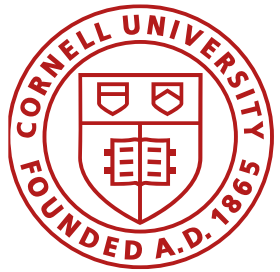
# Learning to Tune Optical WANs

*A Field Deployment of Noise Models in Optical Networks*

**Bhaskar Kataria**[1], Howard Hua[1] Andrea D'Amico[2], Bill Owens[3], Rachee Singh[1]

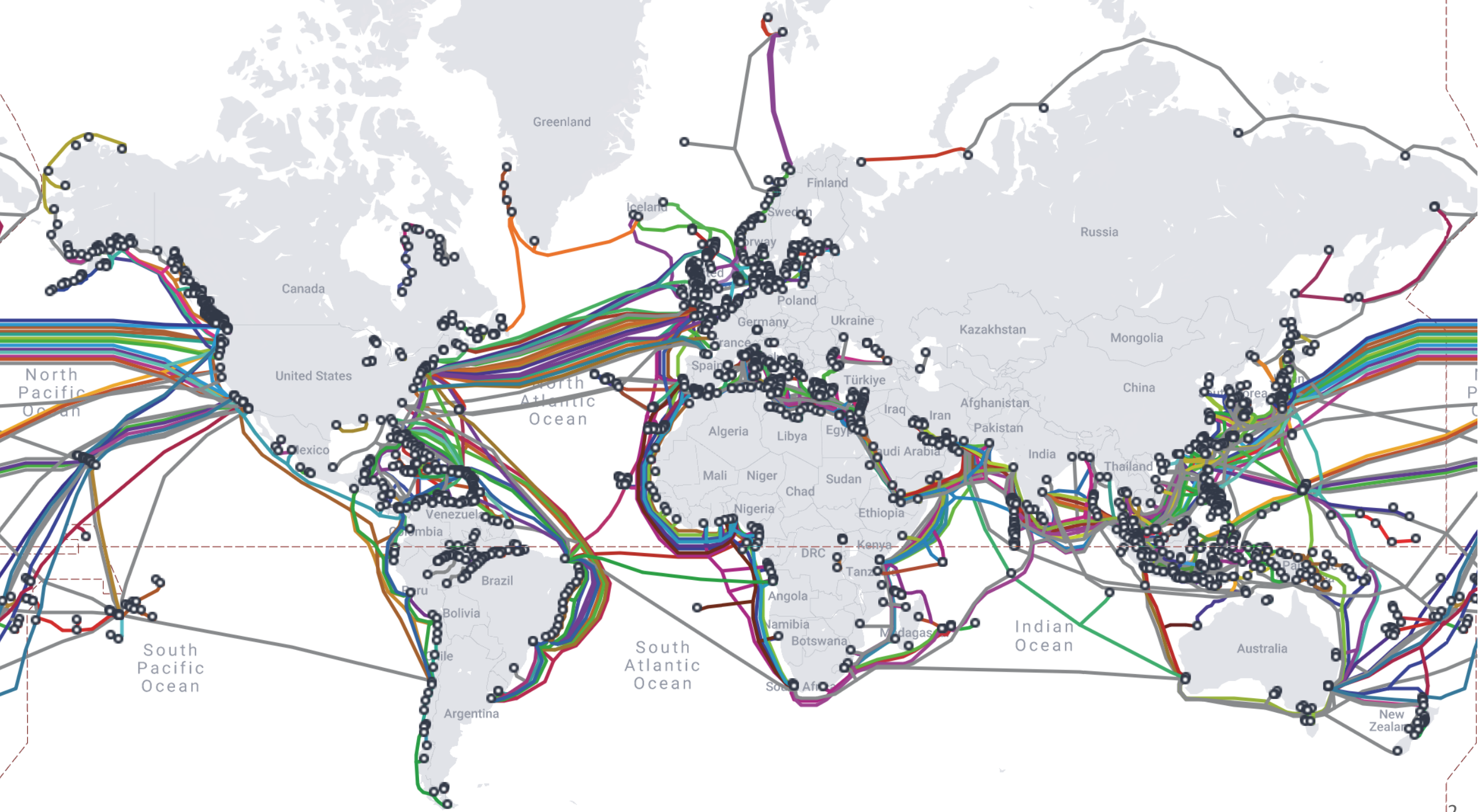
1. Cornell University · 2. NEC Labs · 3. NYSERnet




Cornell University

NEC

nysernet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Germany
France
Spain
Ukraine
Türkiye
Russia
Kazakhstan
Mongolia
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DRC
Tanzania
Angola
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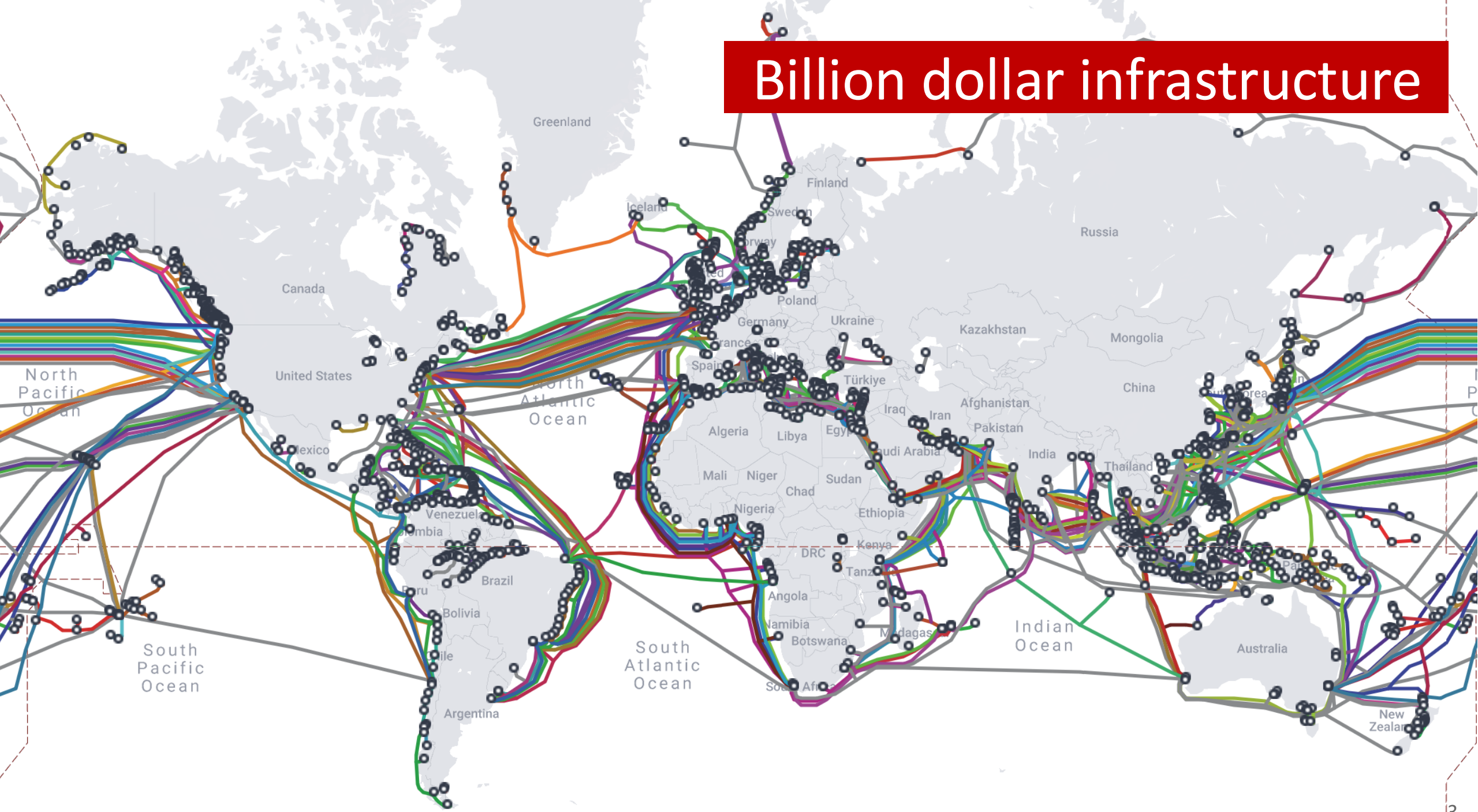
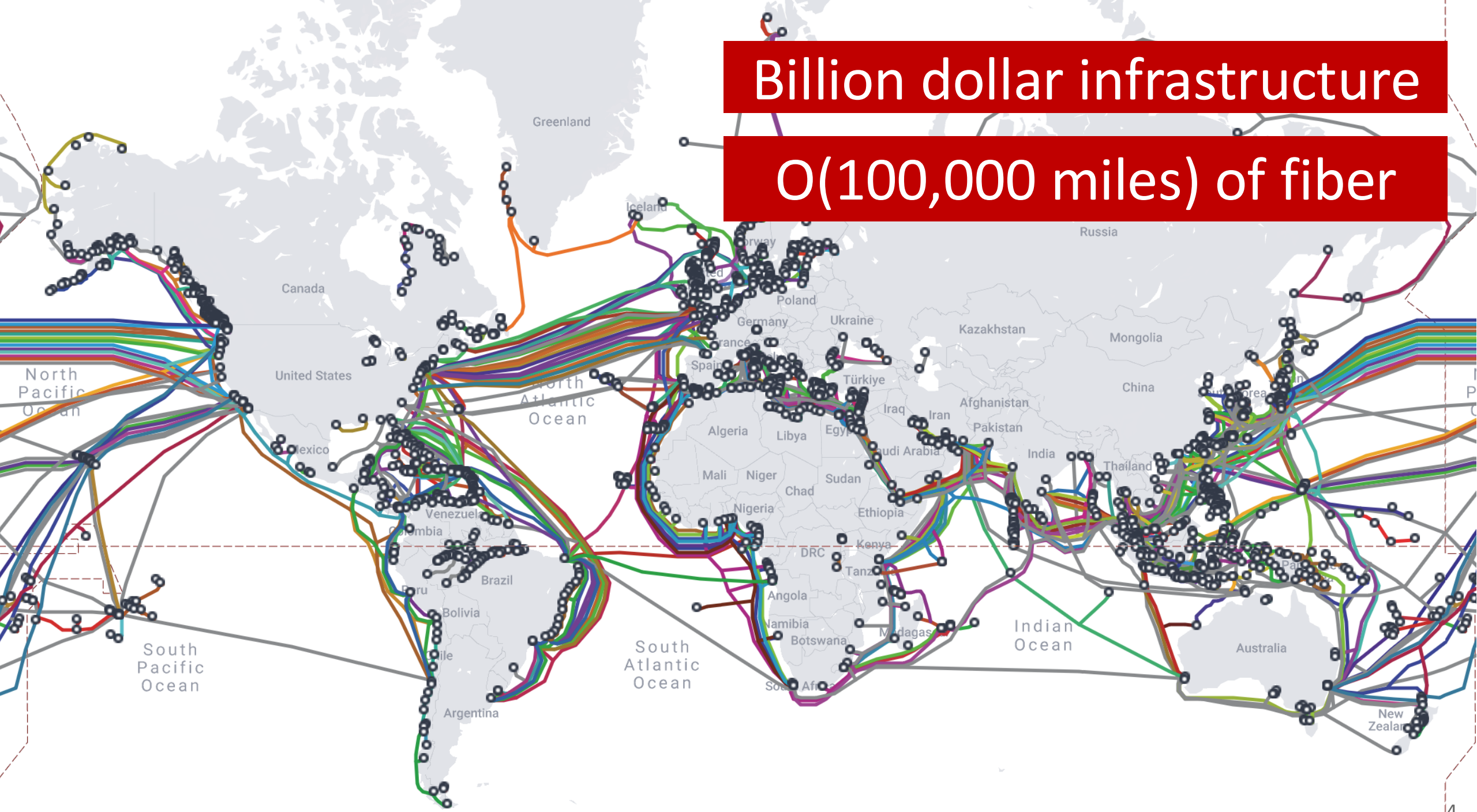
South Africa
Australia
New Zealand
North Pacific Ocean
South Pacific Ocean
North Atlantic Ocean
South Atlantic Ocean
Indian Ocean

# Billion dollar infrastructure




Billion dollar infrastructure
O(100,000 miles) of fiber
Greenland
Iceland
Canada
United States
Russia
Poland
Germany
Ukraine
Kazakhstan
Mongolia
China
Türkiye
Iraq
Iran
Afghanistan
Pakistan
India
Thailand
Algeria
Libya
Egypt
Saudi Arabia
Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
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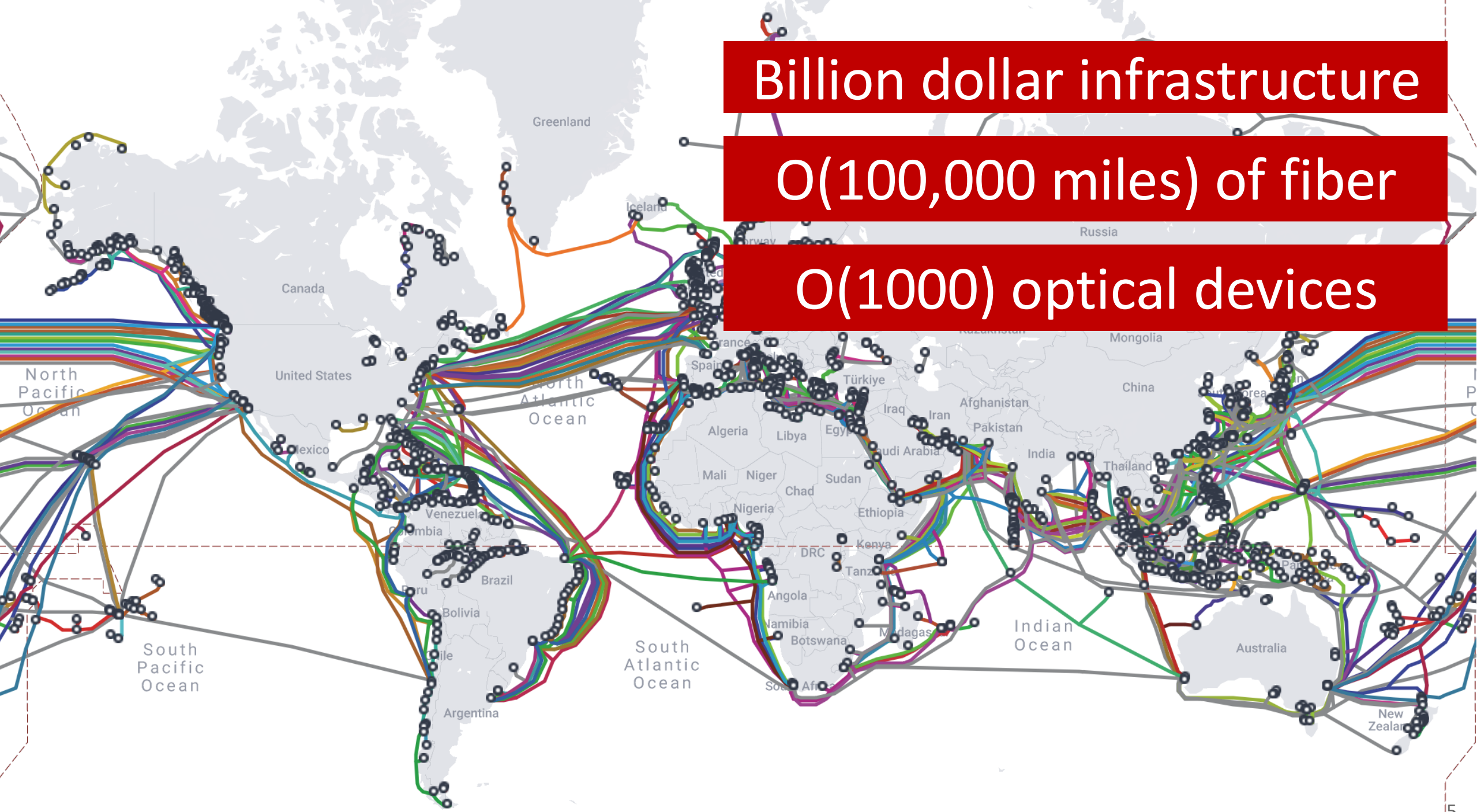
Billion dollar infrastructure
O(100,000 miles) of fiber
O(1000) optical devices
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United States
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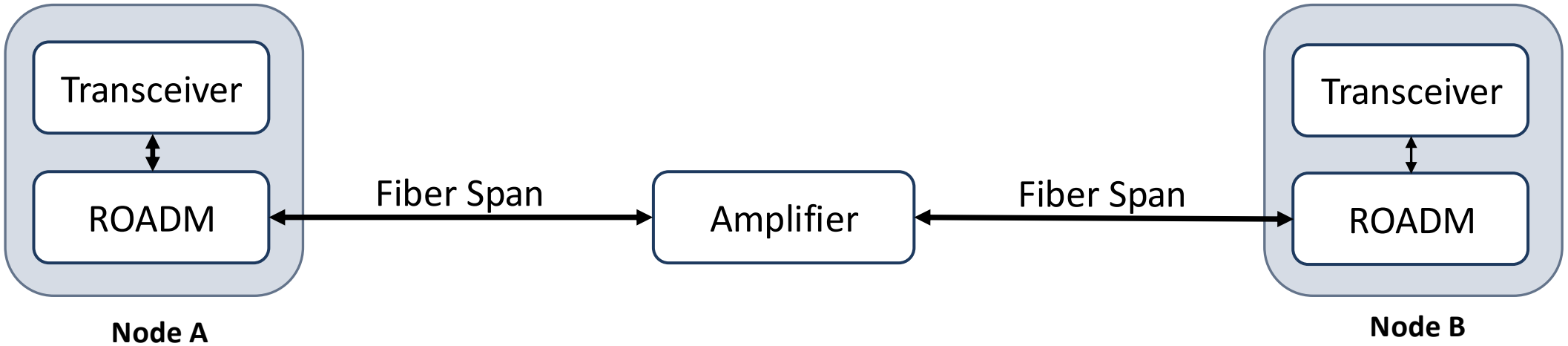
# Main components of the network



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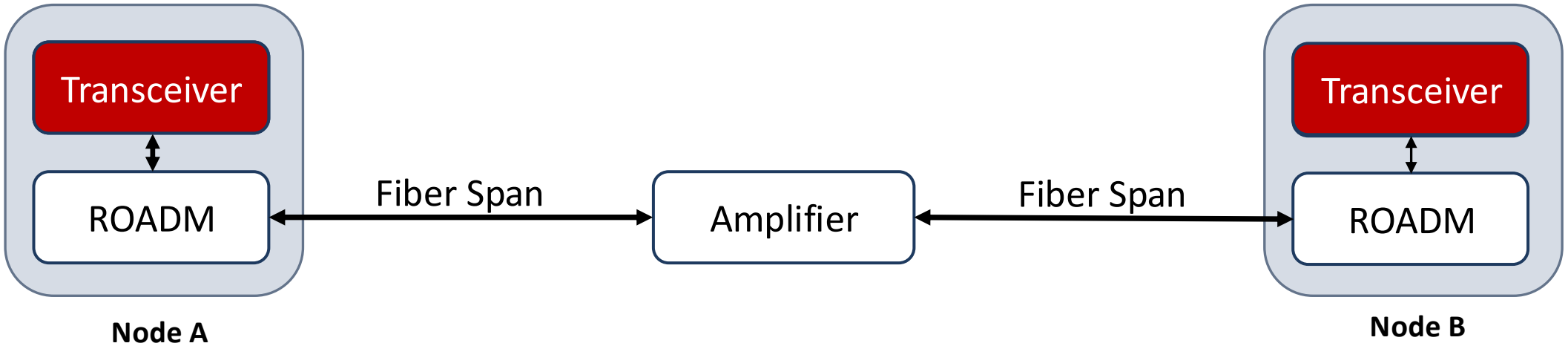


**Transceiver:** Convert electrical signal to optical and vice versa

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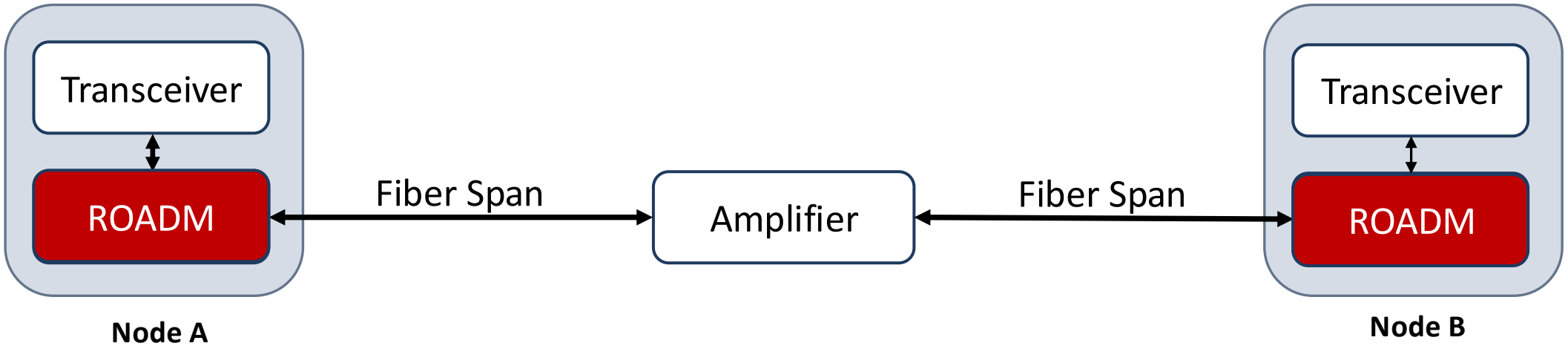


**ROADM:** Routes wavelengths between fiber spans

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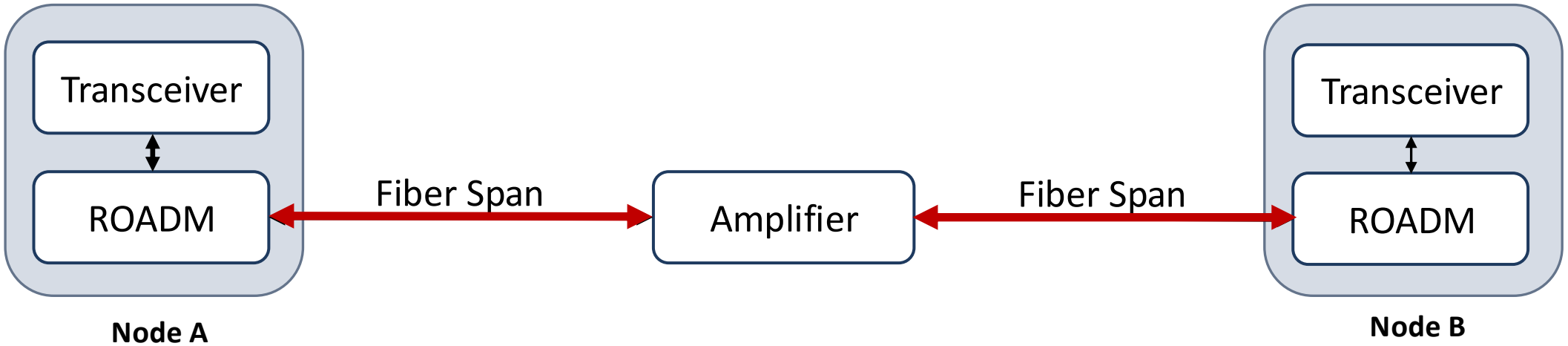
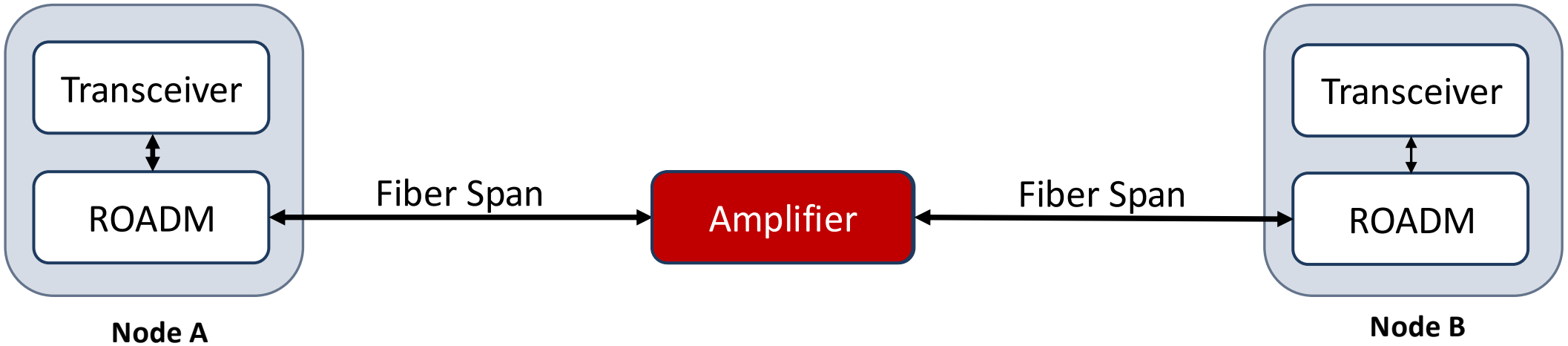


