Deep Learning Aided Signal Detection for SPAD-Based UOWC

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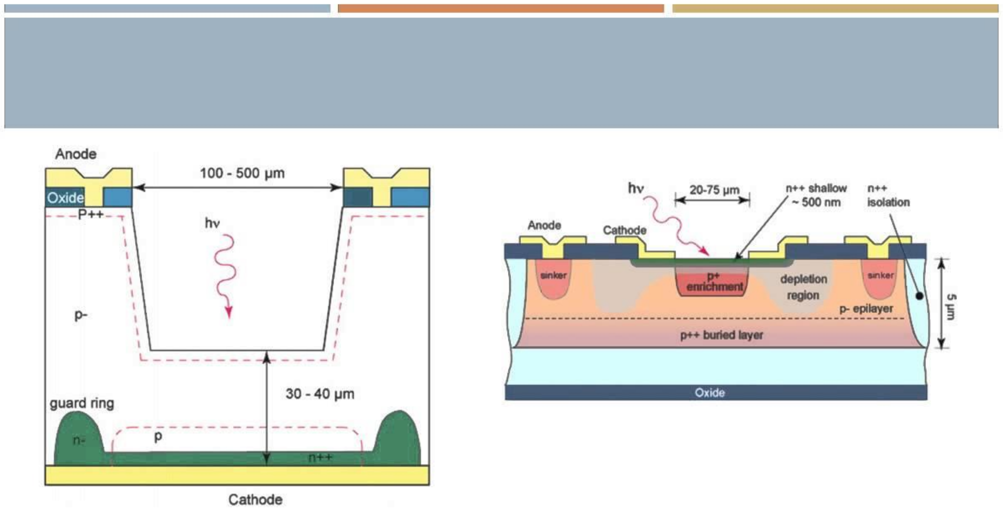
SPAD <Single Photon Avalanche Diode>



Detection Efficiency

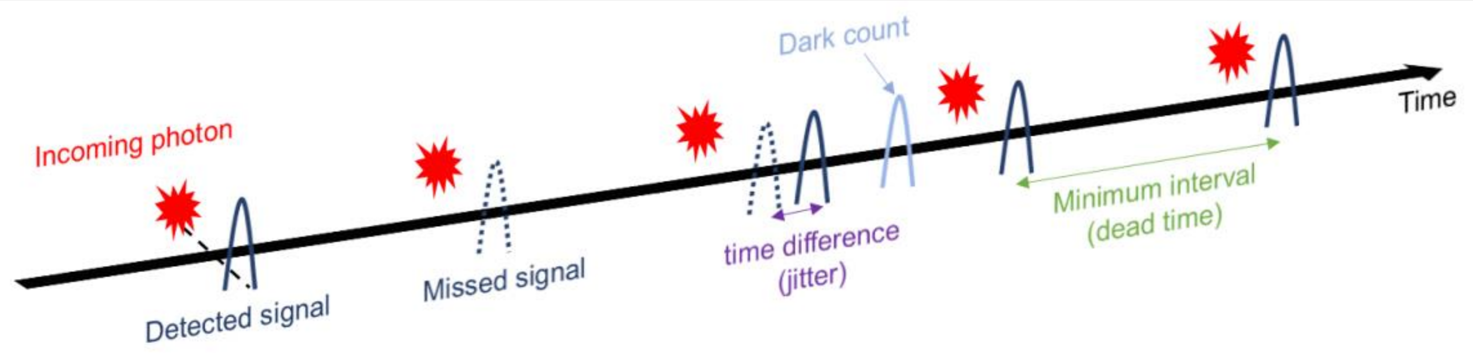
$$\eta = (R_{detected} - R_{dark}) / R_{incident}$$

Dark Count

Dead Time

Timing Jitter

Single Photon Detector



<Paper : Single Photon Detectors Technologies Development Trends for Quantum Information>

