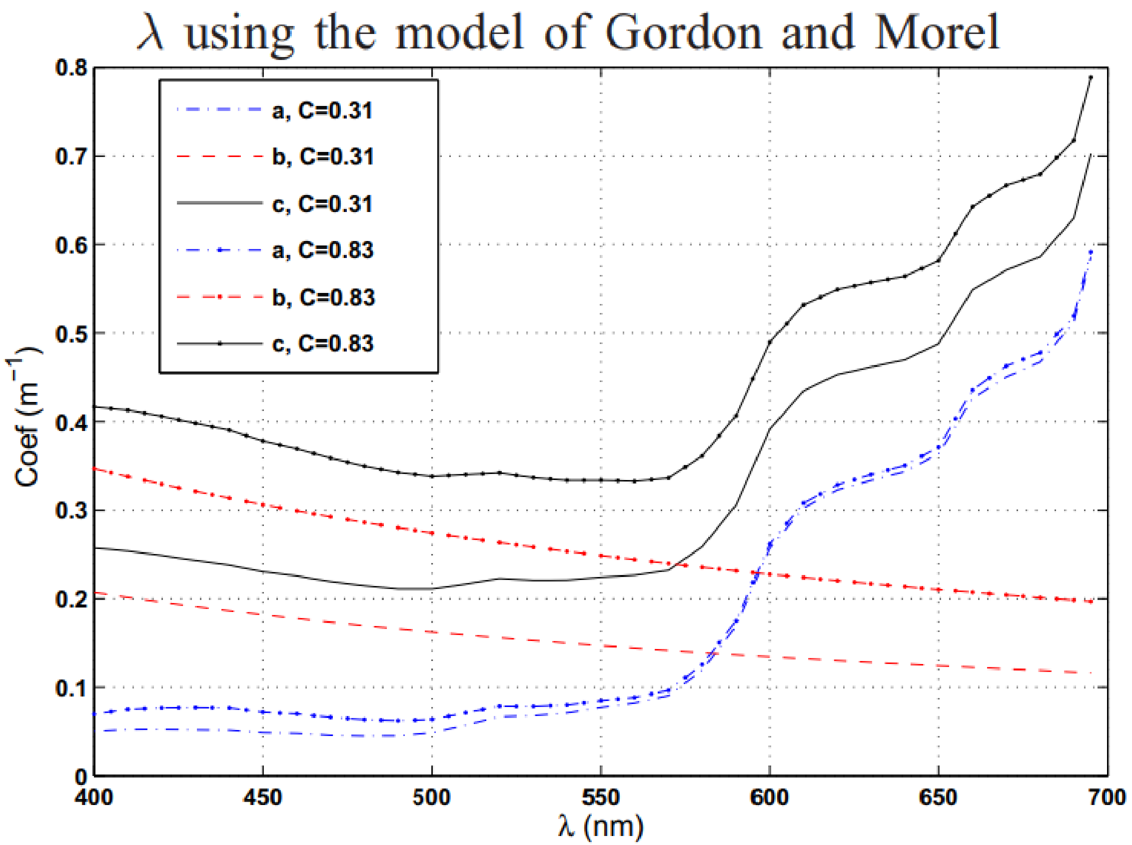

Scattered light
ΔΩ
absorbed light
ψ
particle
Incident light
Transmitted light without scattering


a)
Intensity
Time slot
Pulse
A_o
0
1
1
0
1
Time t
b)
Intensity
A_o
0
1
1
0
1
Time t
Inter-symbol interference





It Causes ISI Problem!



$$b(\lambda) = 2\pi \int_0^{\pi} \beta(\Psi, \lambda)\, \sin(\Psi)\, d\Psi.$$

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

TYPICAL COEFFICIENTS FOR DIFFERENT WATER TYPES.

Water type	C (mg/m^3)	a (m^{-1})	b (m^{-1})	c (m^{-1})
Pure sea	0.005	0.053	0.003	0.056
Clear ocean	0.31	0.069	0.08	0.15
Coastal	0.83	0.088	0.216	0.305
Harbor	5.9	0.295	1.875	2.17

RTE(Radiative Transfer Theory)

Elastic Scattering

- Chlorophyll concentration C and wavelength λ to determine the coefficients a and b (see Subsection III-A).
- Henyey-Greenstein parameter g which is the average of the cosine of the scattering angle Ψ over all scattering directions.
- Distance Z between the transmitter and the receiver.
- Transmitter beam width and maximum initial divergence angle θ_0.
- Receiver aperture size.