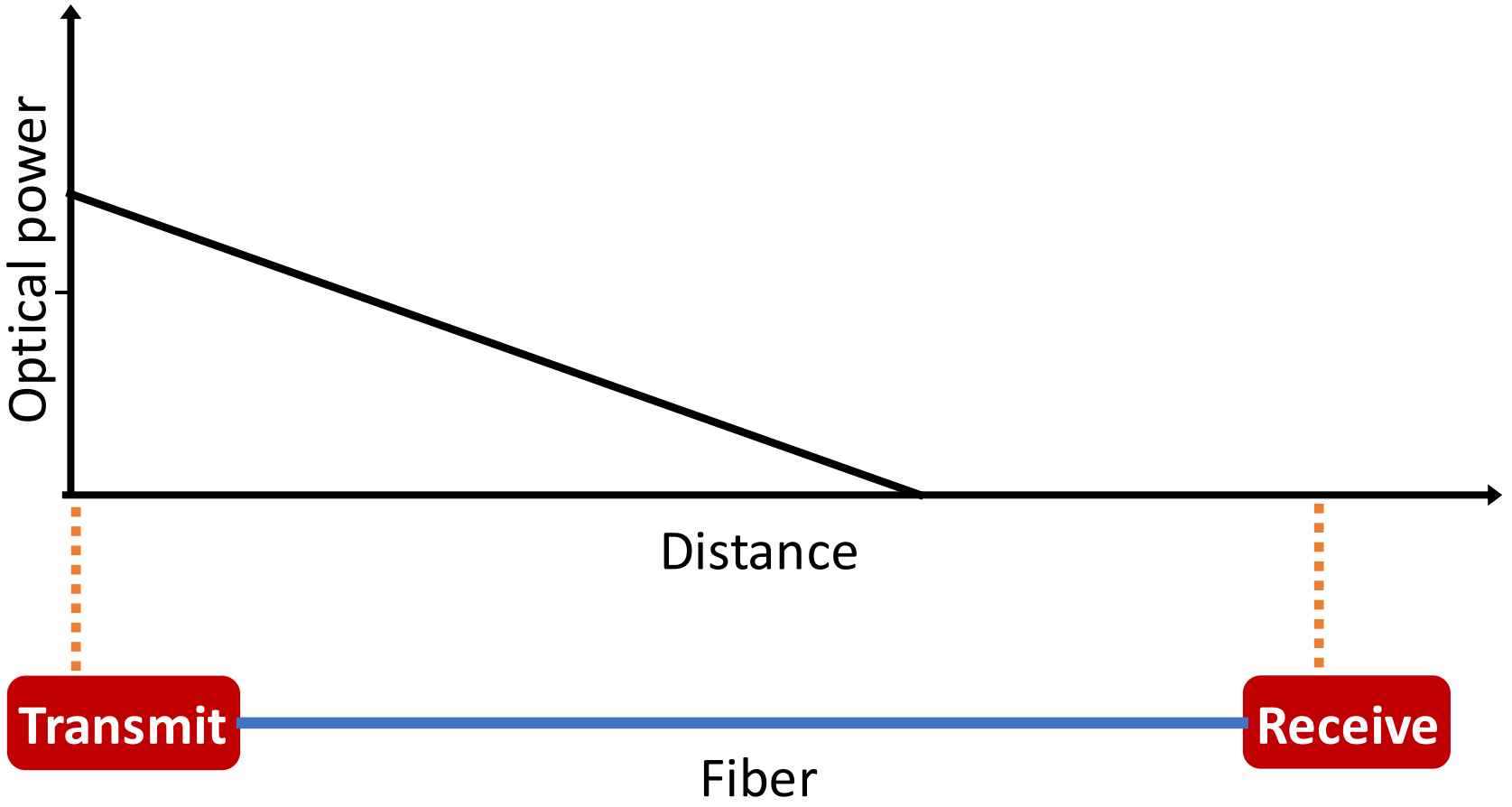

**Fiber span:** Carries optical signal between nodes

# Main components of the network




**Amplifier:** Amplifies optical signal to compensate for loss

# Amplifier gains shape the signal power across the WAN



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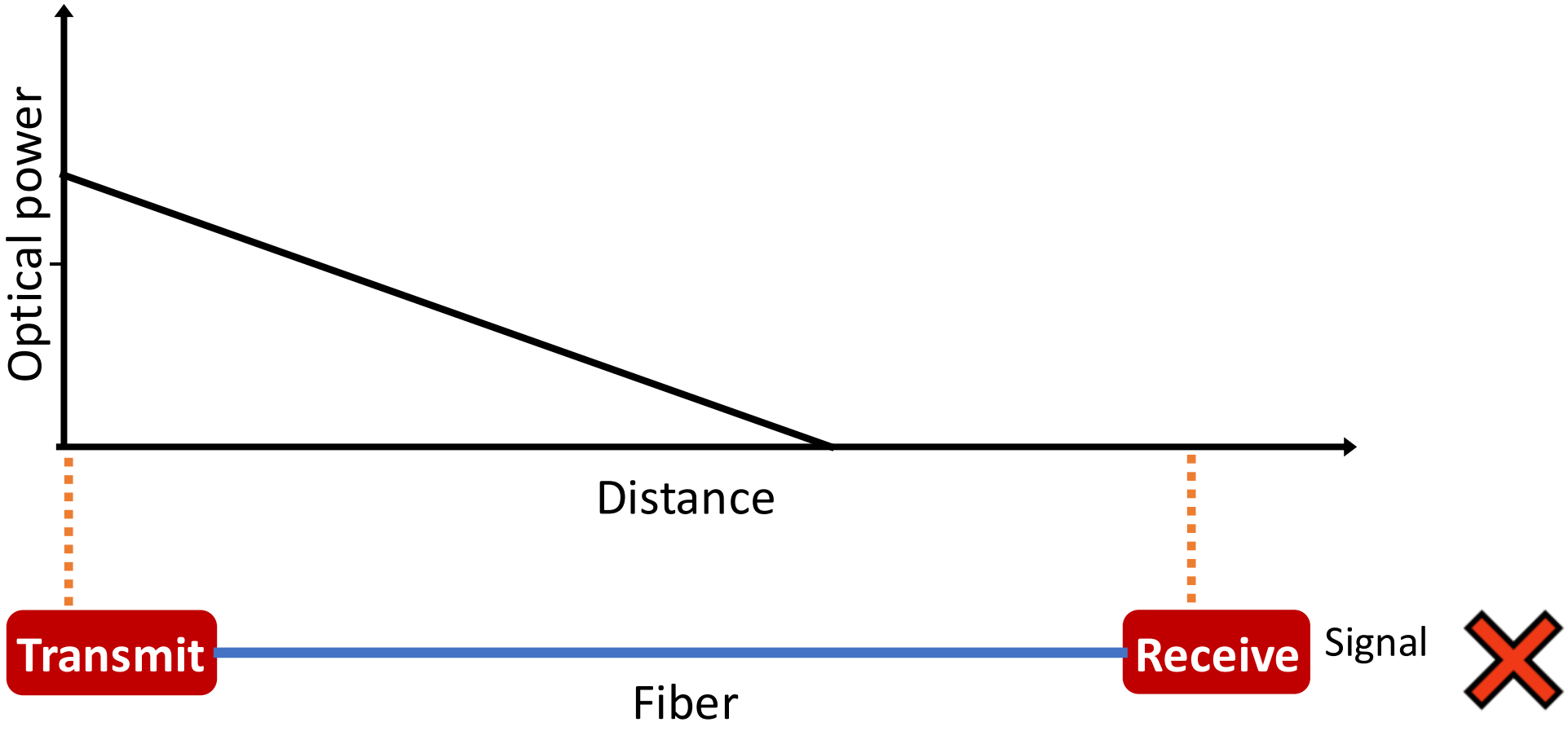

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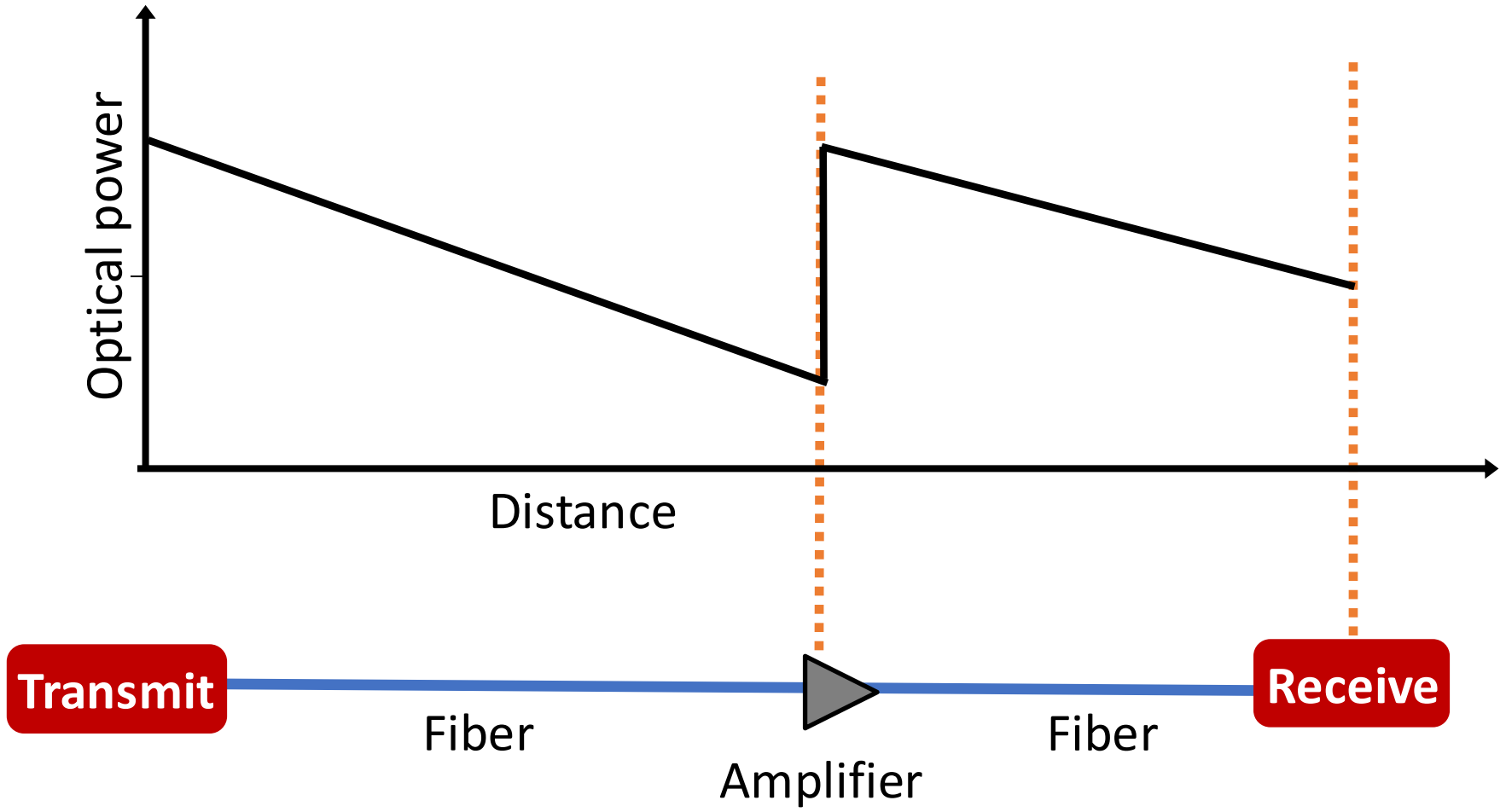

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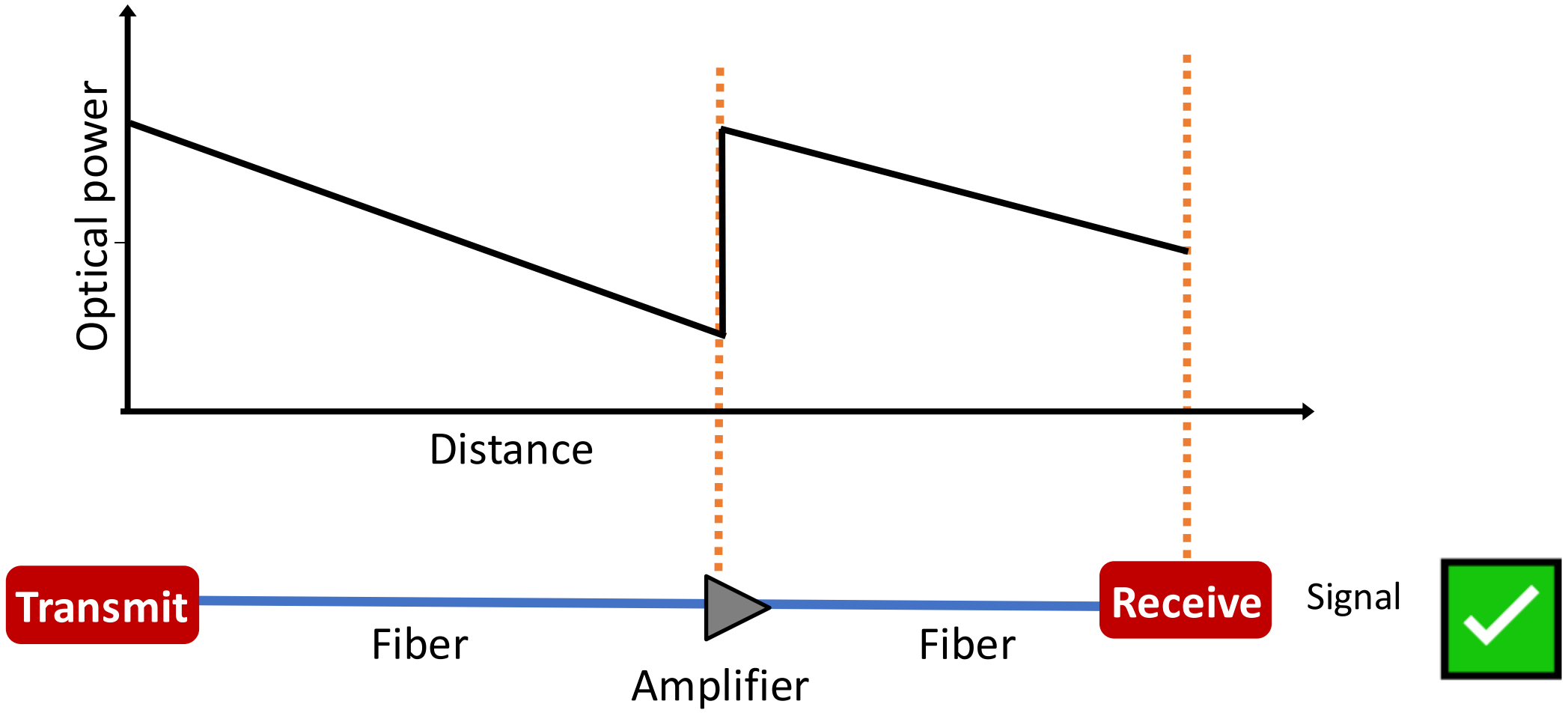

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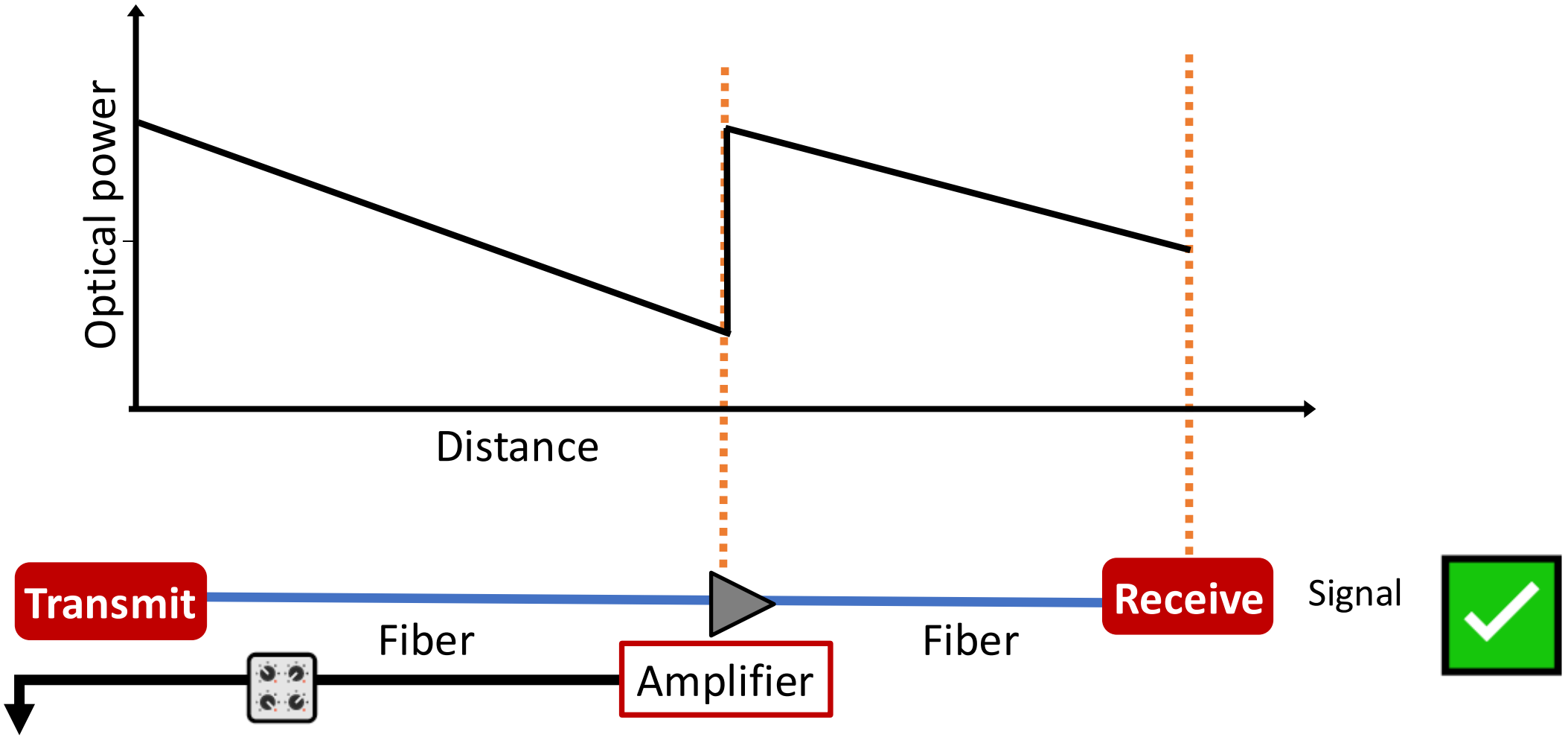
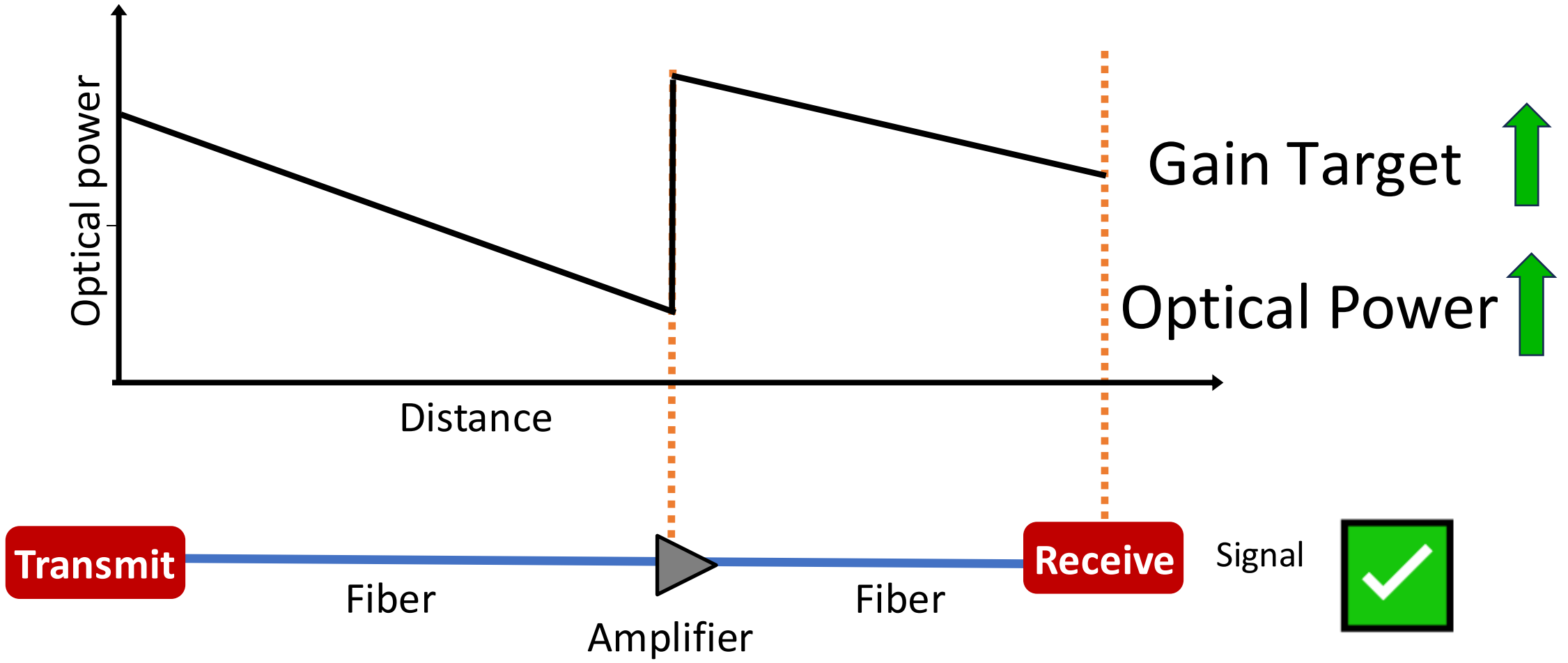