Framework

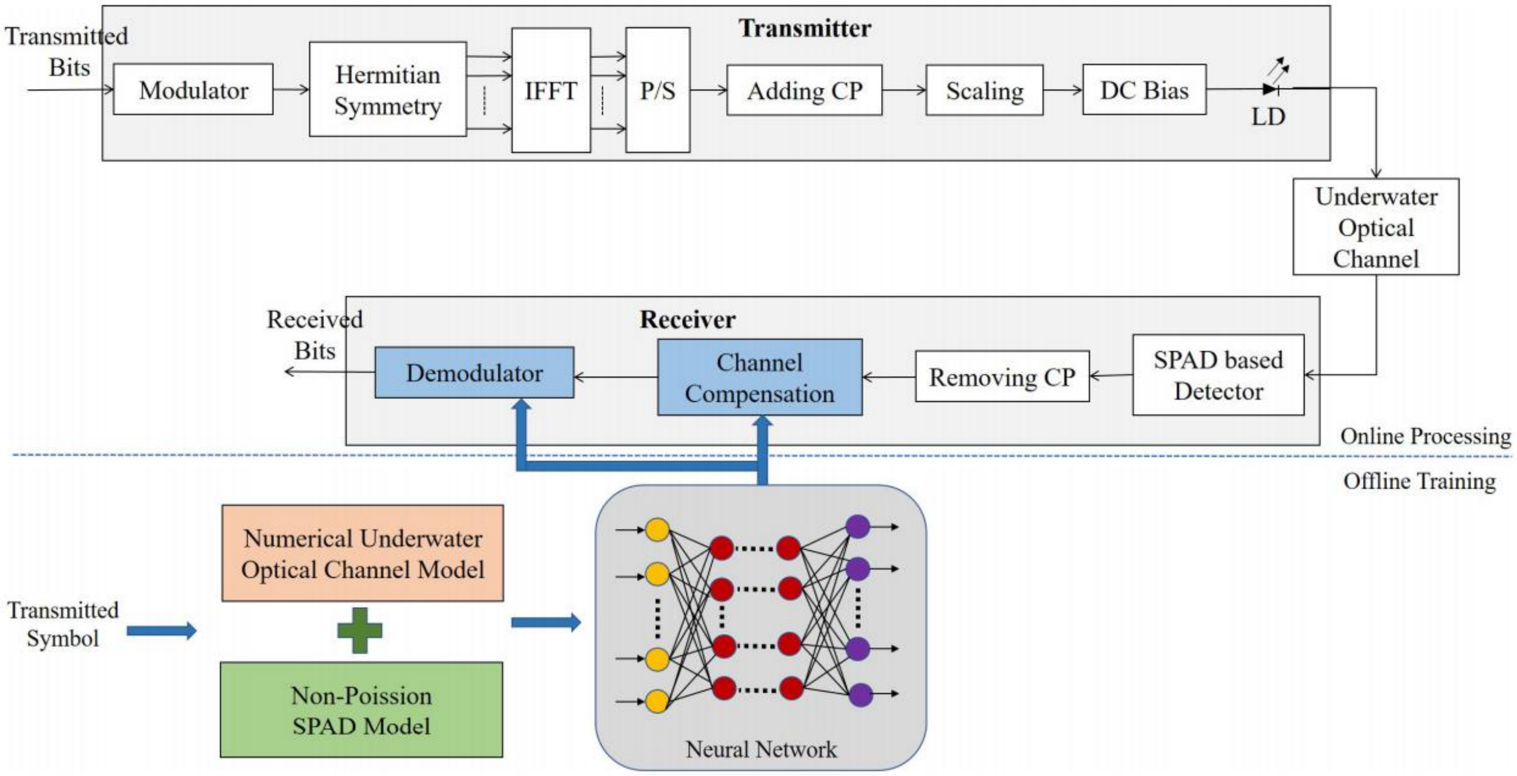


FIGURE 3. **Deep learning aided SPAD based UOWC system framework.**

Two-connected MLP network

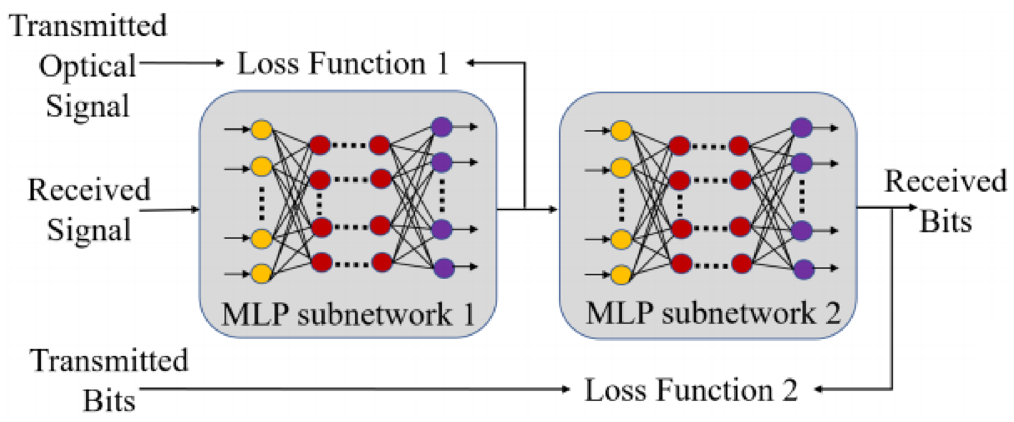


FIGURE 4. Architecture of the proposed two-connected MLP network.

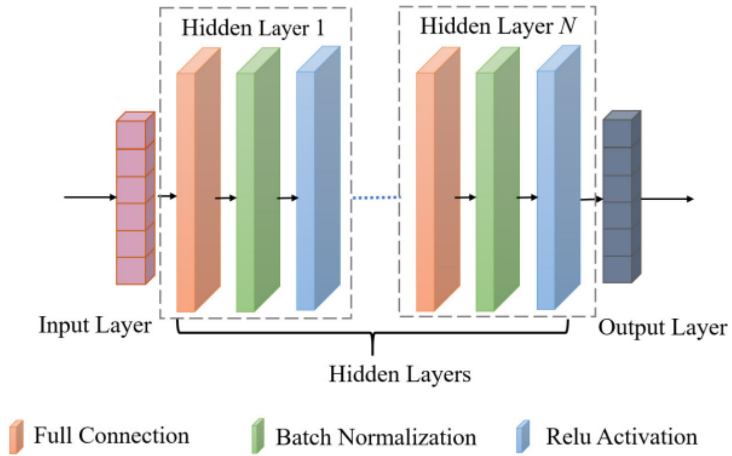


FIGURE 5. Inner structure of the MLP subnetwork.