→ Monte Carlo Simulation

Inelastic Scattering

RTE(Radiative Transfer Theory)

Elastic Scattering

- Chlorophyll concentration C and wavelength λ to determine the coefficients a and b (see Subsection III-A).
- Henyey-Greenstein parameter g which is the average of the cosine of the scattering angle Ψ over all scattering directions.
- Distance Z between the transmitter and the receiver.
- Transmitter beam width and maximum initial divergence angle θ_0.
- Receiver aperture size.

Monte Carlo Simulation

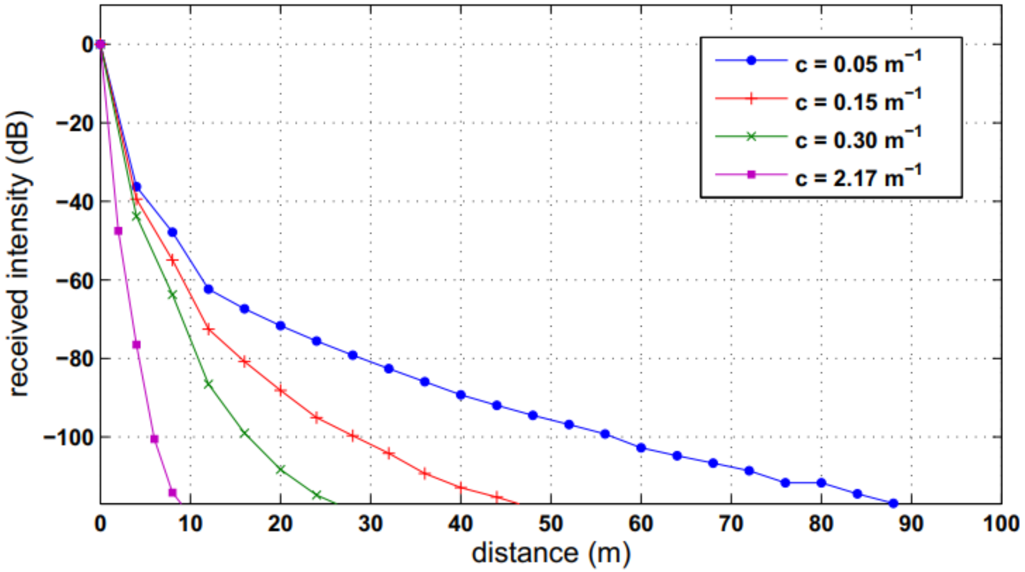
Inelastic Scattering

Monte Carlo Simulation

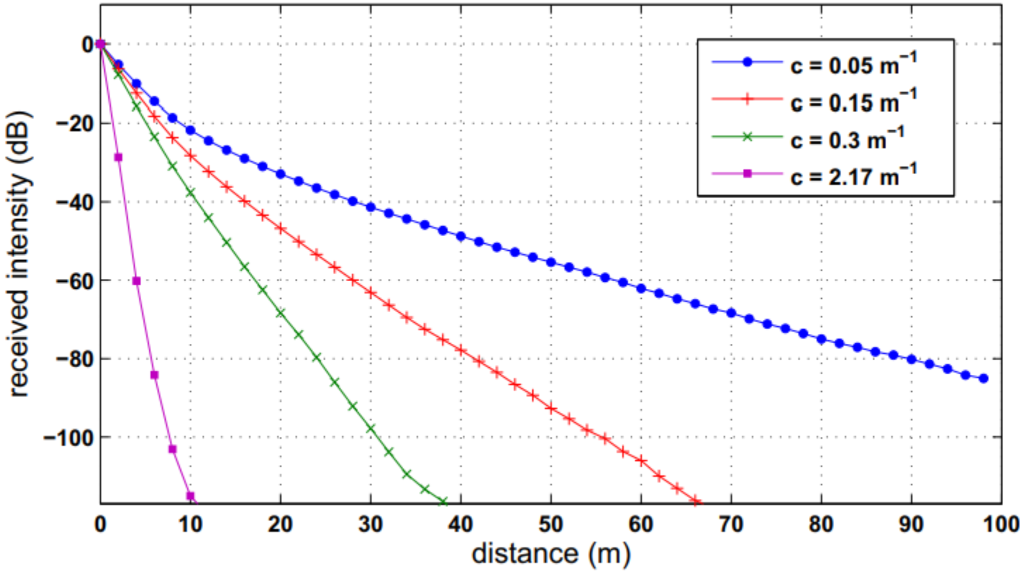
- The photon weight is too small and negligible. The photon is considered as totally absorbed. This limit is set here to 10^{-4}.
- The photon reaches the receiver. If it is in the receiver aperture, it is considered as effectively received. It is considered as lost, otherwise.