Gain target: controls how much the amplifier boosts the signal

# Amplifier gains shape the signal power across the WAN



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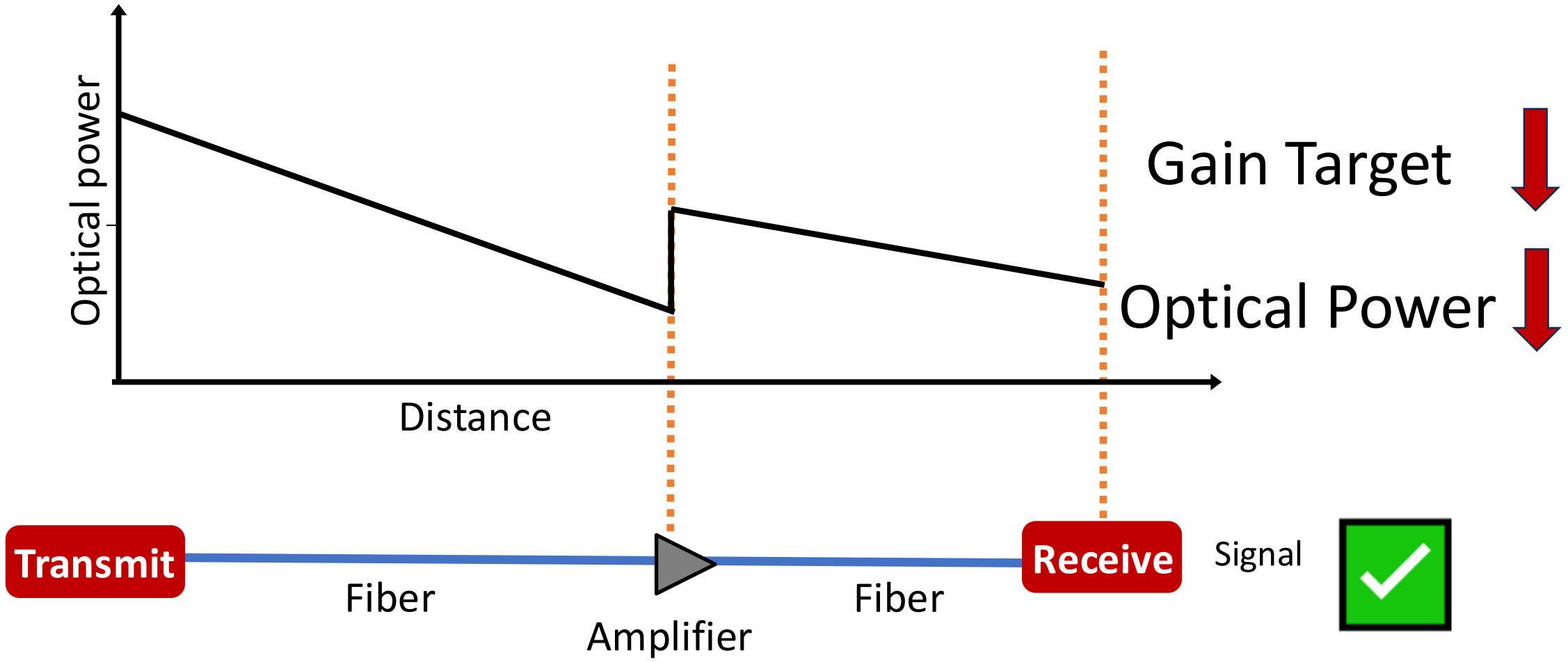
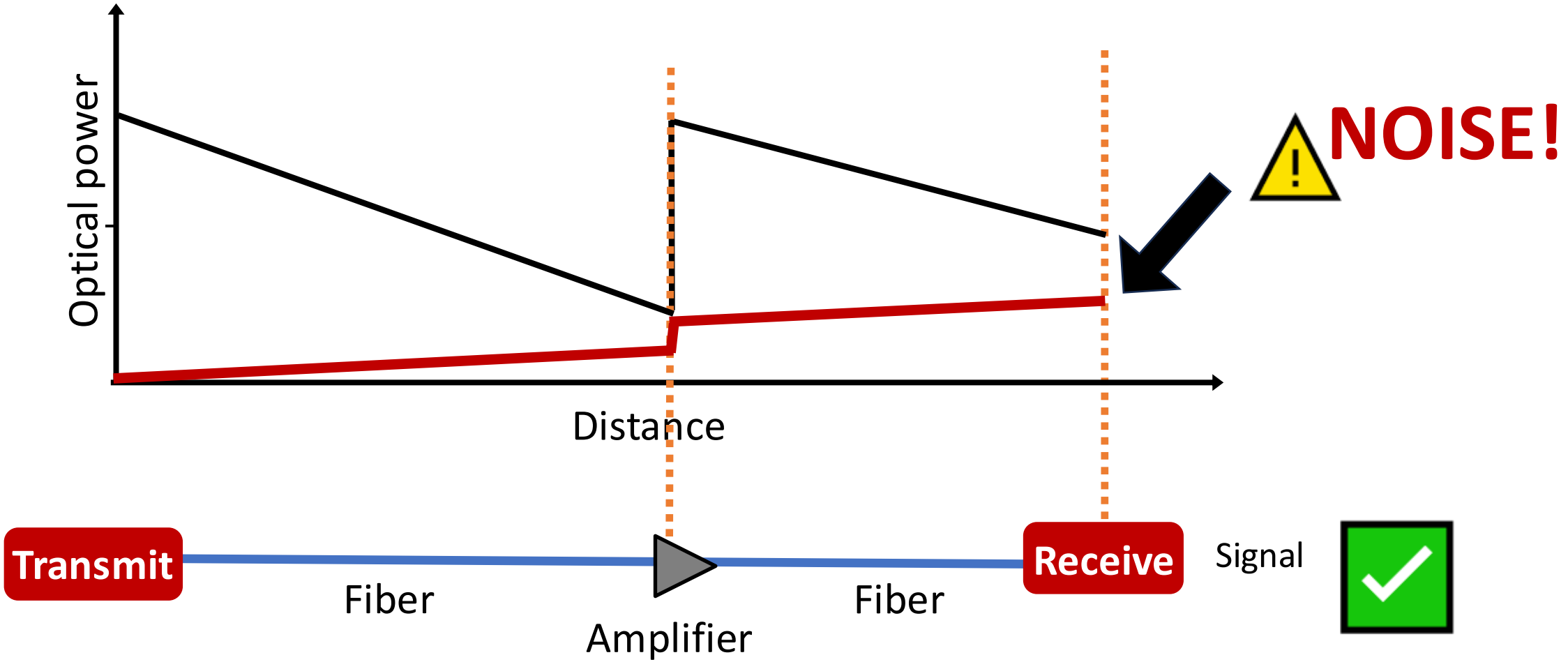


# Noise gets accumulated over the path



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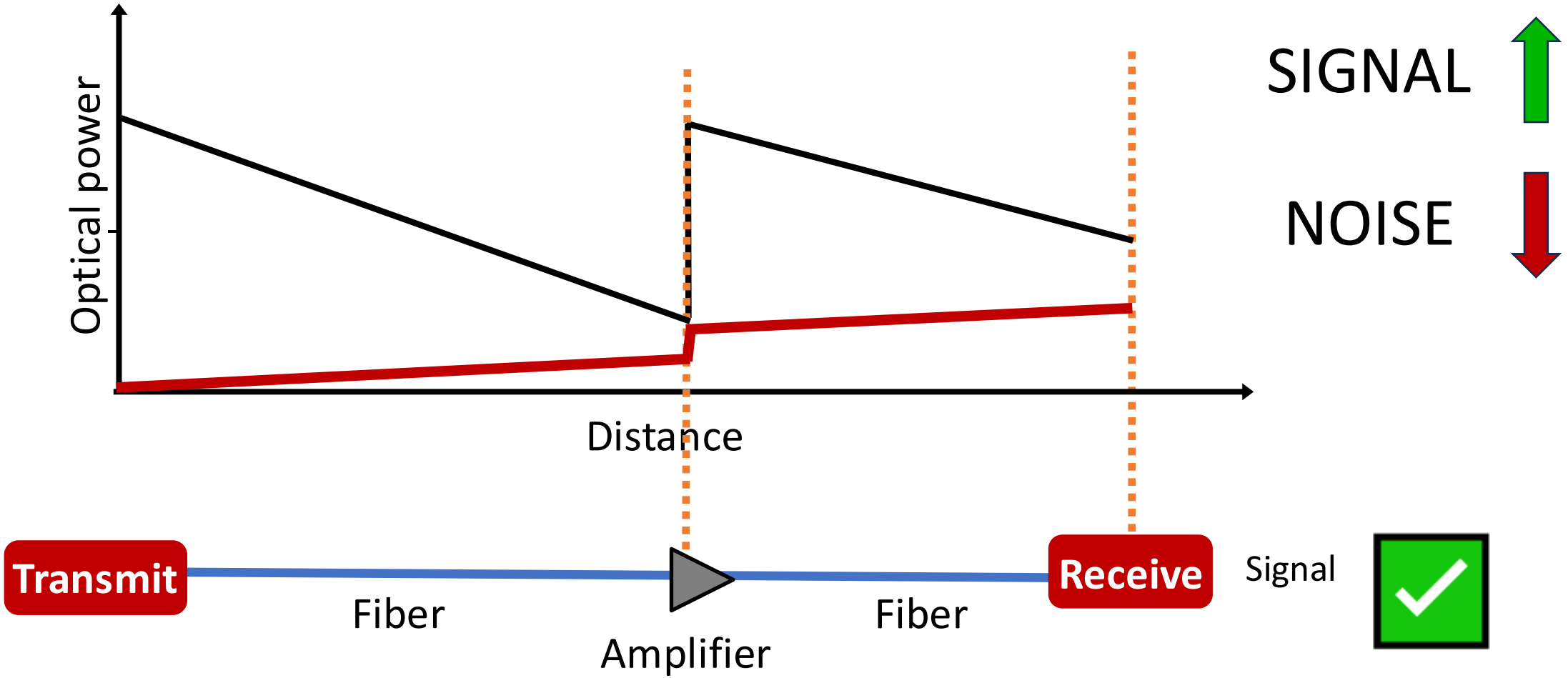
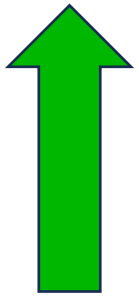


# Higher SNR = Higher Bandwidth

Signal to Noise Ratio (SNR)



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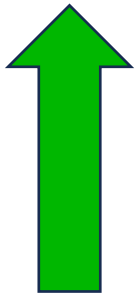
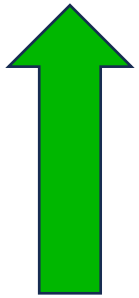


Better data encoding



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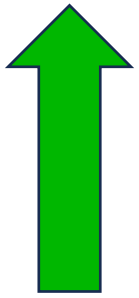

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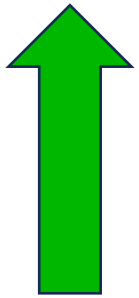
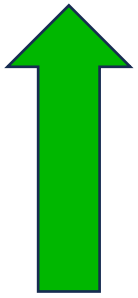


**Higher Bandwidth!**



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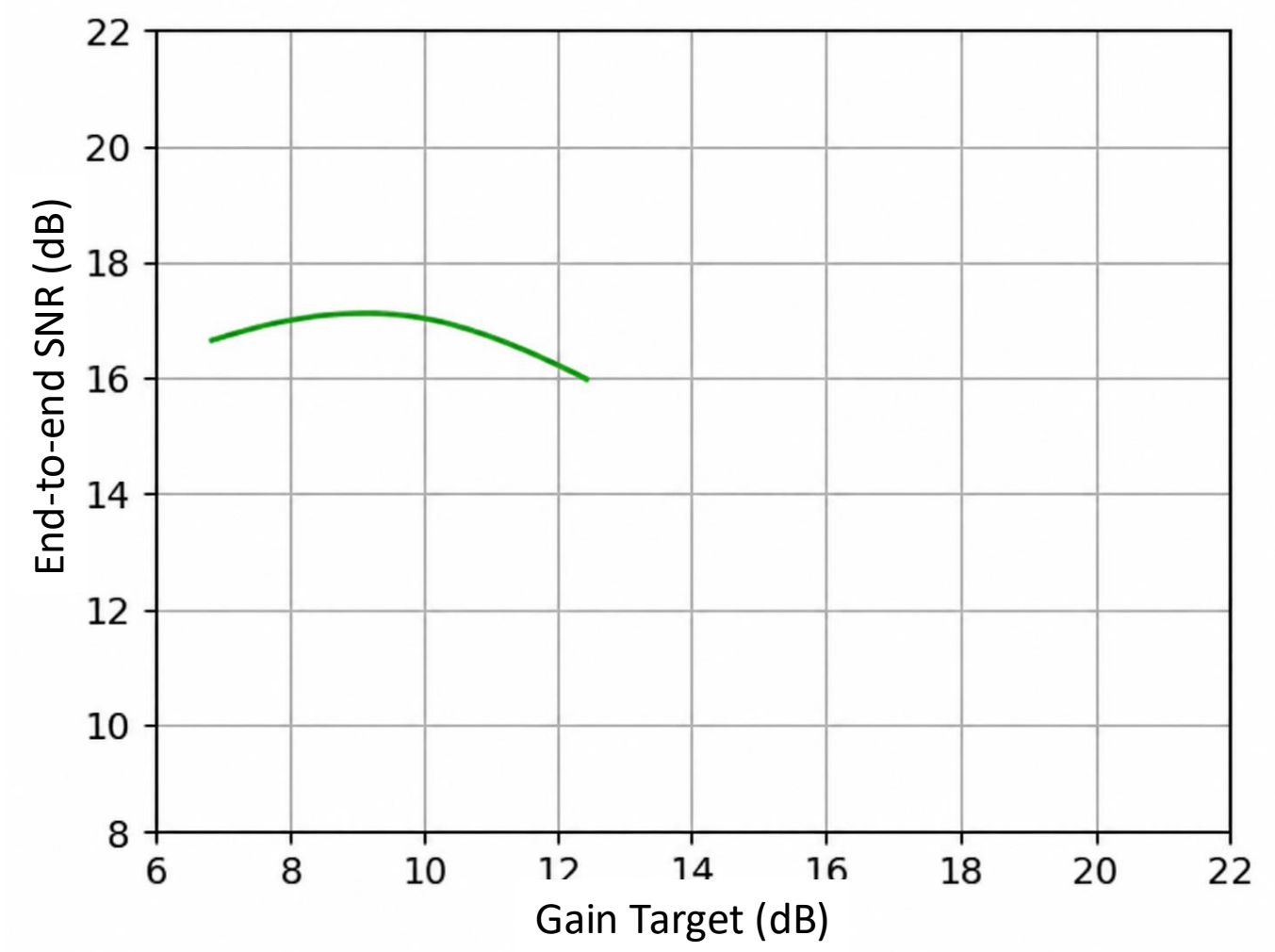

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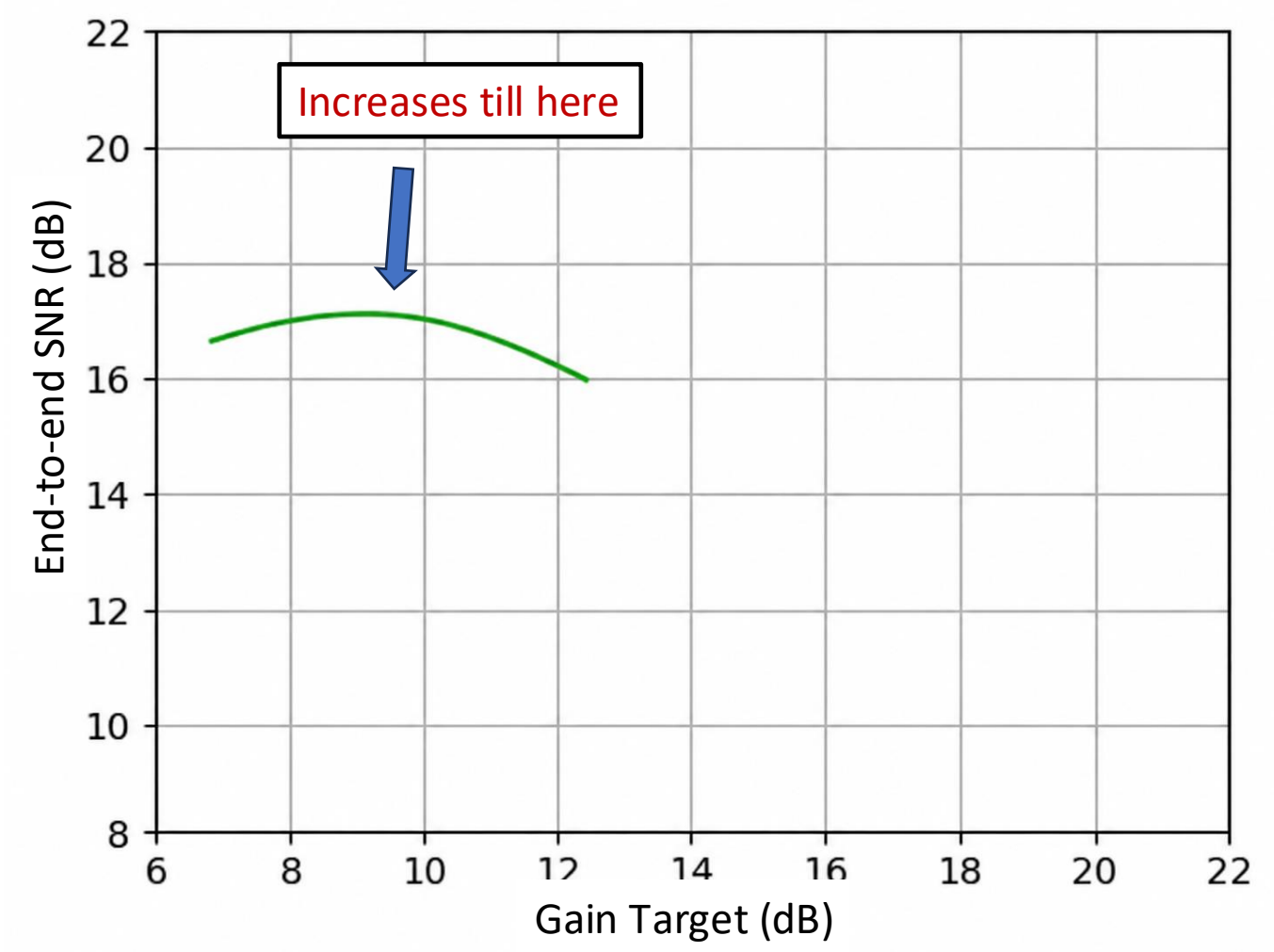

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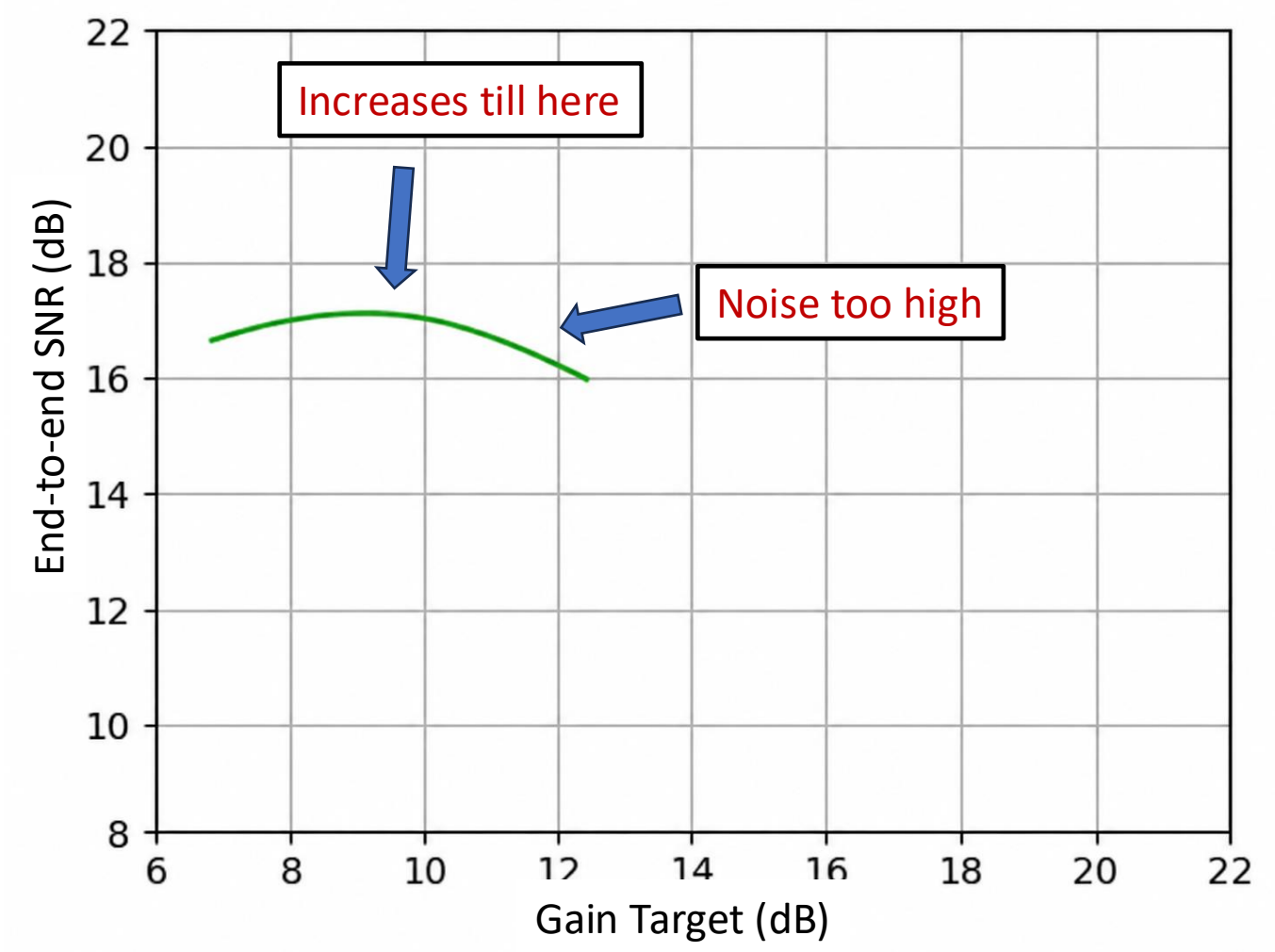
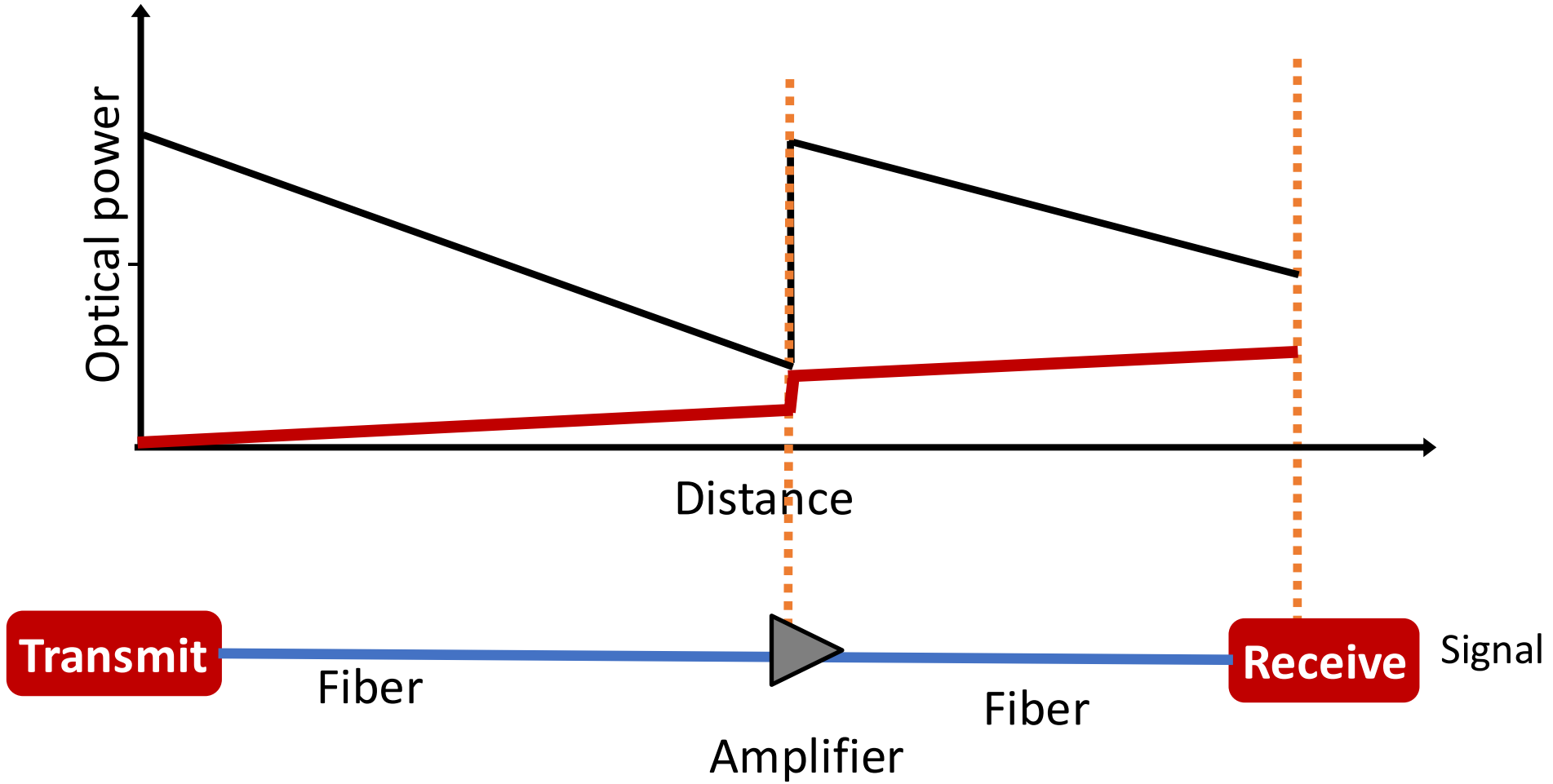