Algorithm

Algorithm 1 Deep Learning Aided Signal Detection Training Algorithm

Input: For each subnetwork, the length of the input, the number of hidden layers, the number of hidden units in each hidden layer, the length of output, training iteration $N_{\mathrm{nn1,ite}}$, $N_{\mathrm{nn2,ite}}$

Start the underwater emulator with the numerical underwater optical channel model and the non-Poisson SPAD model to generate the training data;

Normalize the training data;

Initial the first MLP subnetwork. The iteration is initially to be 0, and randomly generate the weights and bias;

for $k = 1$ *to* $N_{nn1,ite}$ **do**

  Calculate the output of the first MLP subnetwork based on (18);

  Calculate the loss function between the output of this subnetwork (i.e., $\hat{x}_n^{(\mathrm{opt})}$) and the transmitted optical signal: $l_1 = \frac{1}{N_1}\sum_{n=1}^{N_1}(\hat{x}_n^{(\mathrm{opt})} - x_n^{(\mathrm{opt})})^2$;

  Update the weights and bias with Adam algorithm based on (24);

end

Initial the second MLP subnetwork while retaining the structure and parameters of the first subnetwork. The iteration is initially to be 0, and randomly generate the weights and bias of this subnetwork ;

for $k = 1$ *to* $N_{nn2,ite}$ **do**

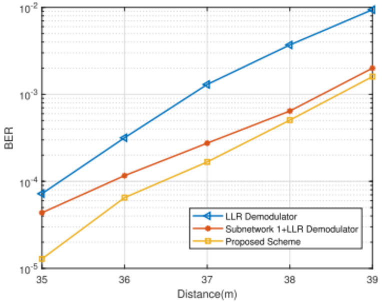
  Calculate the output of the second MLP subnetwork based on (18);

  Calculate the loss function between the output of this subnetwork (i.e., $\hat{z}_i$) and the transmitted bits: $l_2 = \frac{1}{N_2}\sum_{i=1}^{N_2}(\hat{z}_i - z_i)^2$;

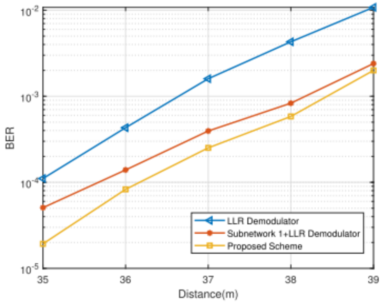
  Update the weights and bias with Adam algorithm based on (24);

end

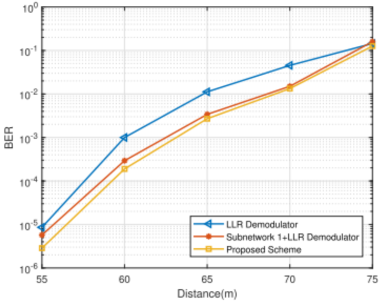
Performance Comparison



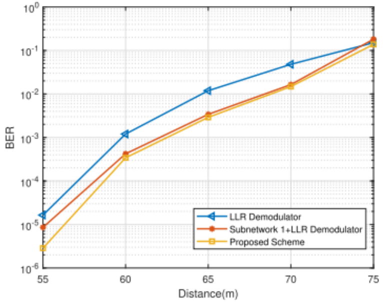
(a) Coastal Water, Numerial Optical Channel Model, AQ SPAD



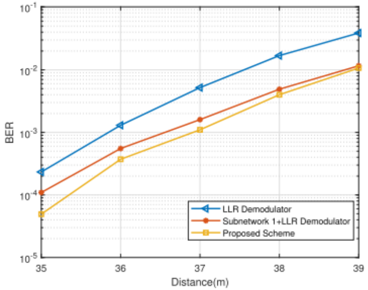
(b) Coastal Water, Numerial Optical Channel Model, PQ SPAD



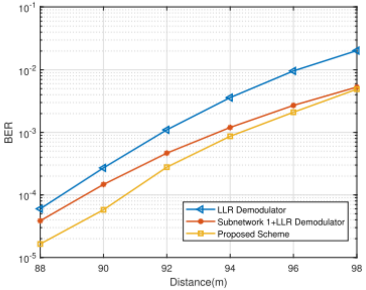
(c) Clear Ocean, Numerial Optical Channel Model, AQ SPAD



(d) Clear Ocean, Numerial Optical Channel Model, PQ SPAD



(e) Coastal Water, Beer Law Model, AQ SPAD



(f) Clear Ocean, Beer Law Model, AQ SPAD

FIGURE 6. **BER comparison on the received signals in different cases.**

Conclusion

More Easier

More efficiency

Better Performance

THANKS