$$\chi_\theta = \frac{1-g^2}{2(1+g^2-2g\cos\theta)^{\frac{3}{2}}}.$$

Monte Carlo Simulation



(a) $D = 5\,\mathrm{mm}$



(b) $D = 50\,\mathrm{cm}$

Monte Carlo Simulation – Water Type

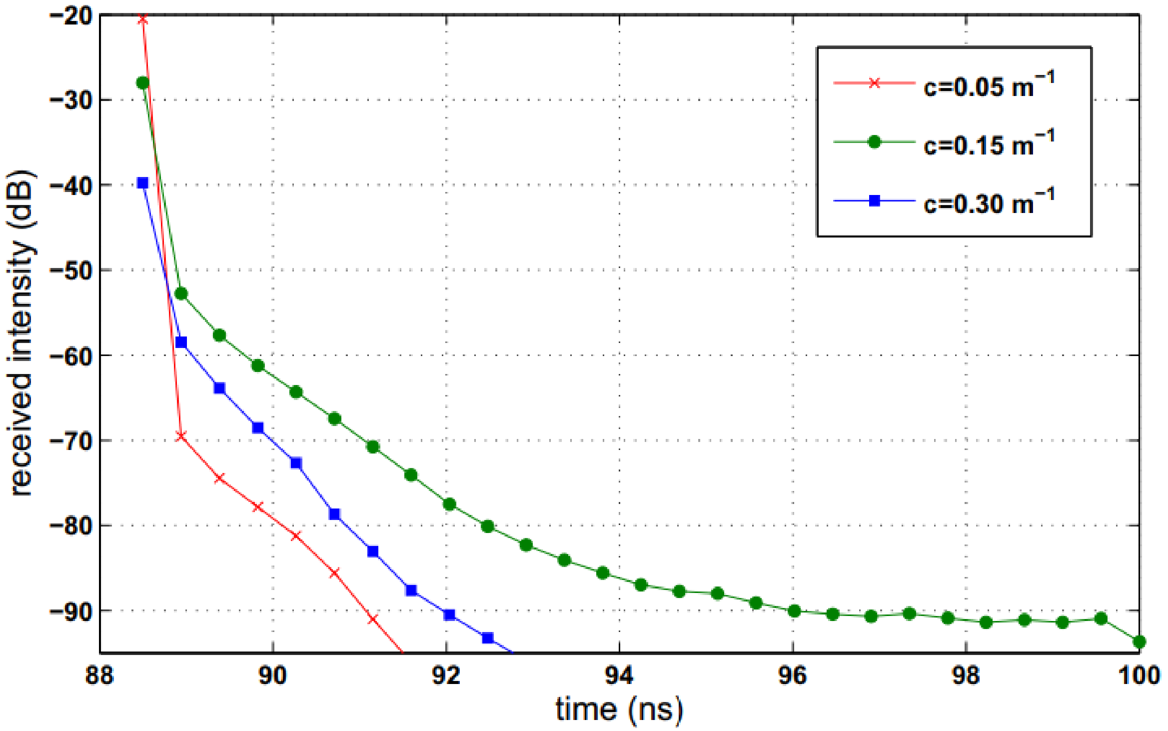


Fig. 4. Channel IR (received intensity as a function of time) for pure sea, clear ocean, and coastal waters. $Z = 20\,\mathrm{m}$, $D = 20\,\mathrm{cm}$