# Tuning amplifier gain is a peak finding optimization problem



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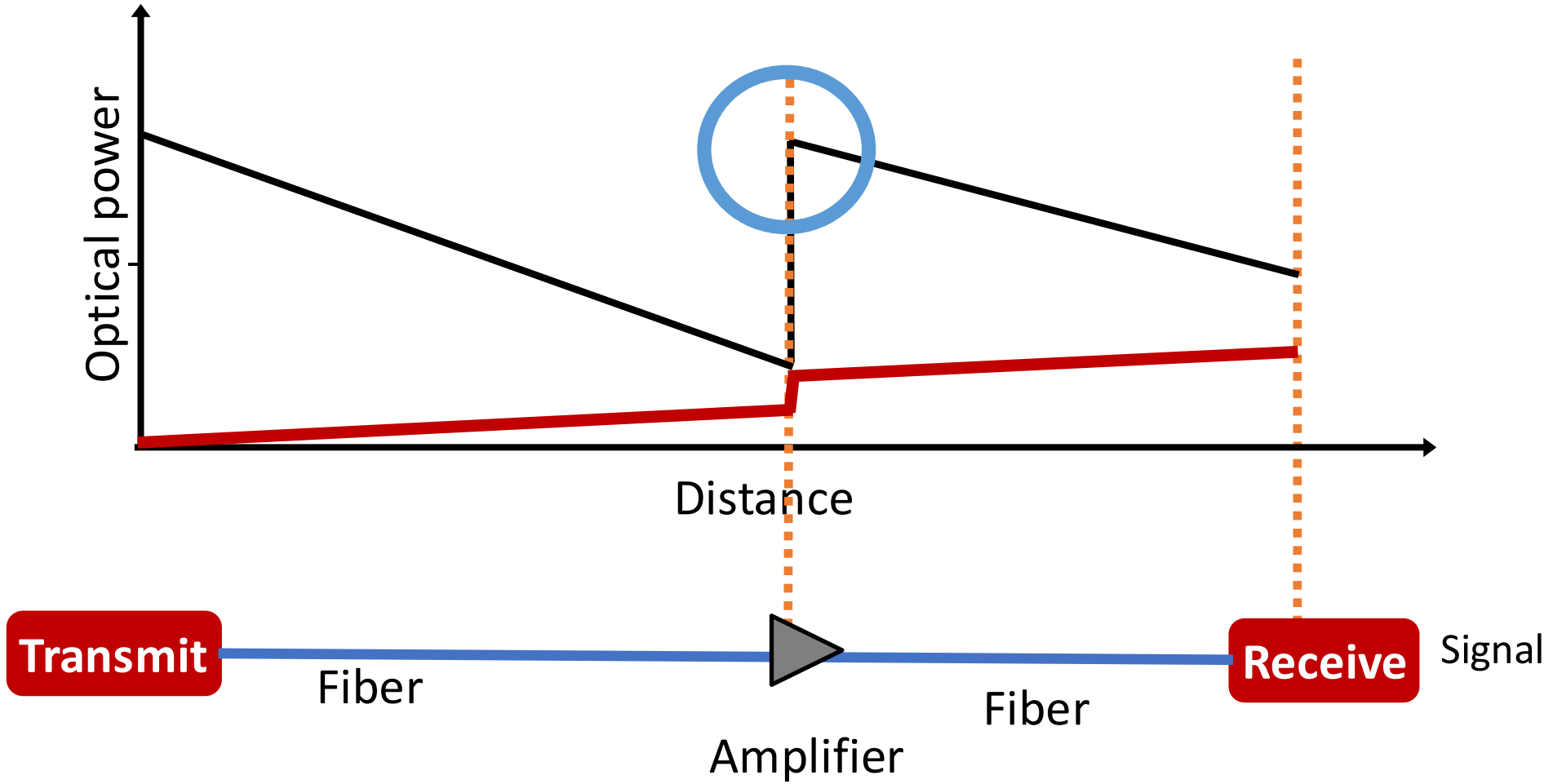

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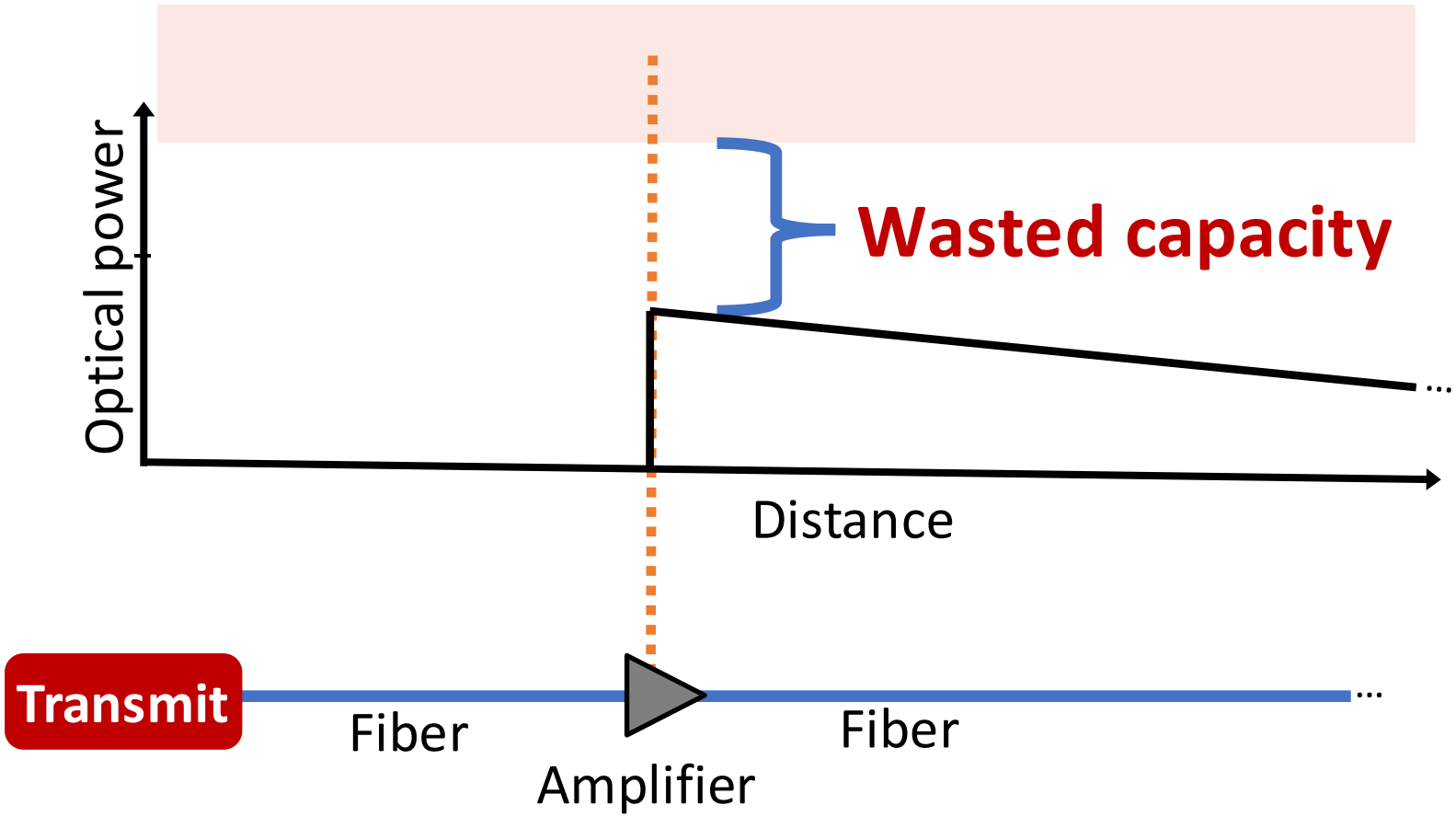

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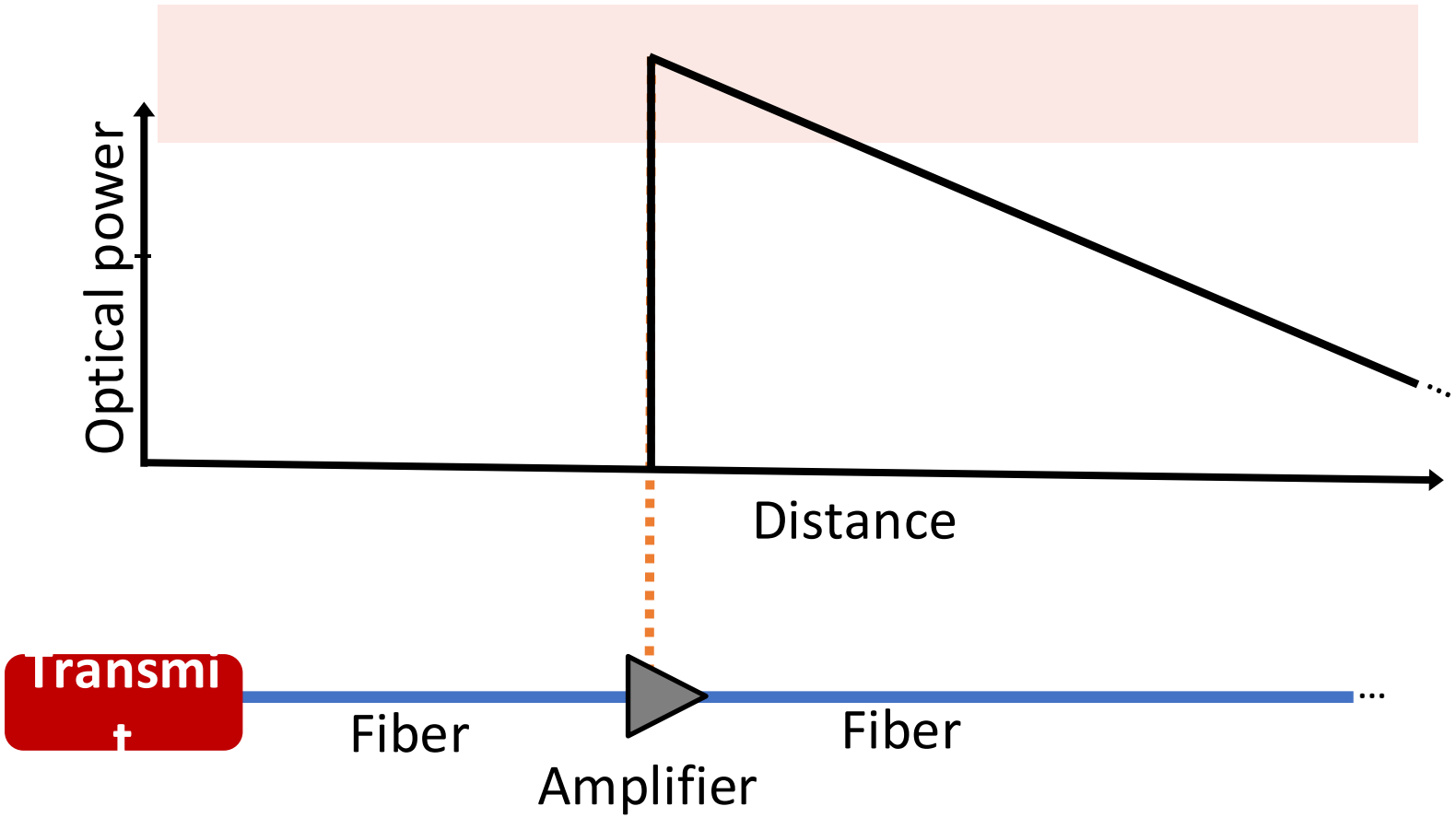

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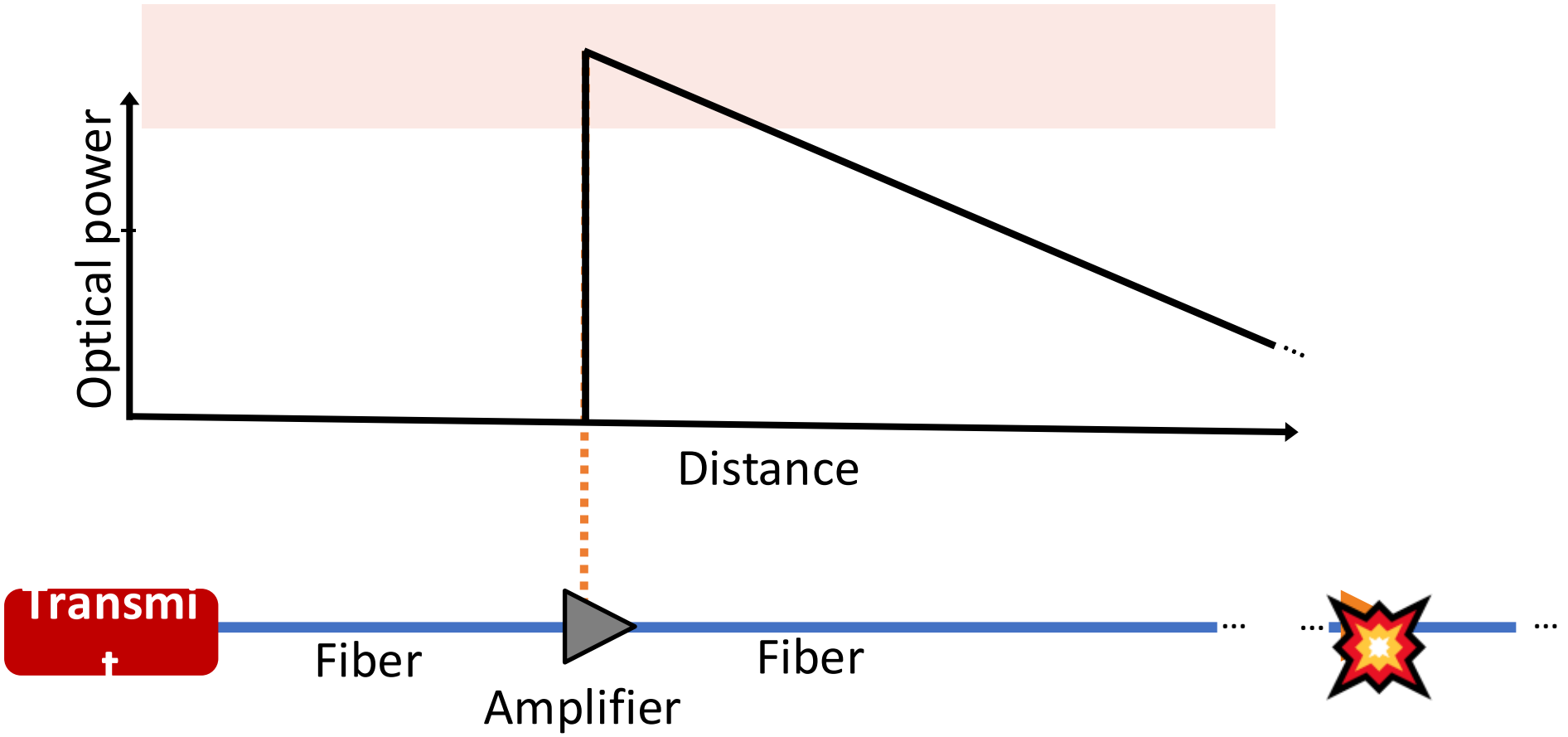

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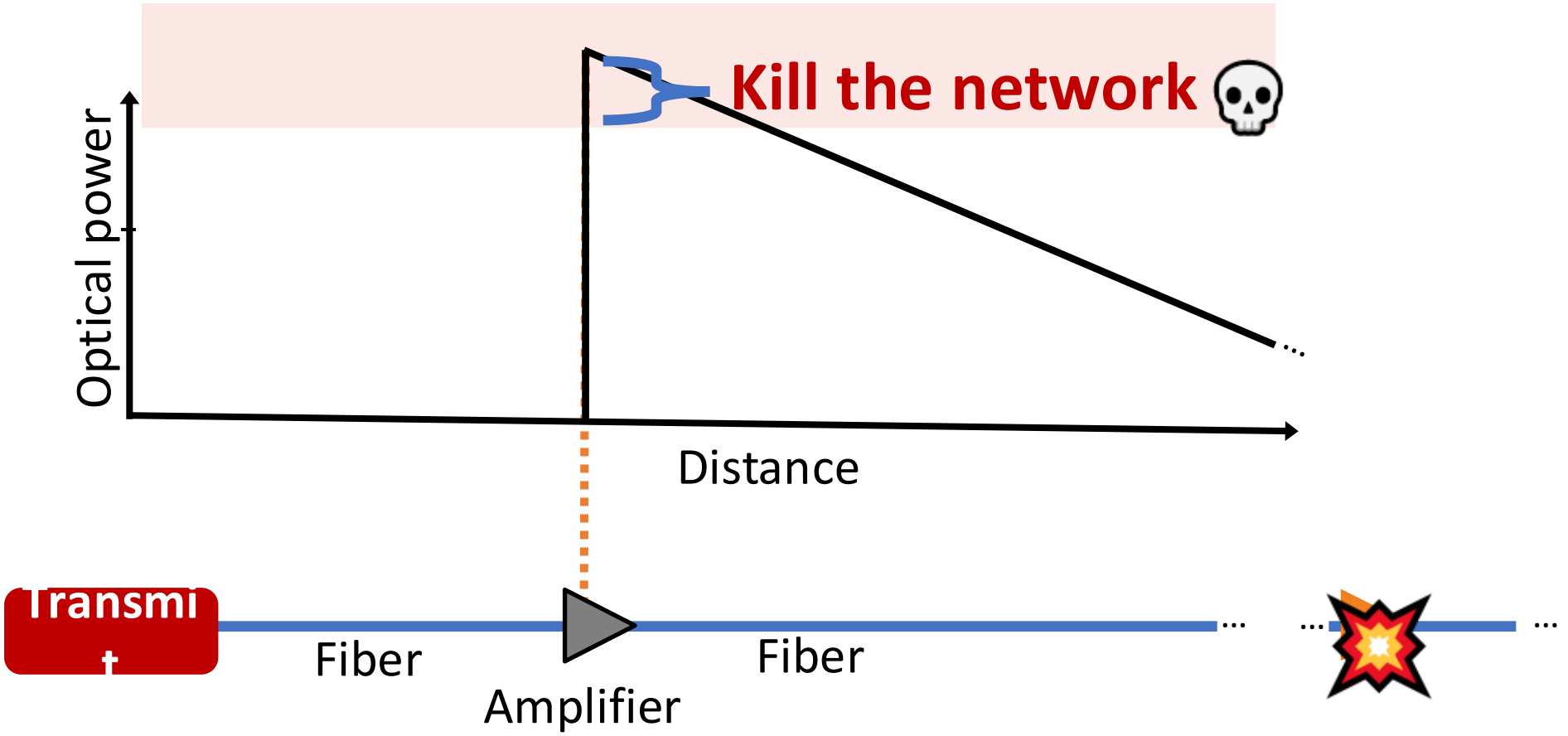
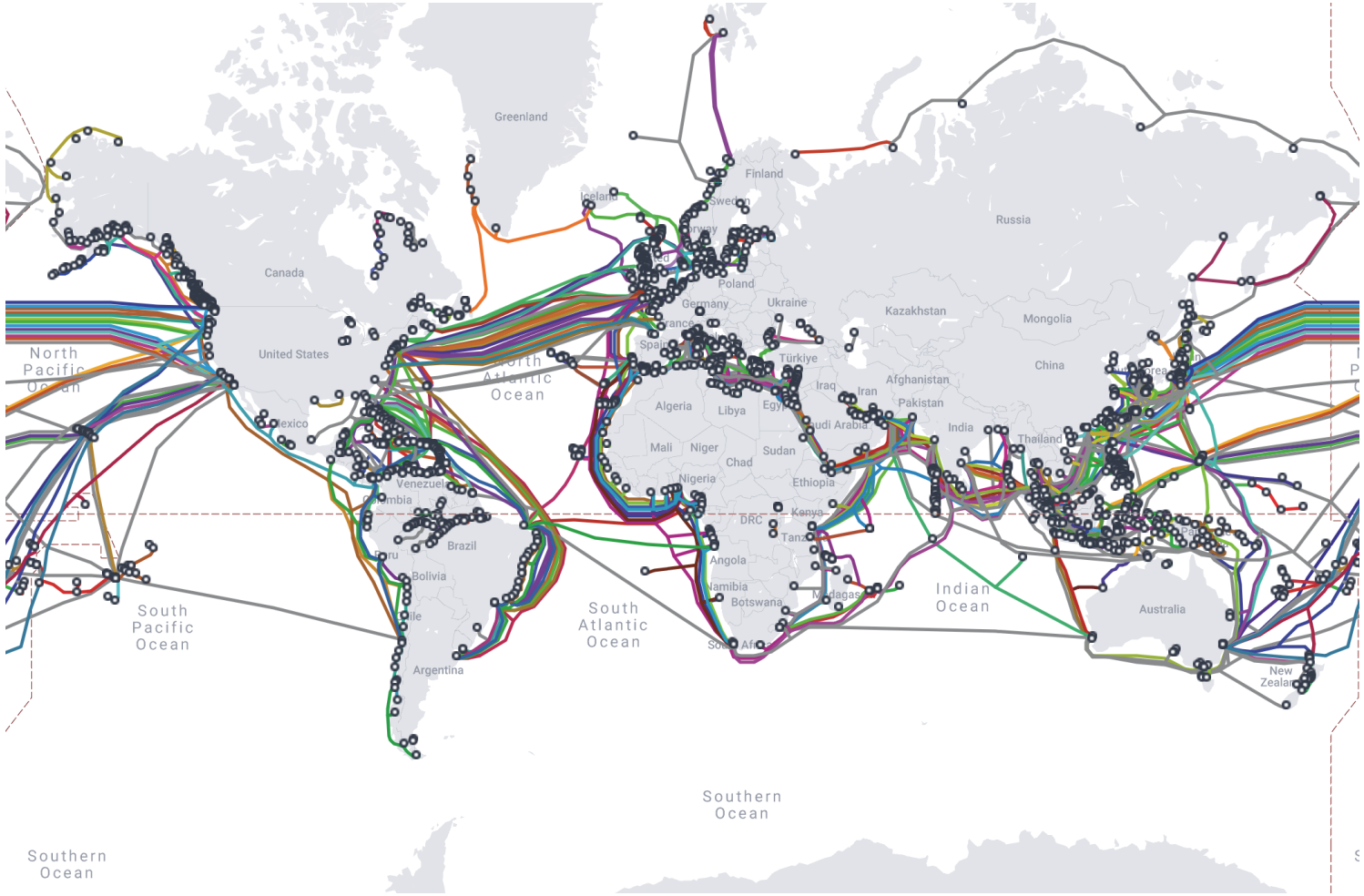