Monte Carlo Simulation – Impulse Response

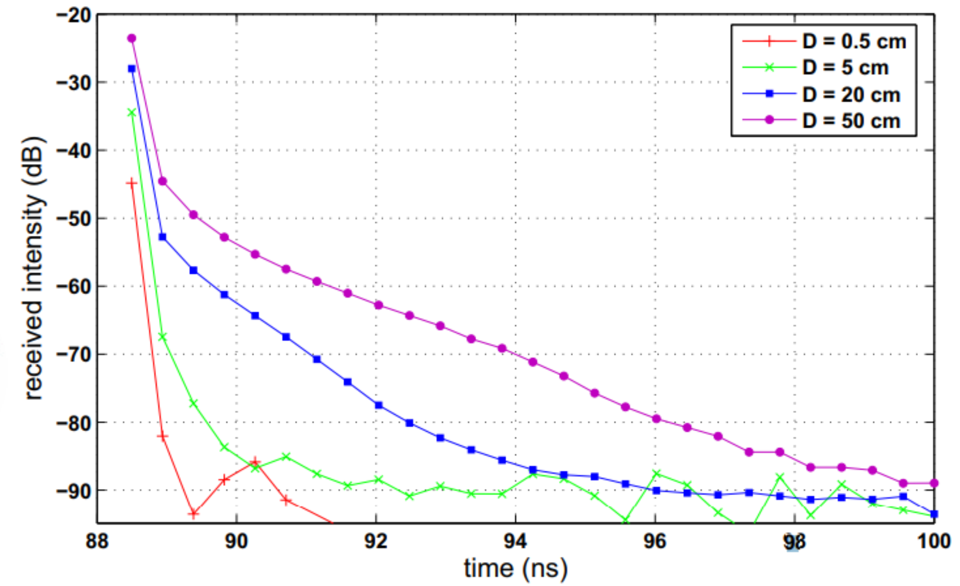


Fig. 5. Channel IR for different receiver aperature diameters D. $Z = 20\,\text{m}$, clear ocean waters.

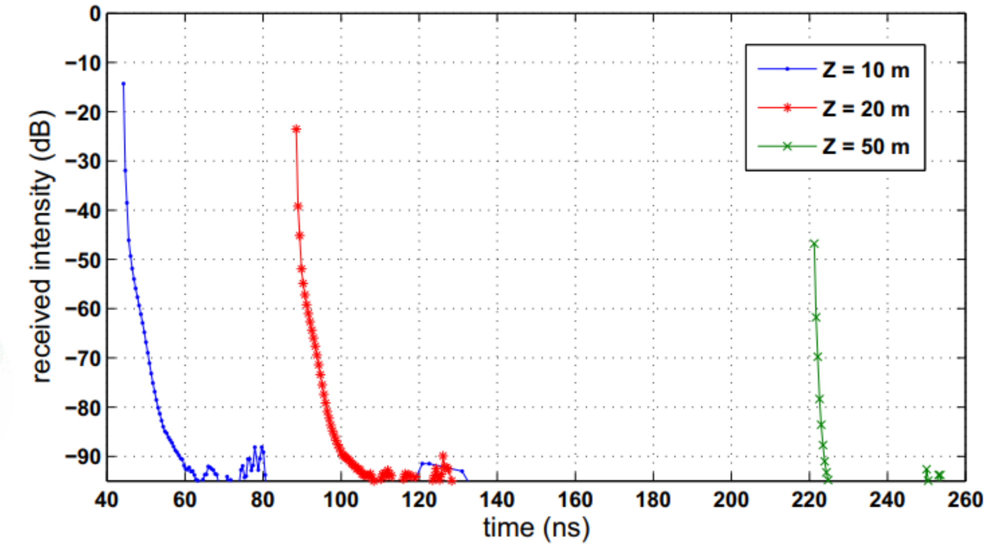


Fig. 6. Channel IR for different link distances Z. $D = 50\,\text{cm}$, clear ocean waters.

Monte Carlo Simulation – Conclusion of Experiments

TABLE II

SUMMARY OF INTENSITY LOSS AND CHANNEL TIME DISPERSION FOR DIFFERENT SYSTEM PARAMETERS.

c (m^{-1})	Z (m)	D (cm)	Intensity loss (dB)	τ (ns)
0.05	20	20	-20.55	0.18
0.15	20	20	-28.03	0.35
0.31	20	20	-39.82	0.38
0.15	20	0.5	-44.83	0.17
0.15	20	5	-34.43	0.27
0.15	20	20	-27.99	0.35
0.15	20	50	-23.52	0.42
0.15	10	50	-14.29	0.37
0.15	20	50	-23.52	0.42
0.15	50	50	-46.78	0.59

VII. CONCLUSIONS

In this paper, we presented a realistic model for an underwater wireless optical channel using an elaborate Monte Carlo simulator taking into account different parameters such as the water type and the transmitter/receiver characteristics. Considering a maximum bit rate of 1 Gbps, we demonstrated that the 1 channel time dispersion is negligible in most practical cases. Even when working over distances up to 50 m in clear waters and using a receiver aperture diameter as large as 50 cm, we showed that the channel can effectively be considered as frequency non-selective. 2 As a result, we do not suffer from any ISI and do not need to perform computationally complex signal processing such as channel equalization at the receiver.