# Number of amplifiers required depends on the length of the network



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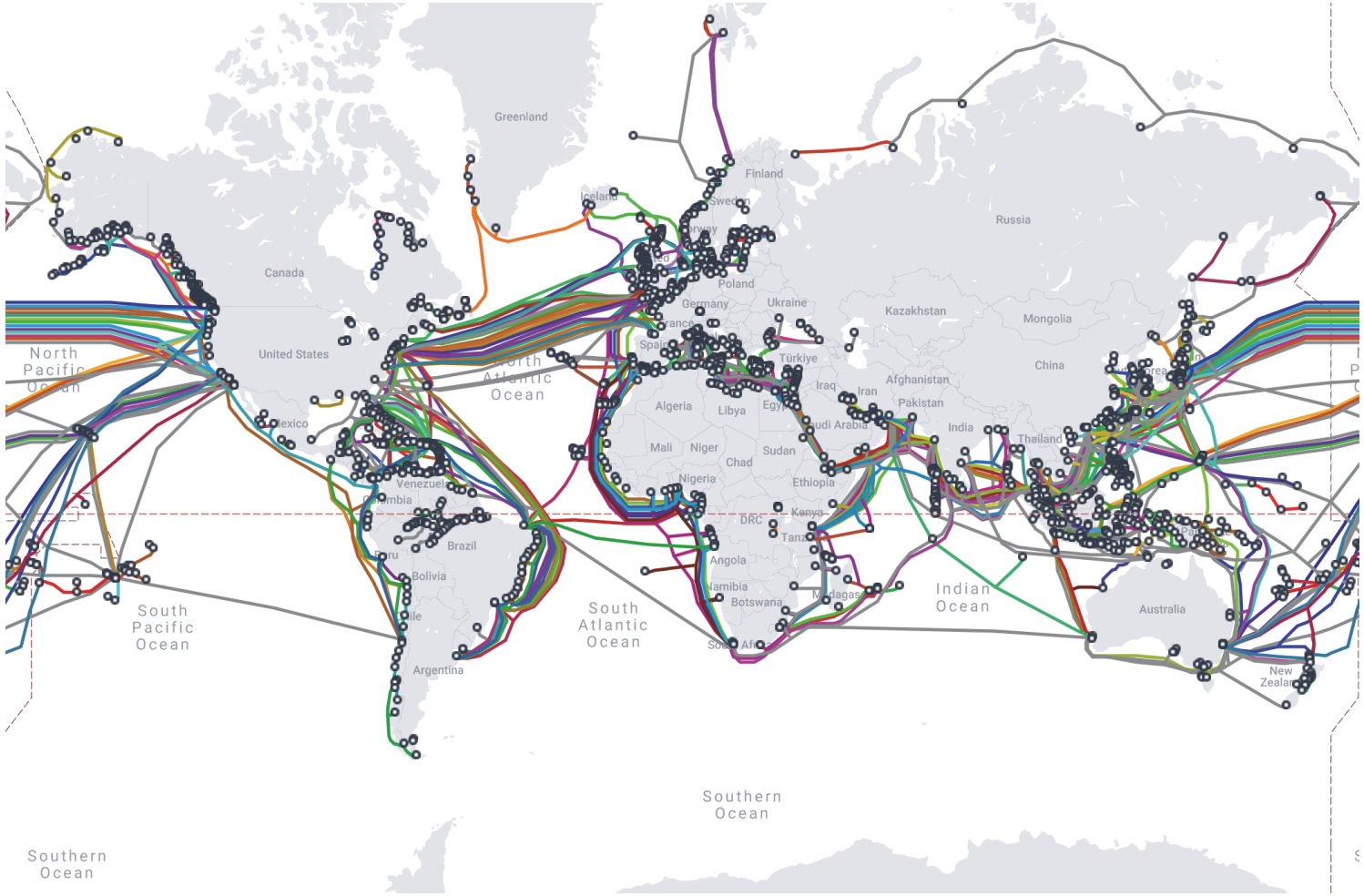


Longest optical fiber system

45000 KM

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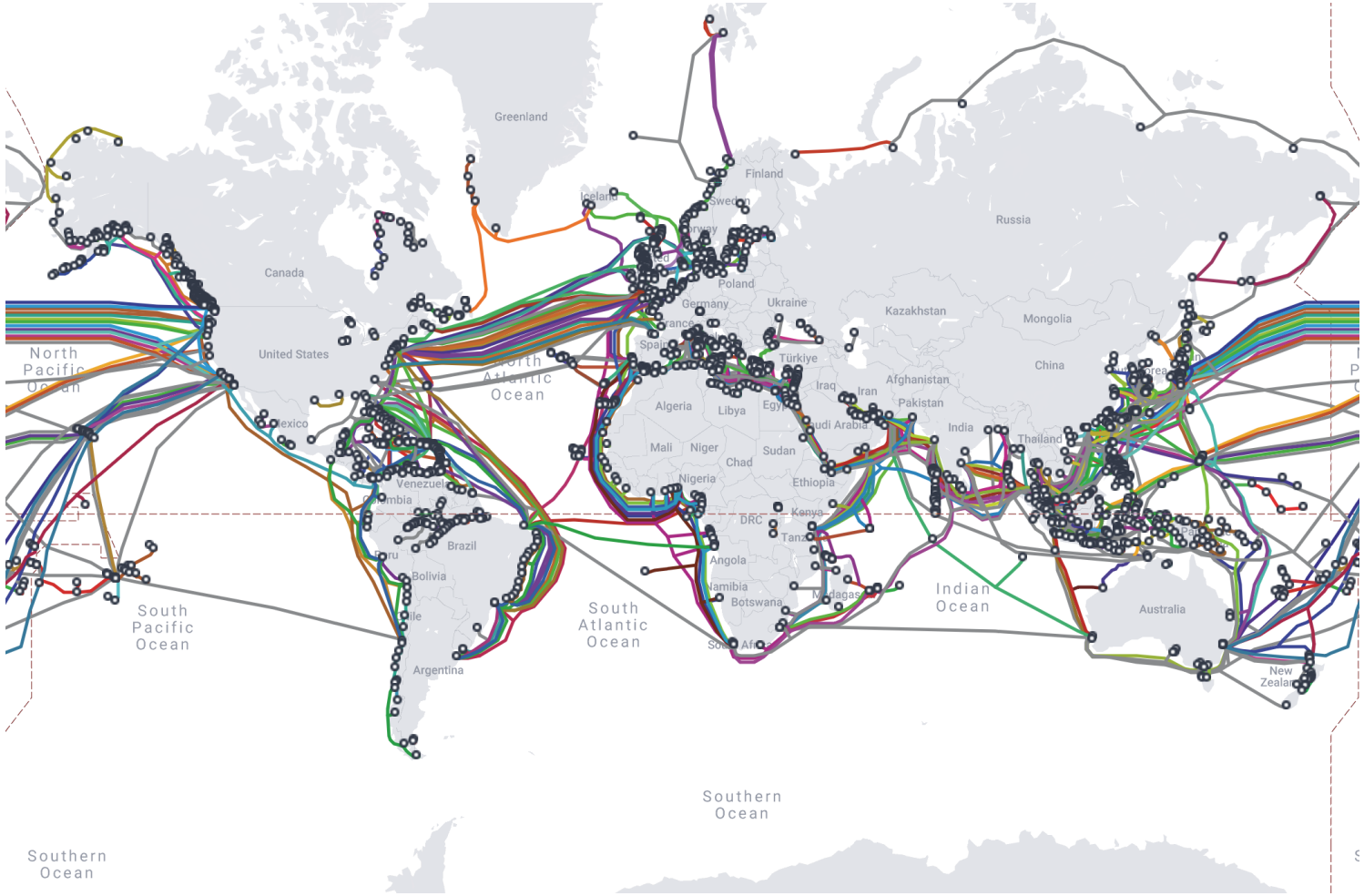


Longest optical fiber system
45000 KM

Need an amplifier every
50-100 KM

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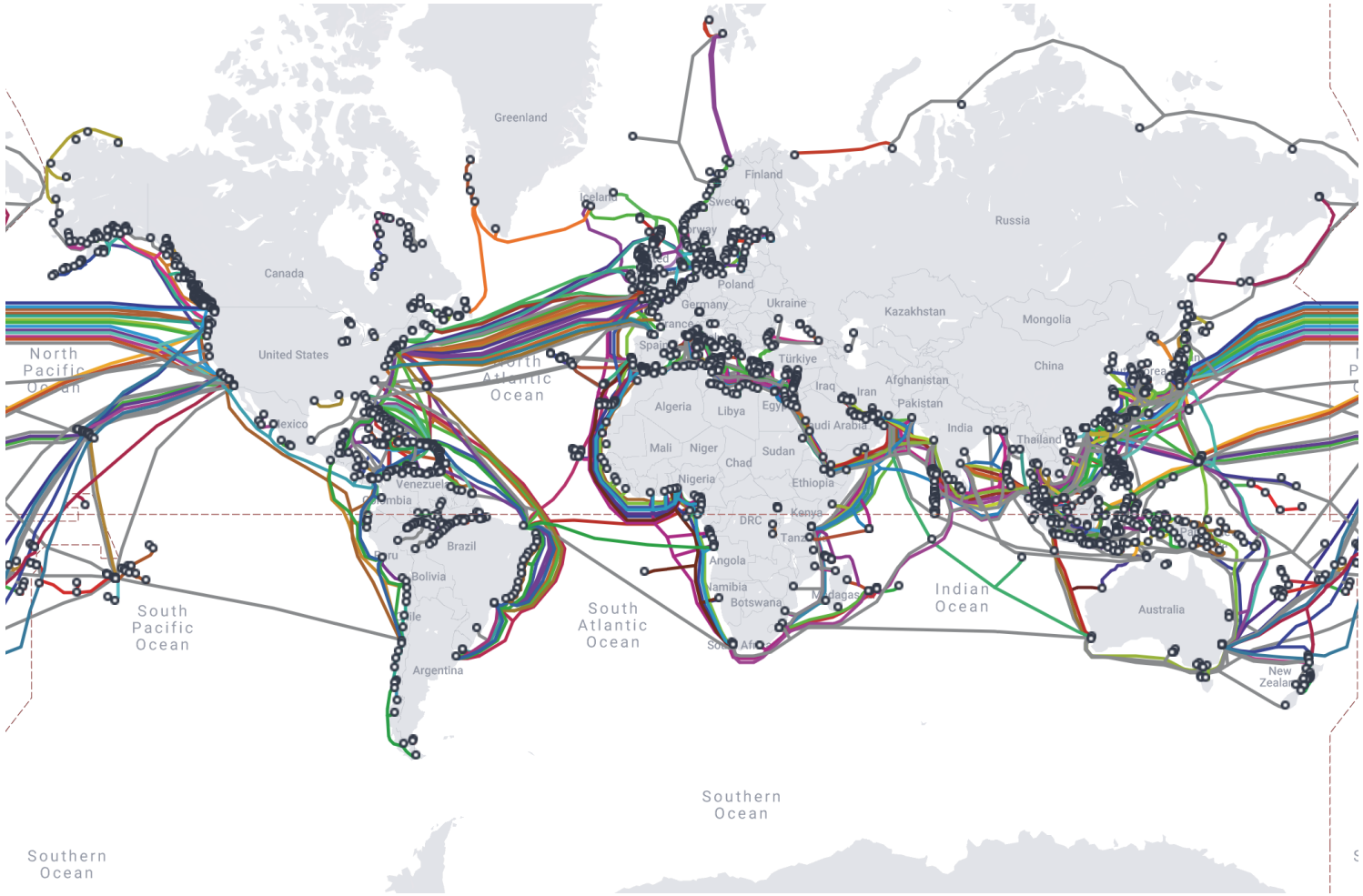
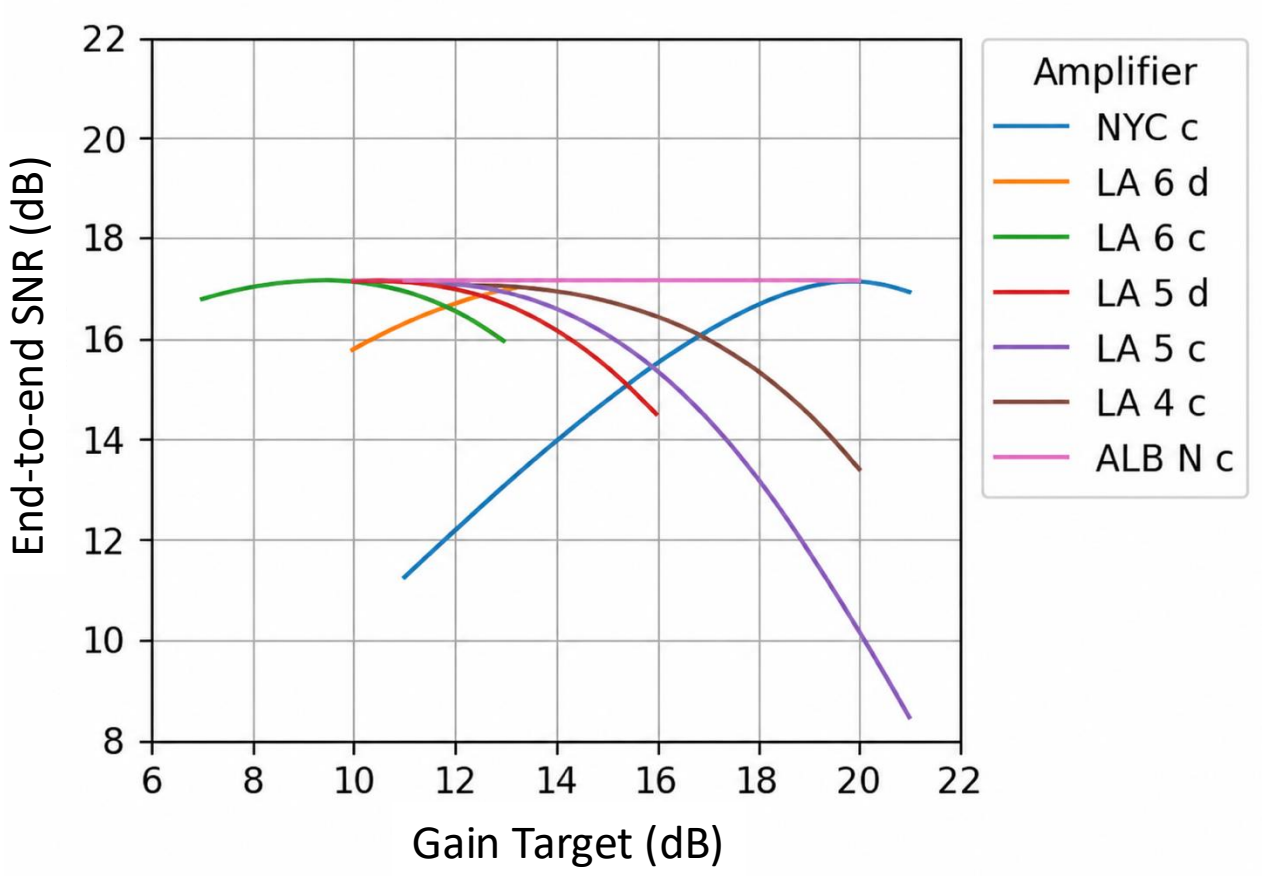



Longest optical fiber system
45000 KM

Need an amplifier every
50-100 KM

Required number of amplifiers
At least 450

# Different amplifiers have different profiles




**Takeaway:** Different amplifiers reach max end to end SNR at different gain values

# More issues with tuning the optical network

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- **Lots of different vendors –** with proprietary configurations







# More issues with tuning the optical network

- **Lots of different vendors –** with proprietary configurations

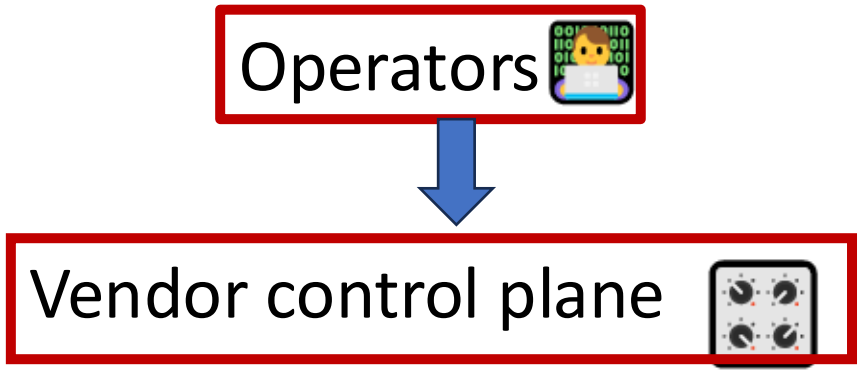
- **Different types of amplifiers –** EDFA, Raman etc.

# Finding the peak end to end SNR on a optical WAN is hard

Operators 

Vendor control plane 

# Finding the peak end to end SNR on a optical WAN is hard



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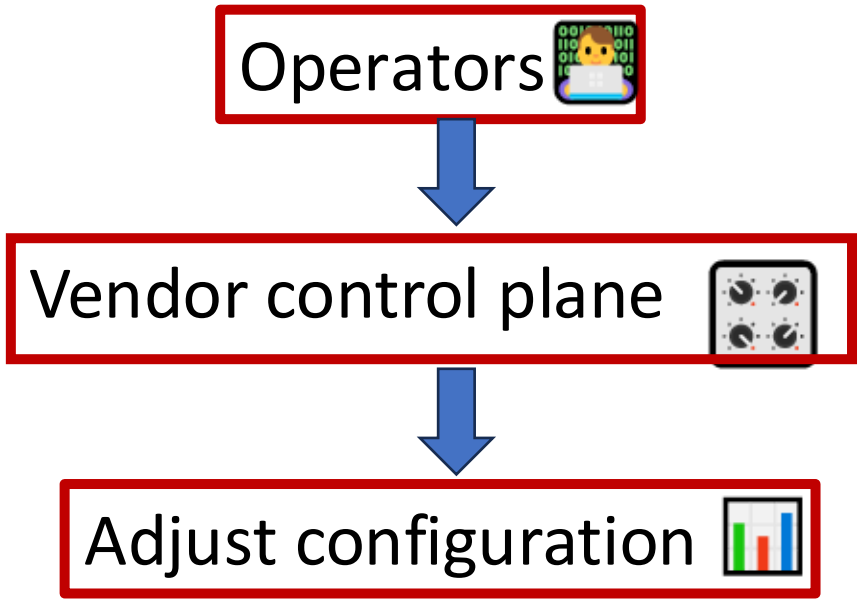

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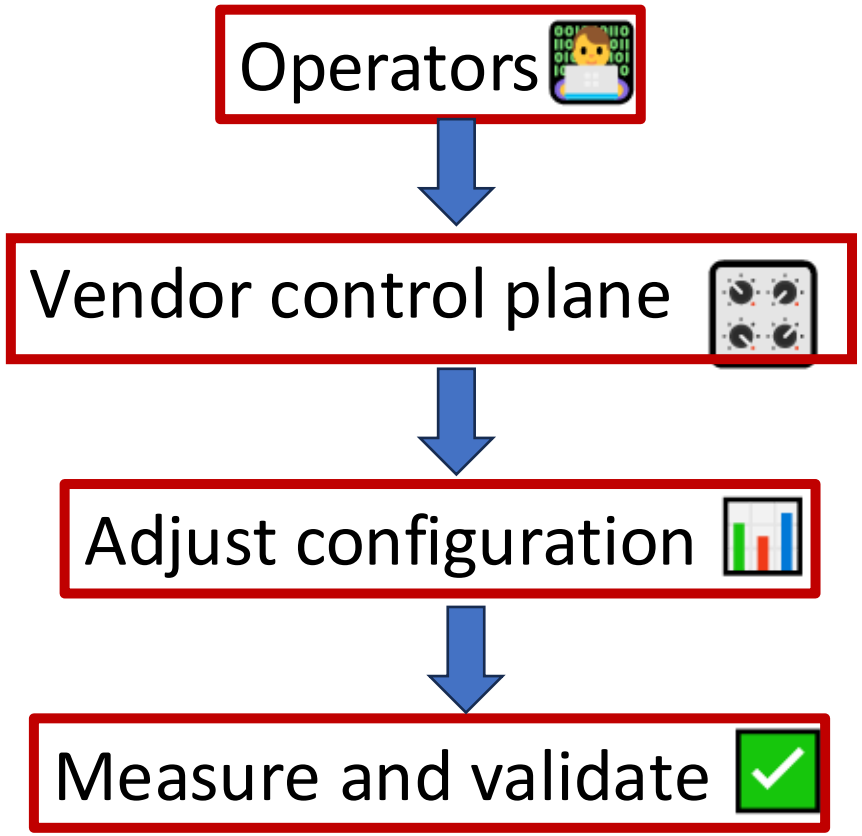

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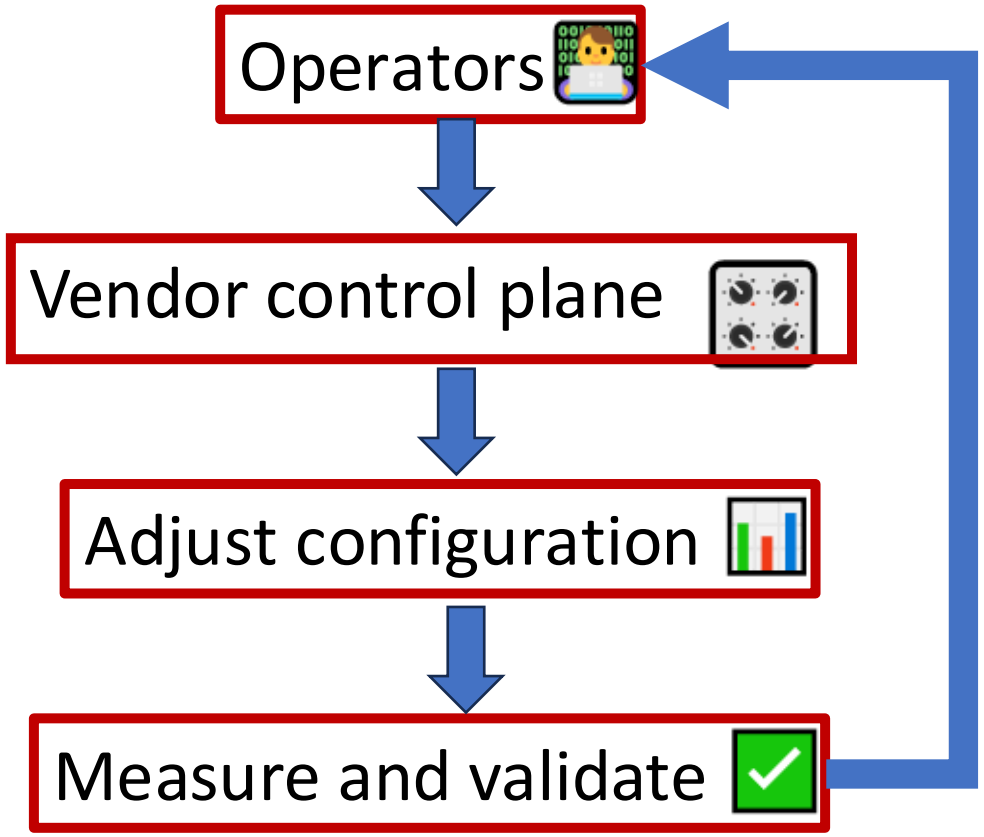

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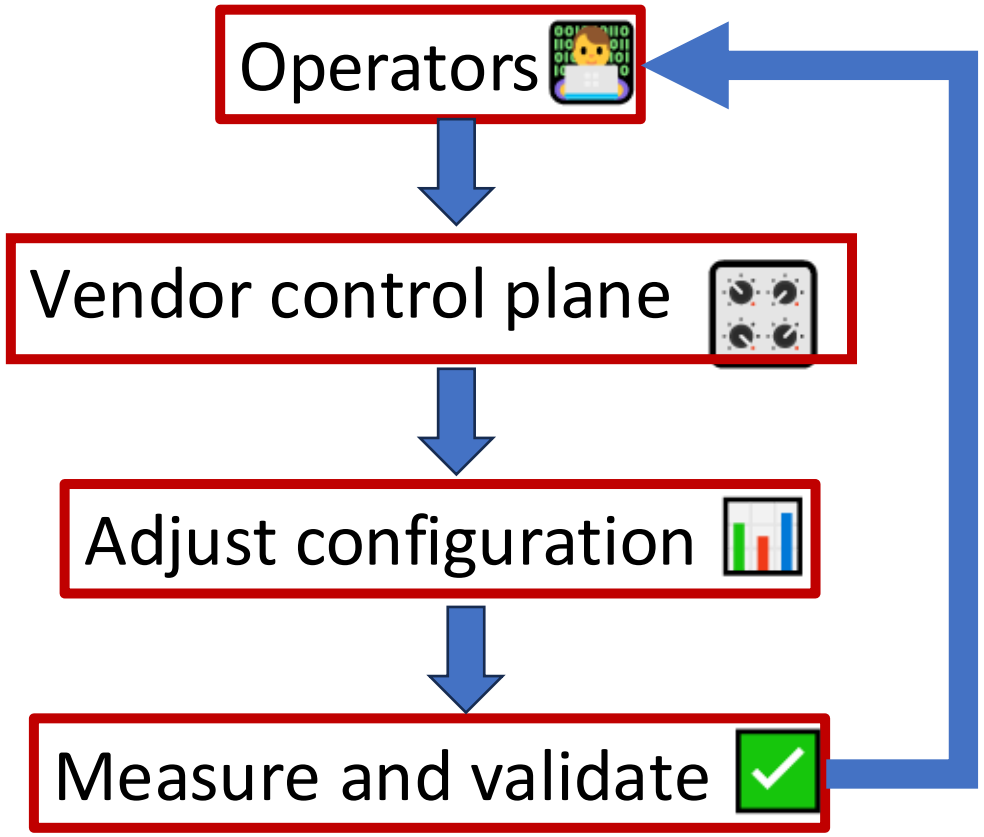


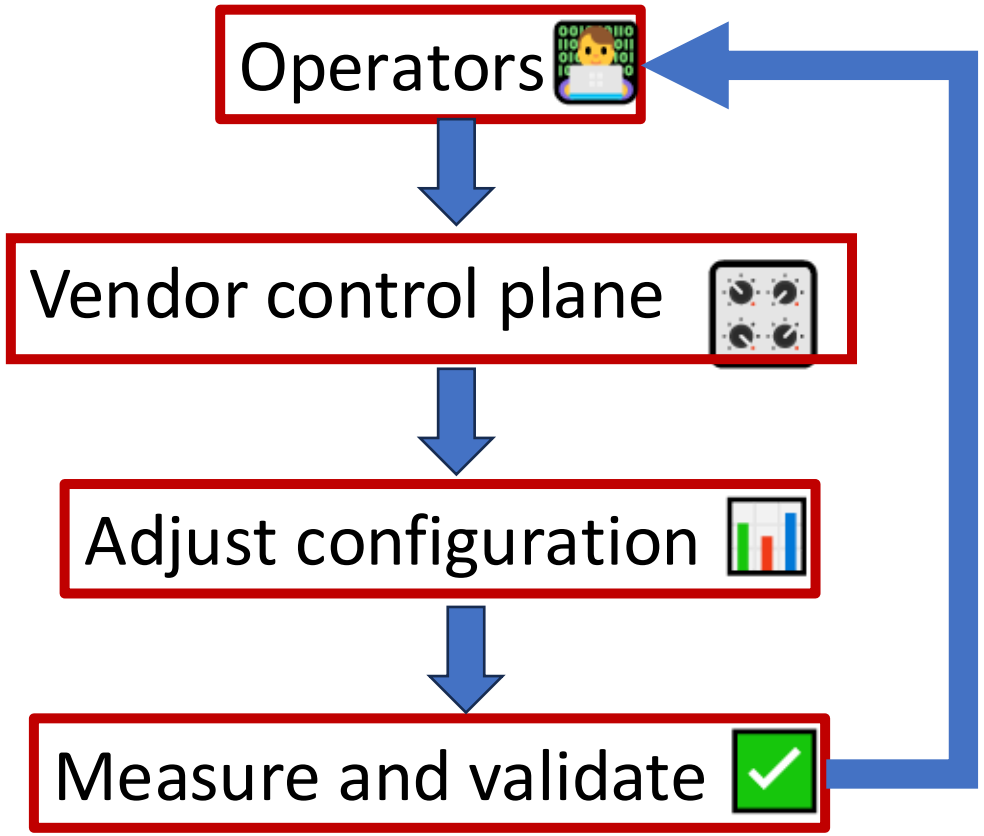

## Slow

Adjust and validate

## Risky

Network might go down

# Finding the peak end to end SNR on a optical WAN is hard




## Slow

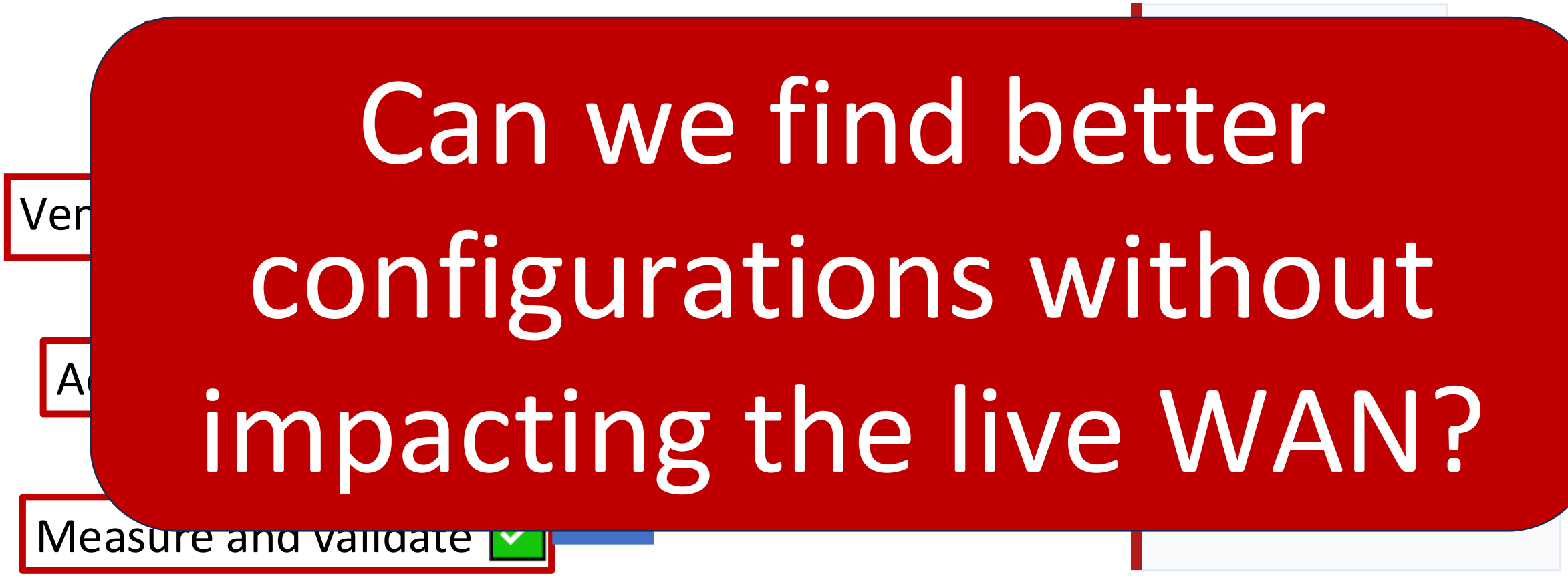
Adjust and validate

## Risky

Network might go down

**Leaves optimization opportunity on the table**

## Finding the peak end to end SNR on a optical WAN is hard




Can we find better configurations without impacting the live WAN?

Leaves optimization opportunity on the table

# Talk outline

# Talk outline

1

## The network

NYSERnet's production optical backbone

# Talk outline

1

## The network

NYSERnet's production optical backbone

2

## Modeling the network

Modeling with real heterogeneous gear

# Talk outline

1

## The network

NYSERnet's production optical backbone

2

## Modeling the network

Modeling with real heterogeneous gear

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## Optimization

Opaque-box search over configurations

# Talk outline

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## The network

NYSERnet's production optical backbone

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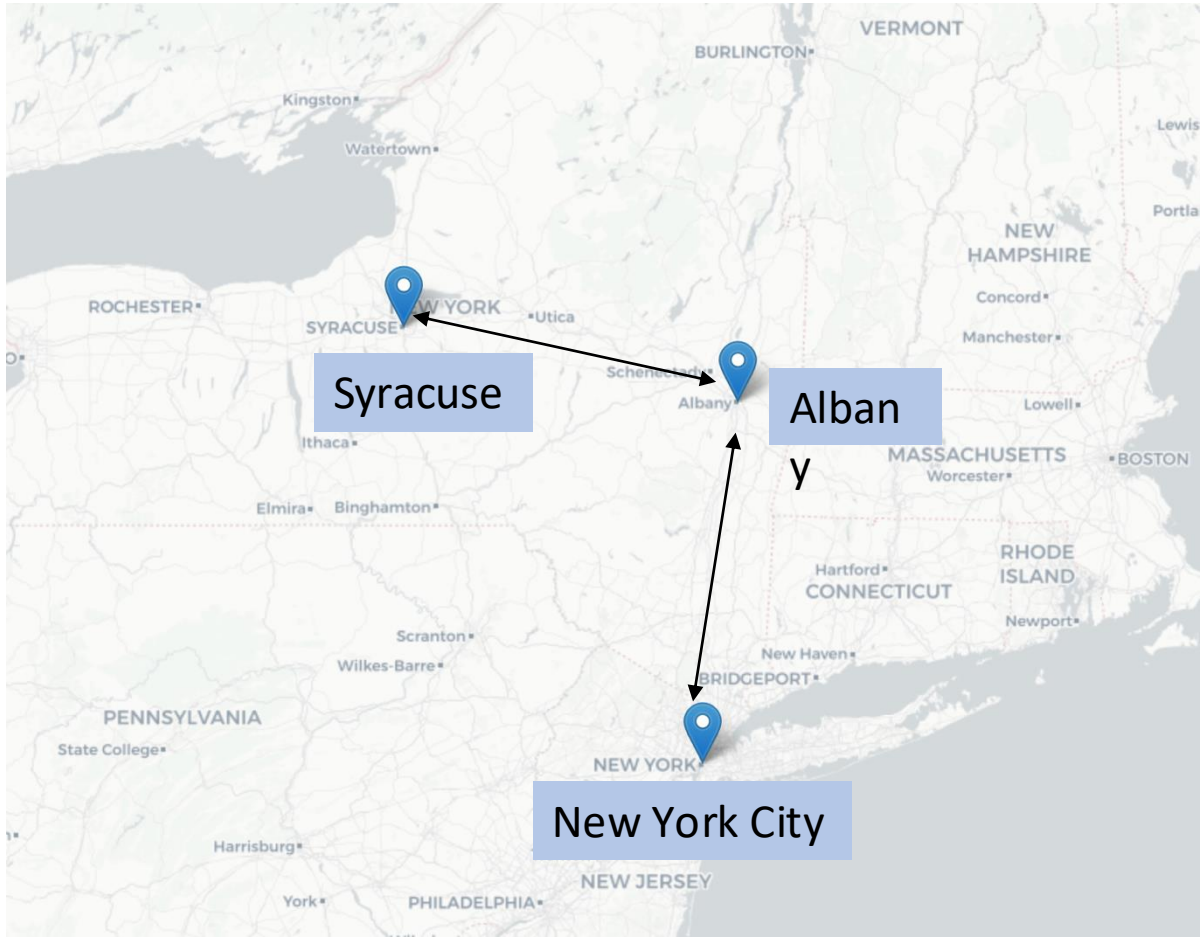
4

## Production deployment & Results

Phased rollout to production

# NYSERnet: a production NY state optical WAN




- Non-profit R&E ISP

Optical paths modeled in this work

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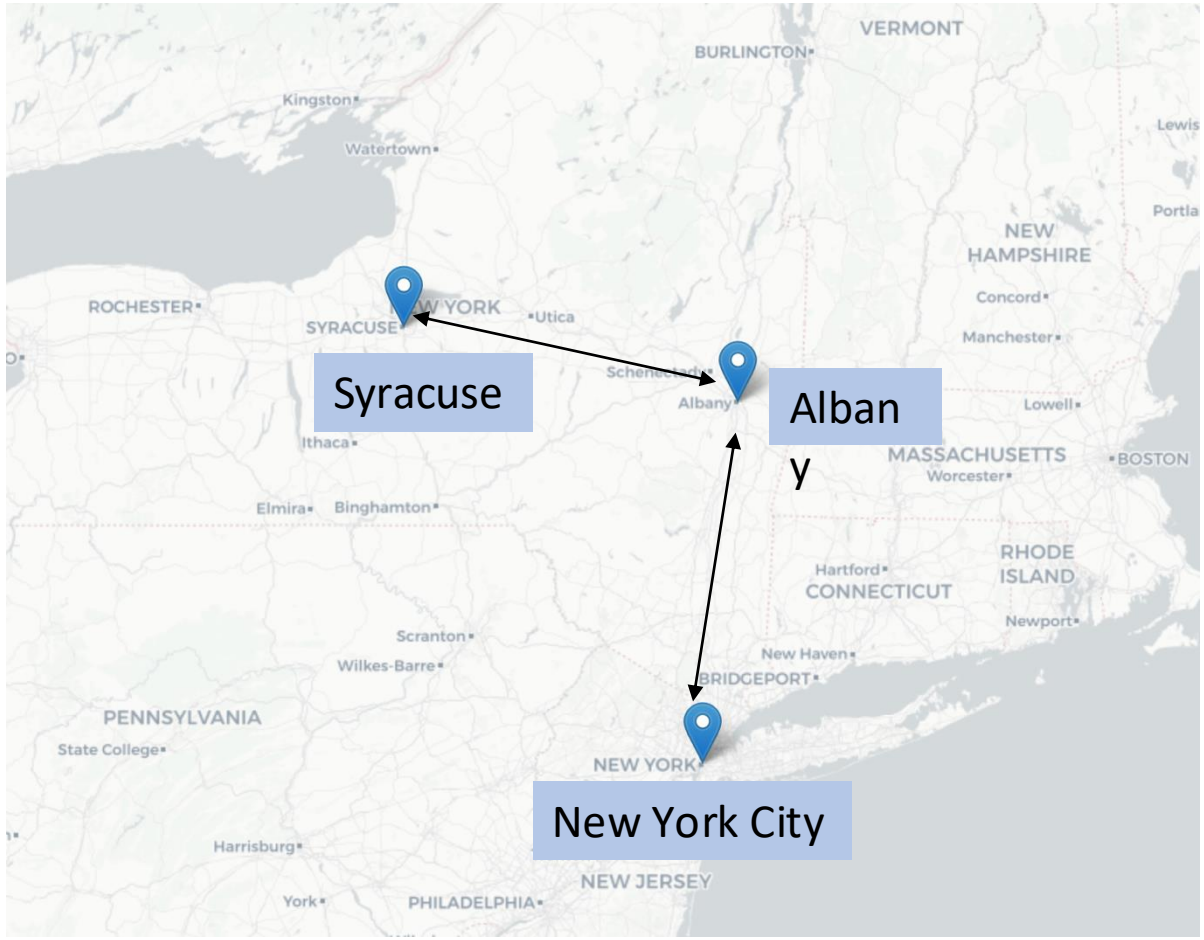
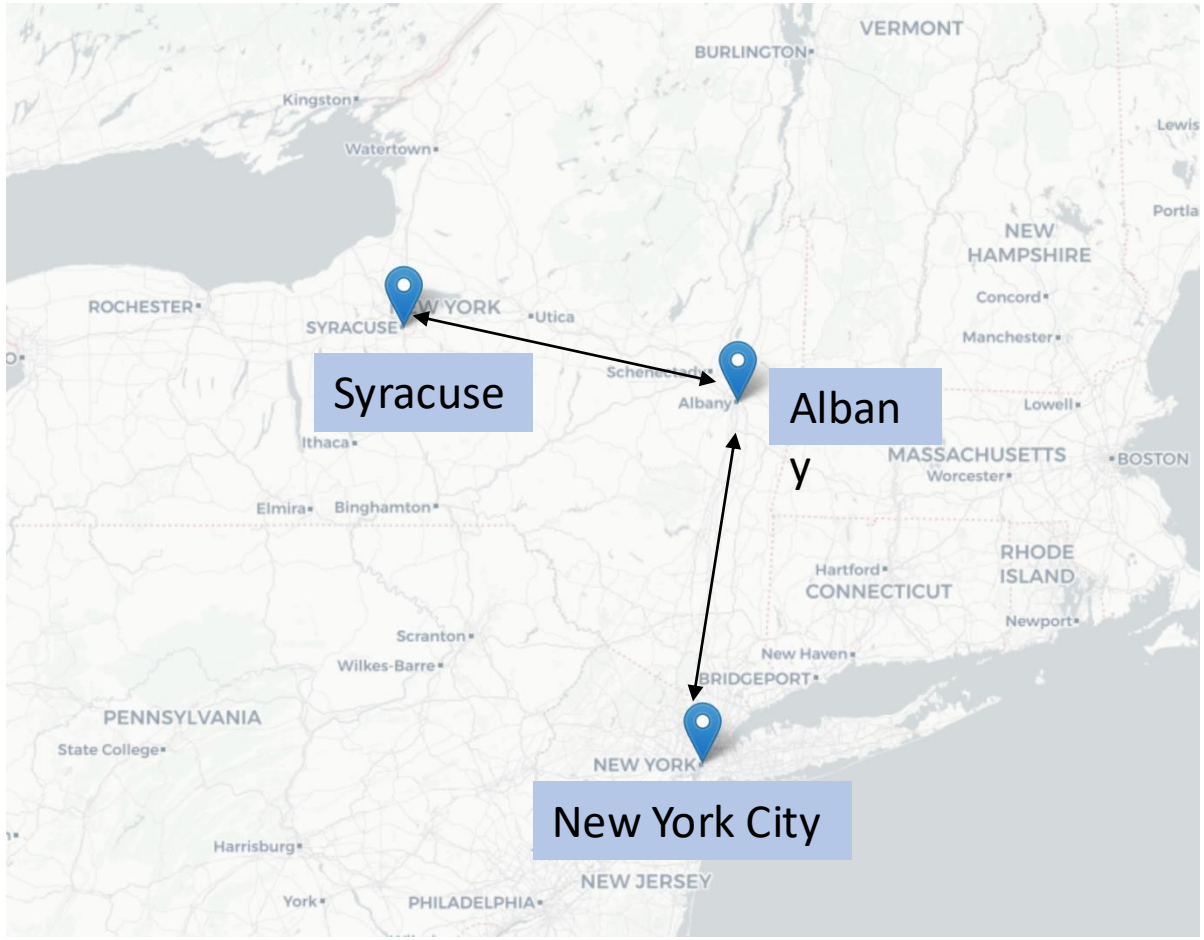



Optical paths modeled in this work

- Non-profit R&E ISP
- Two segments used in the experiment

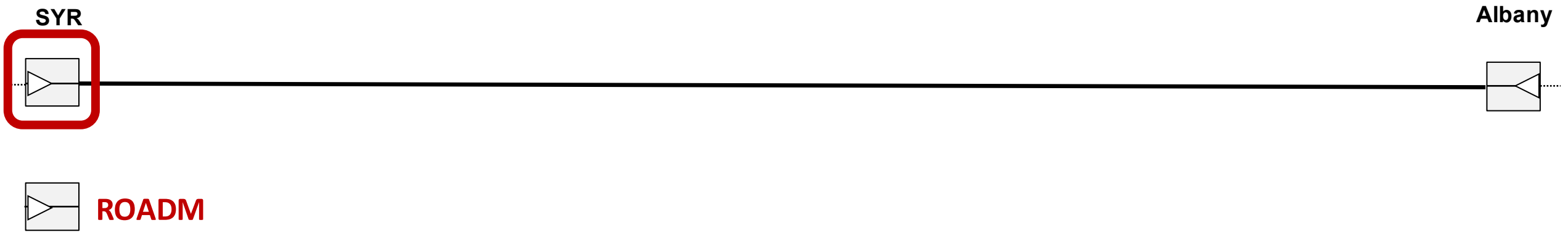
# NYSERnet: a production NY state optical WAN




Optical paths modeled in this work

- Non-profit R&E ISP
- Two segments used in the experiment
- Model all the main components

# Single direction physical view of NYC to ALB segment




ROADM

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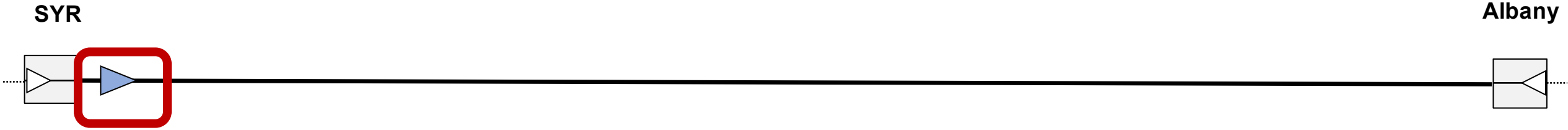
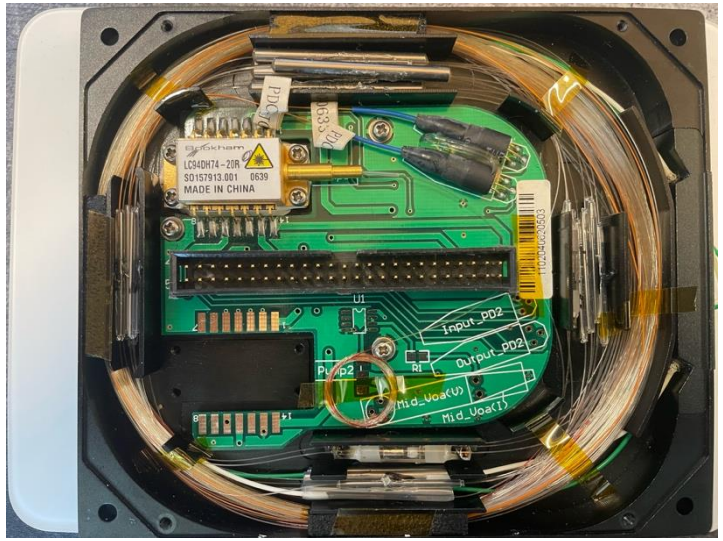



ROADM

**High gain**
**EDFA Amplifier**



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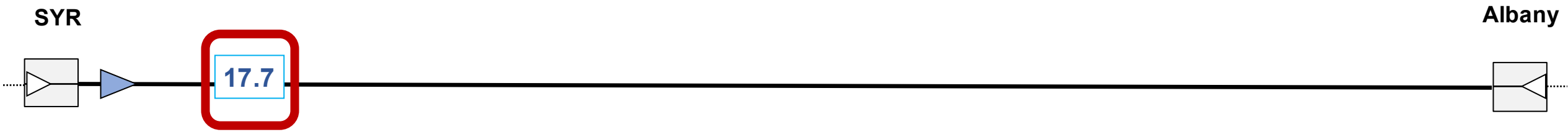


ROADM

High gain
EDFA Amplifier

17.7 **Fiber attenuation (dB)**

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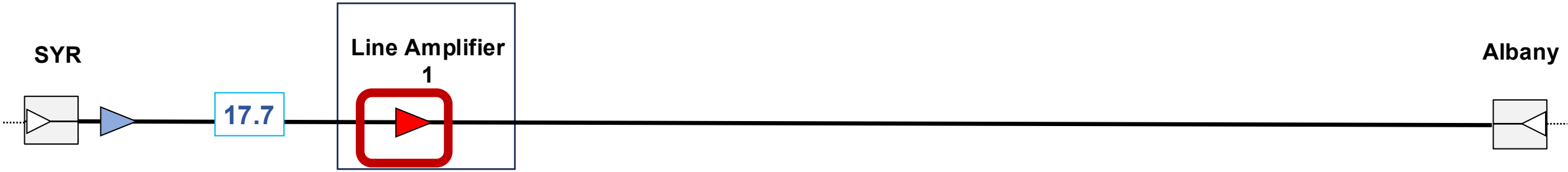


ROADM

RAMAN Amplifier

High gain
EDFA Amplifier

17.7 Fiber attenuation (dB)

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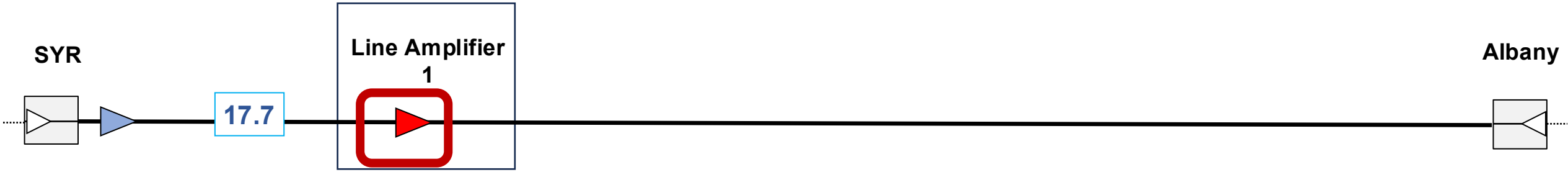


ROADM

RAMAN Amplifier

High gain **EDFA** Amplifier

17.7 Fiber attenuation (dB)

| EDFA | RAMAN |
|---|---|
| High noise | Less noise |
| Hits desired output power | Increases the span |
| Easier to operate | More difficult to operate |

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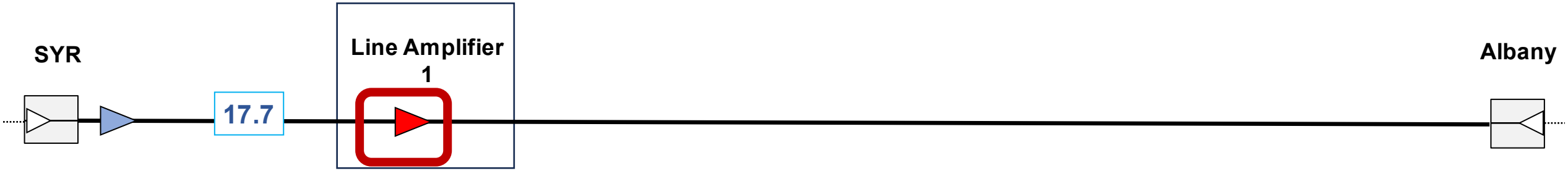


ROADM

**RAMAN Amplifier**

Why are both used?

High gain
**EDFA** Amplifier

17.7 Fiber attenuation (dB)

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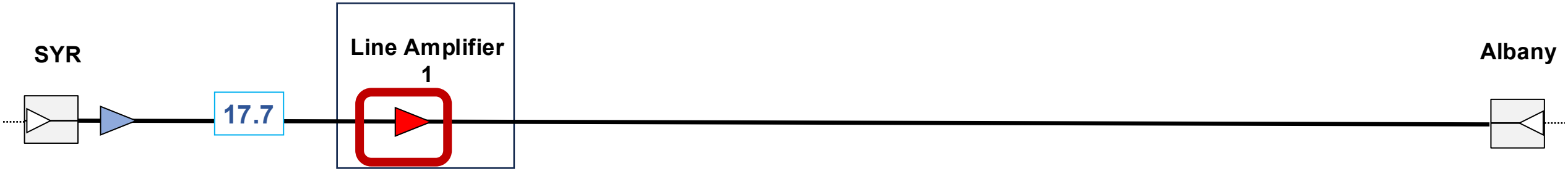


ROADM

**RAMAN Amplifier**

Why are both used?

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**EDFA** Amplifier

EDFA: Overall simpler control than RAMAN only

17.7 Fiber attenuation (dB)

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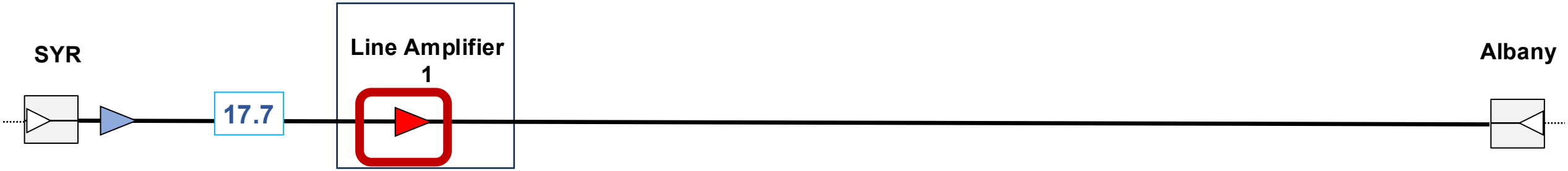


ROADM

**RAMAN Amplifier**

High gain
**EDFA** Amplifier

17.7 Fiber attenuation (dB)

Why are both used?

EDFA: Overall simpler control than RAMAN only

RAMAN: Overall better SNR than EDFA only

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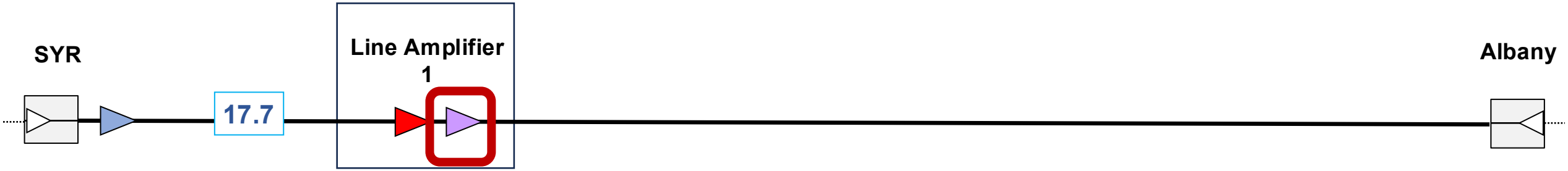


ROADM

RAMAN Amplifier

High gain
EDFA Amplifier

**Low gain EDFA Amplifier**

17.7 Fiber attenuation (dB)

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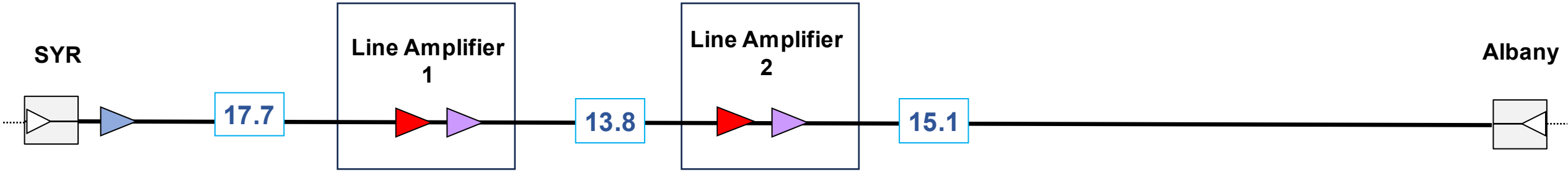


ROADM

RAMAN Amplifier

High gain EDFA Amplifier

Low gain EDFA Amplifier

17.7 Fiber attenuation (dB)

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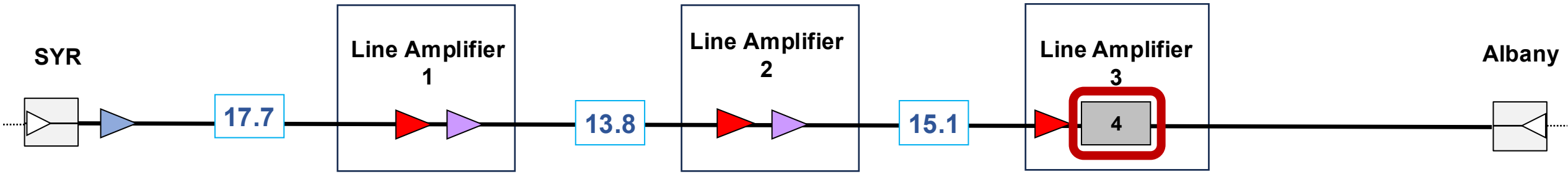


ROADM

RAMAN Amplifier

4 Jumper Attenuation (dB)

High gain EDFA Amplifier

Low gain EDFA Amplifier

17.7 Fiber attenuation (dB)

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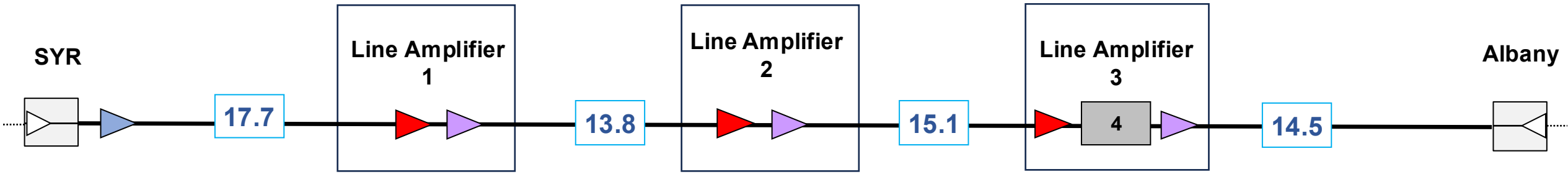


ROADM

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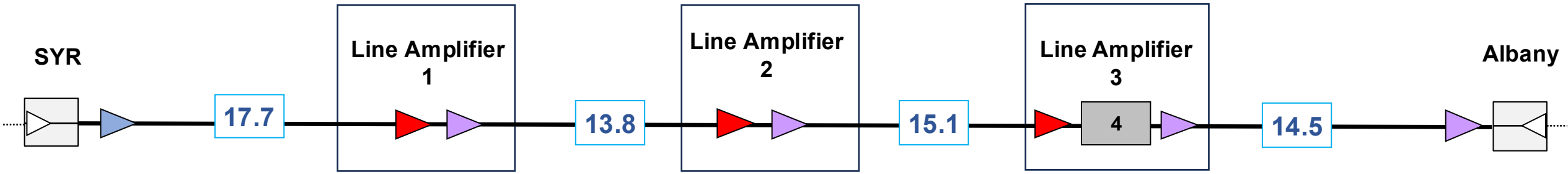


ROADM

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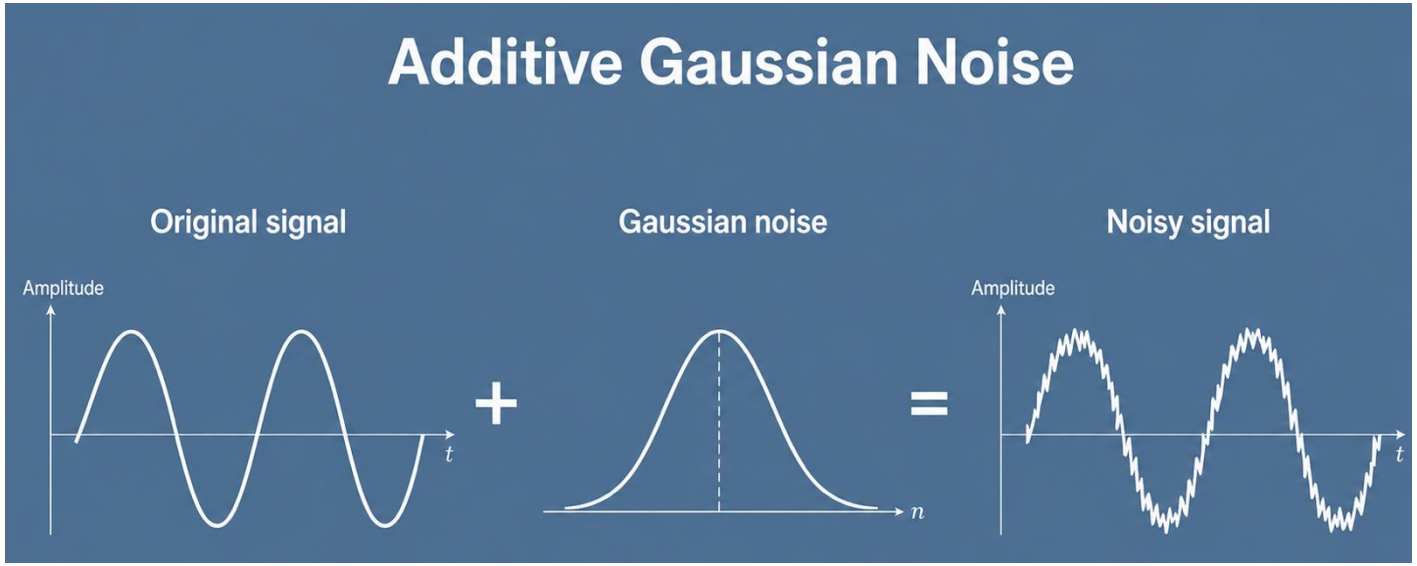
# Gaussian noise abstraction

# Gaussian noise abstraction

- Each component adds noise

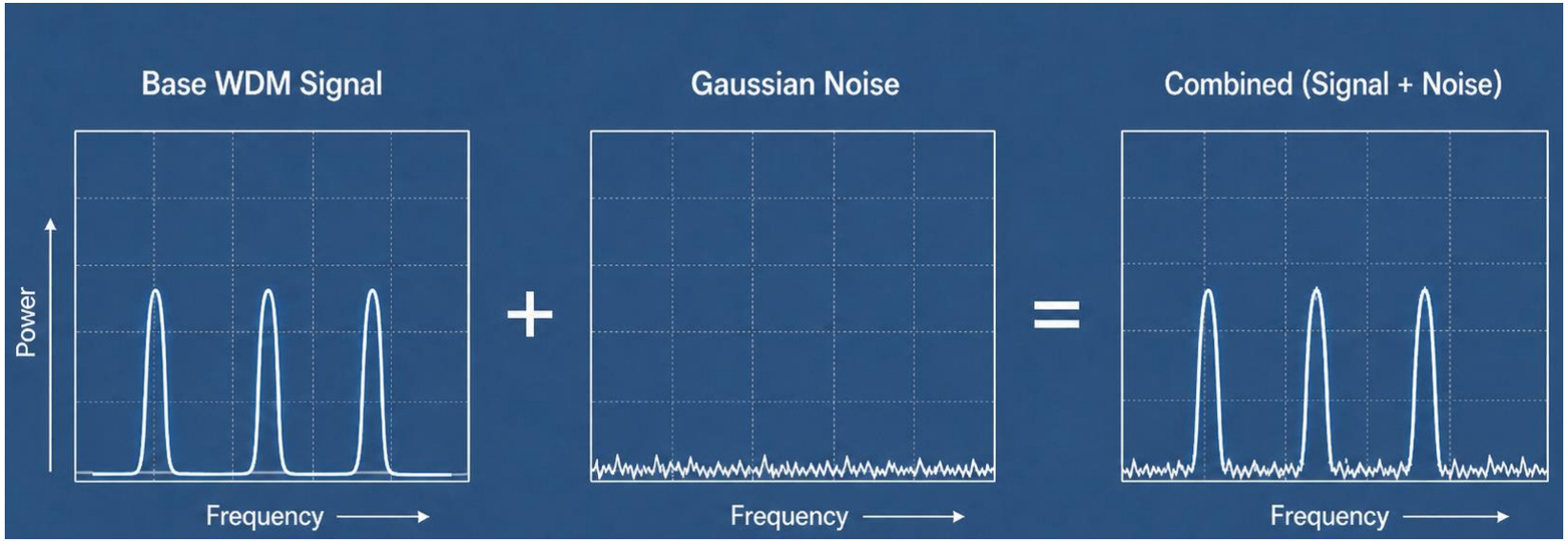
# Gaussian noise abstraction

- Each component adds noise
- Additive



# Gaussian noise abstraction

- Each component adds noise
- Additive
- Independent



# Gaussian noise abstraction

- Each component adds noise
- Additive
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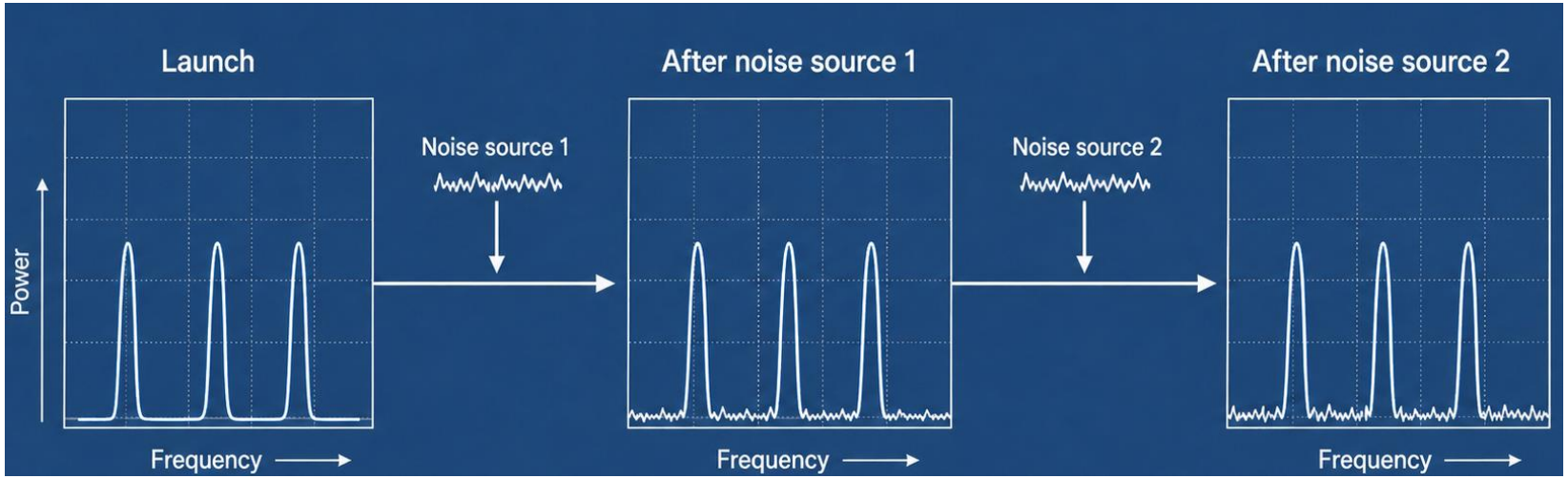
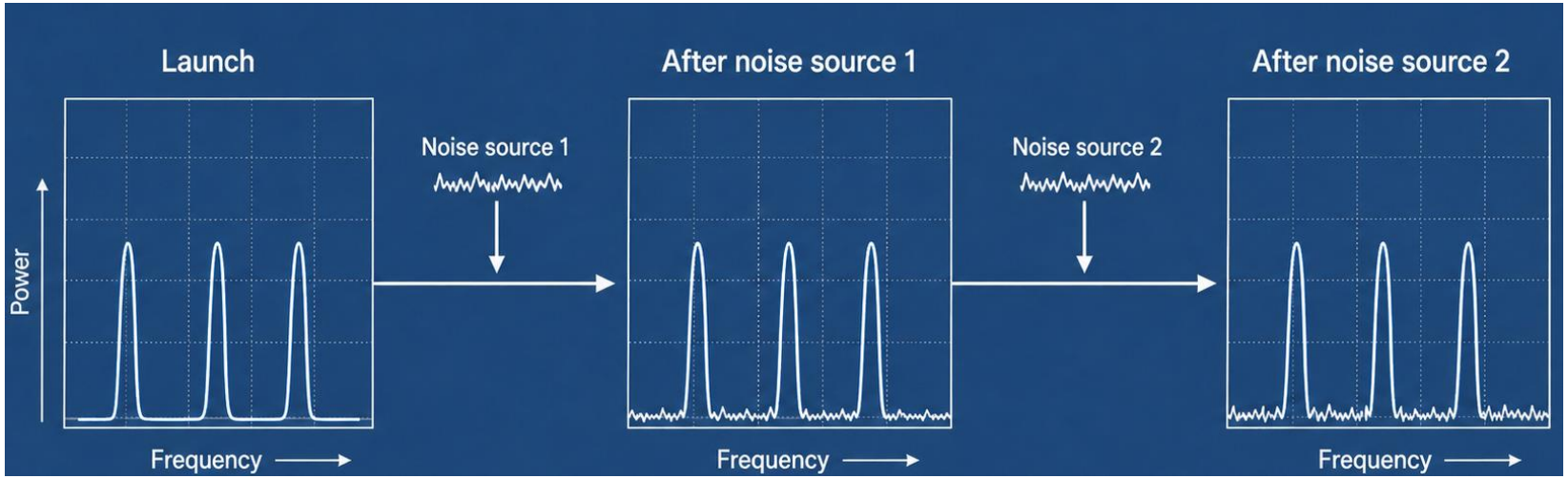
- Accumulates over the path

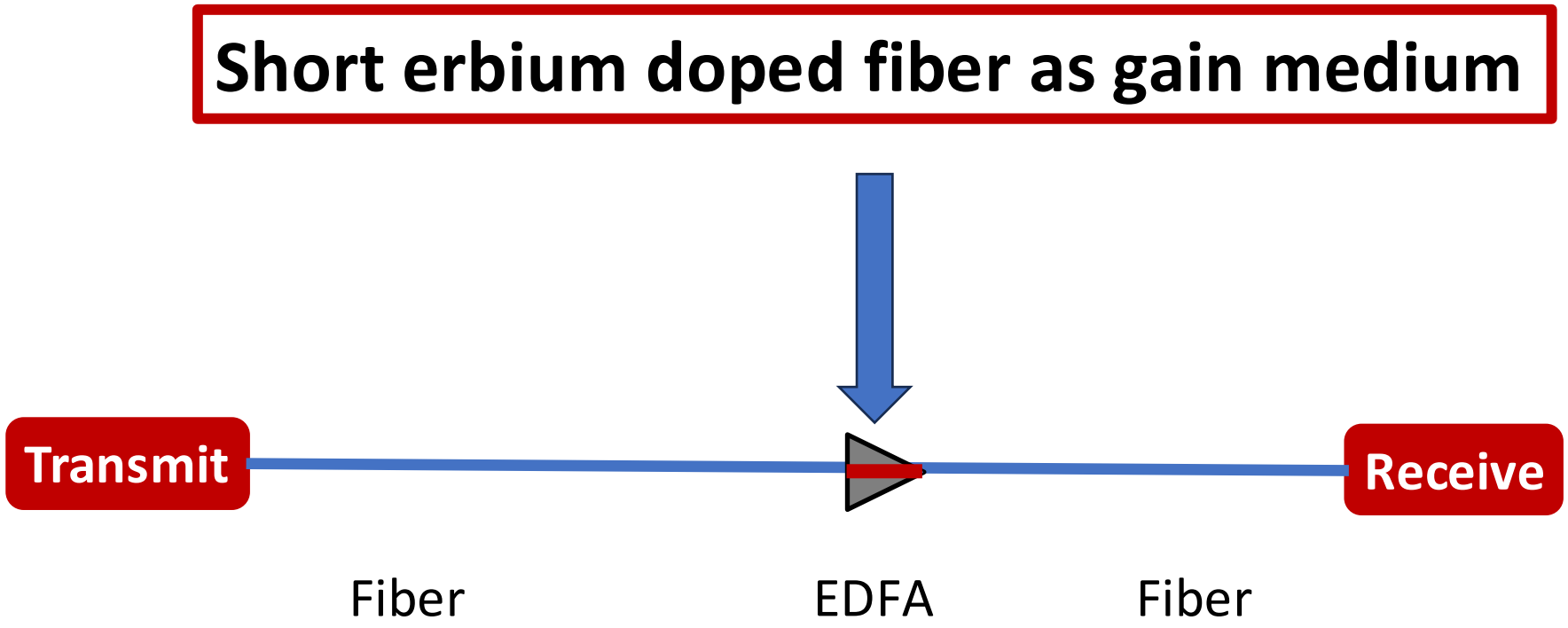


# Gaussian noise abstraction

- Each component adds noise
- Additive
- Independent
- Accumulates over the path
- Implemented with GNPy



# Modeling EDFA



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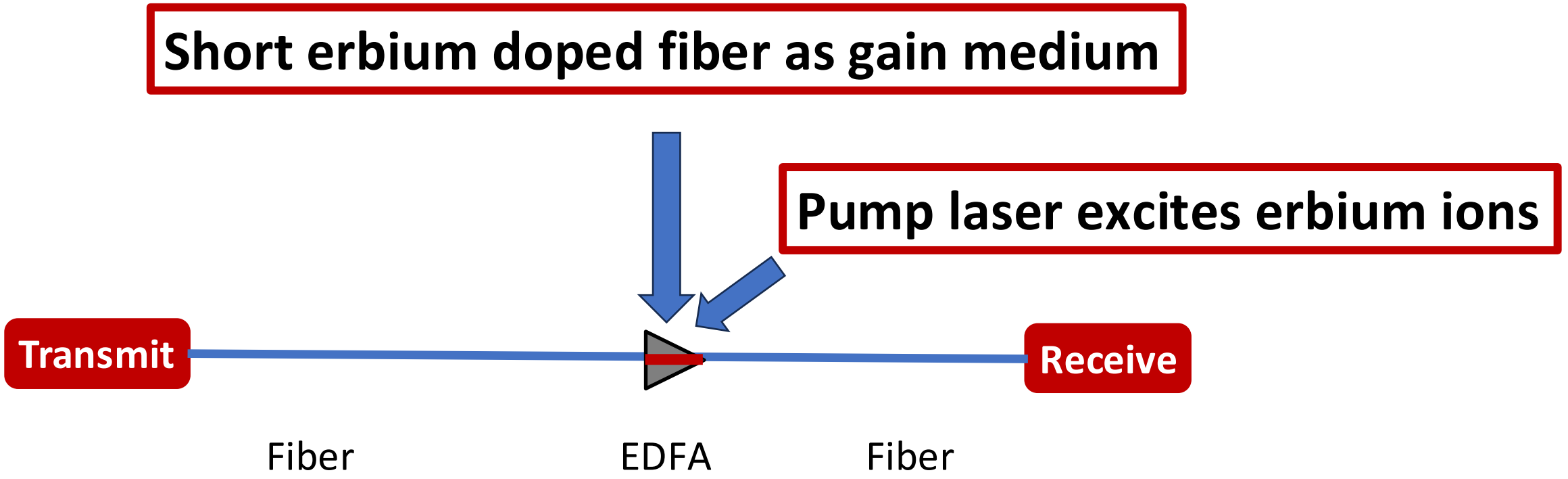
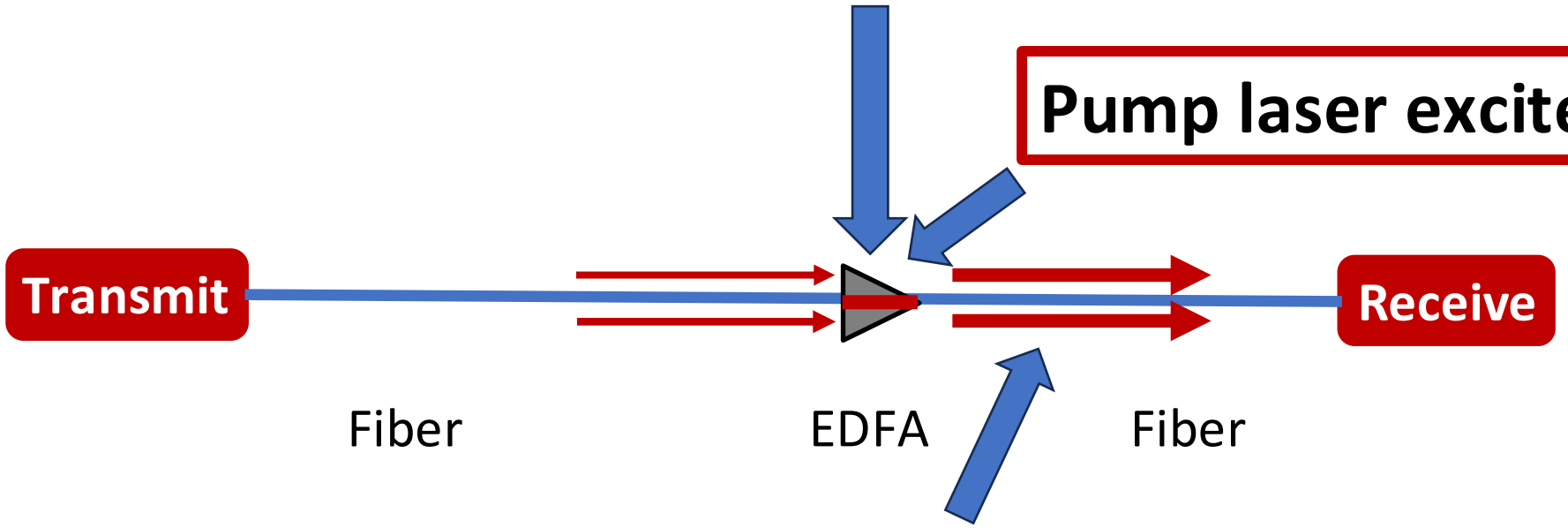


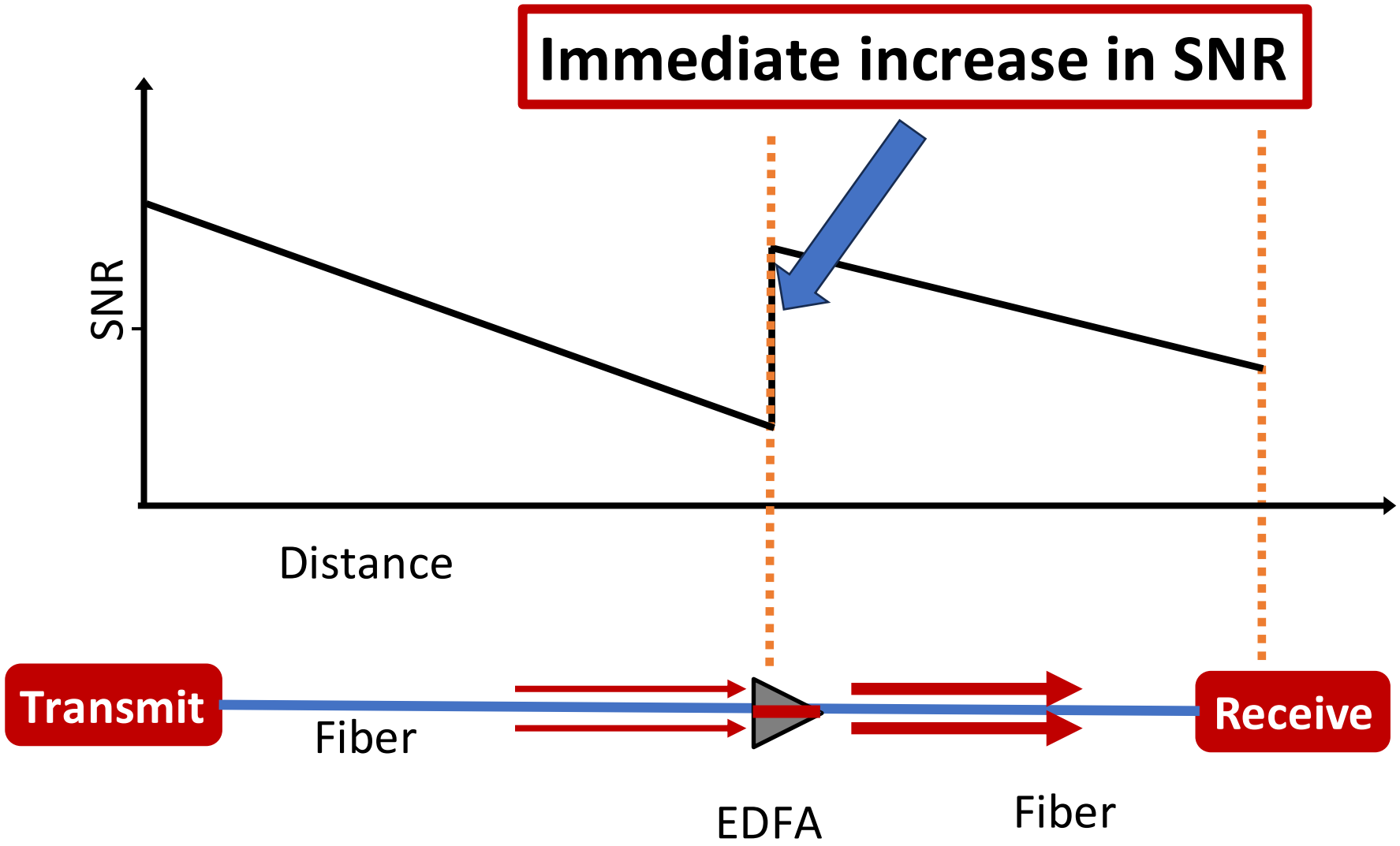
# Modeling EDFA

**Short erbium doped fiber as gain medium**




**Signal photons trigger stimulated emission and get amplified**

# Modeling EDFA



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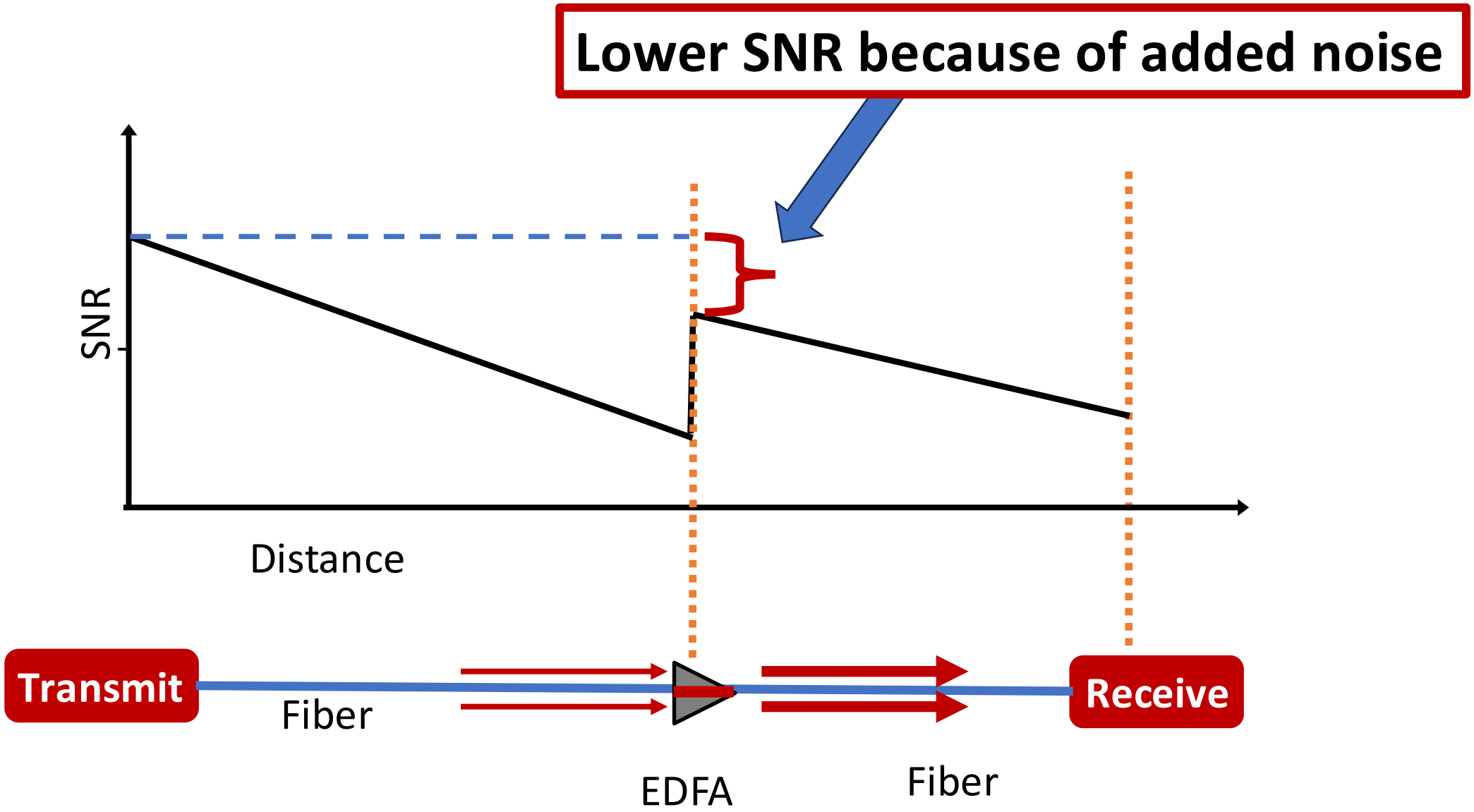
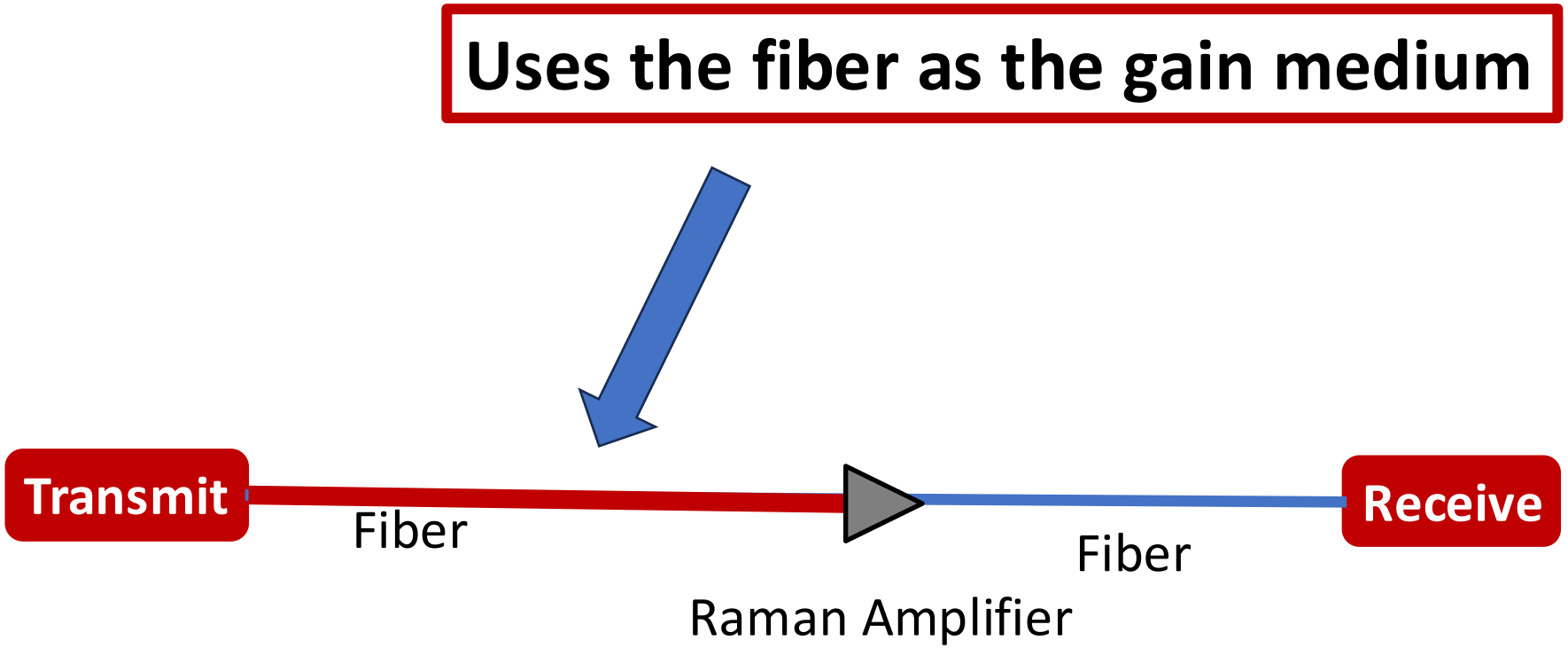
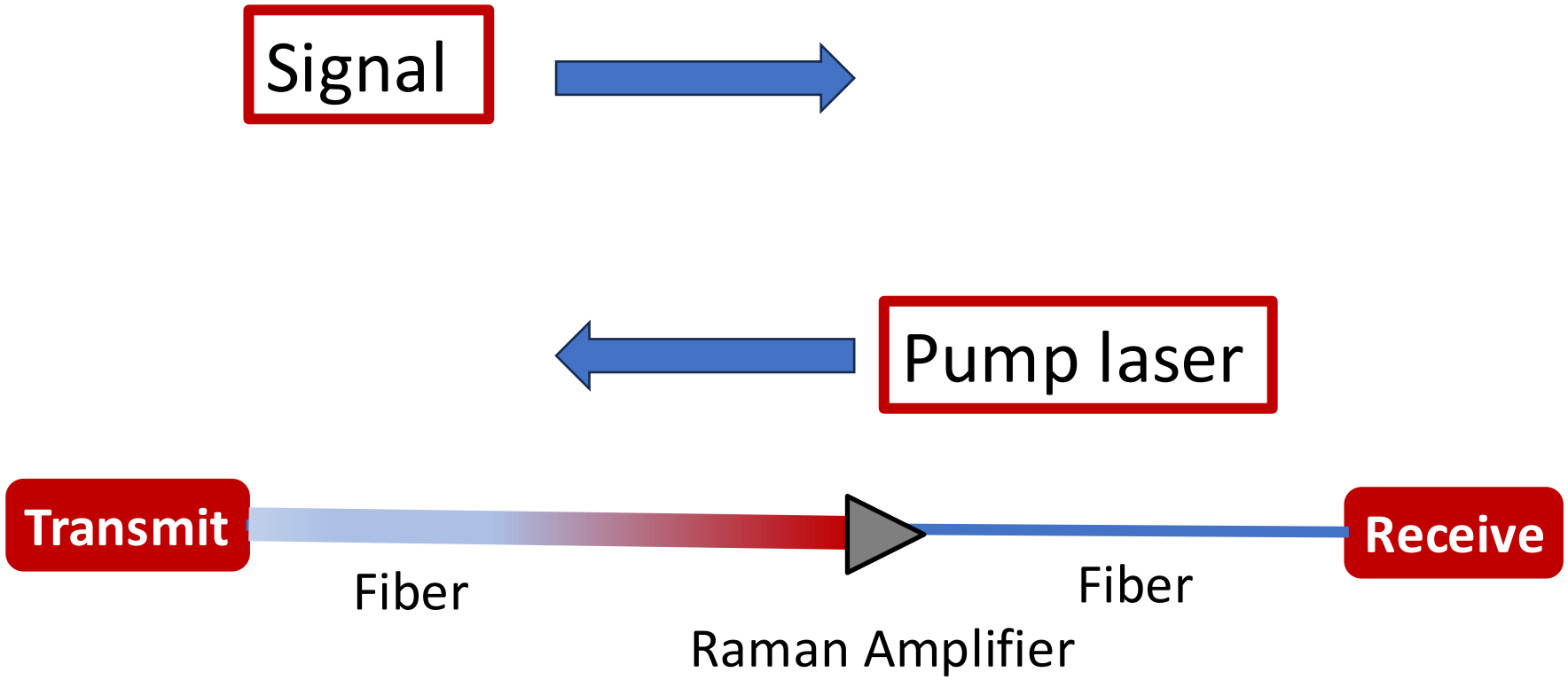


# Raman amplifier



# Raman amplifier

**Pump laser in direction opposite to the signal**



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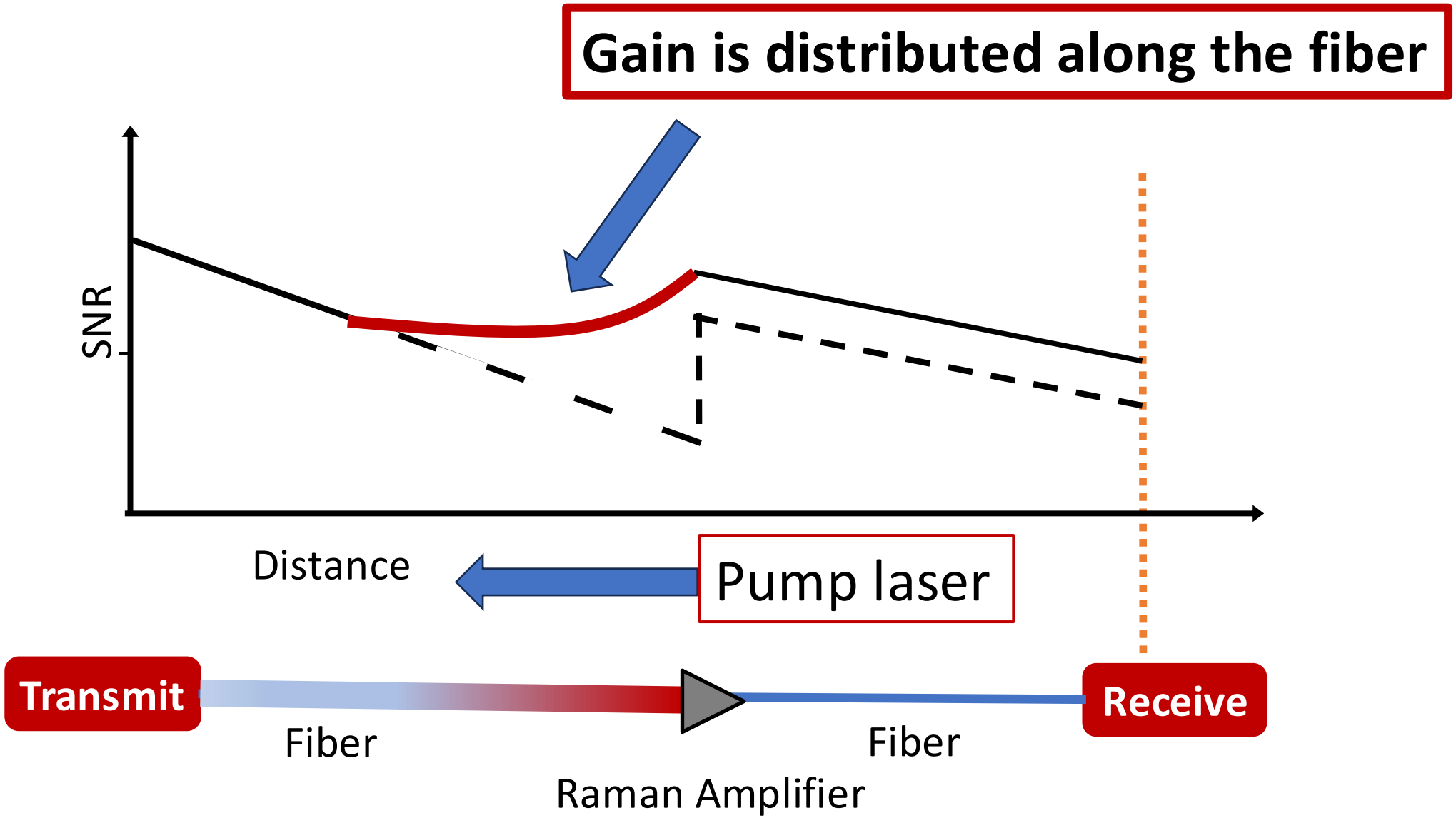

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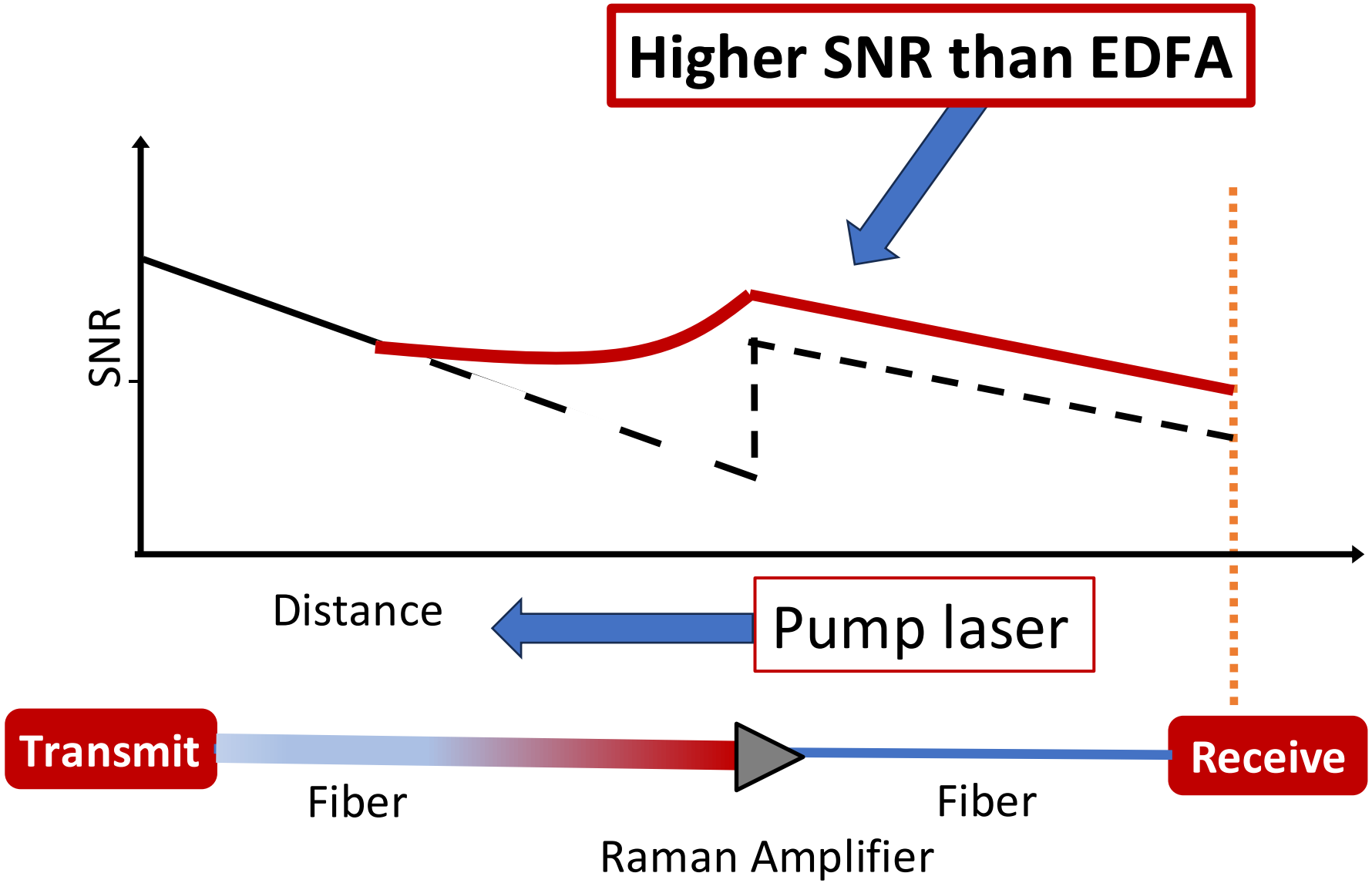

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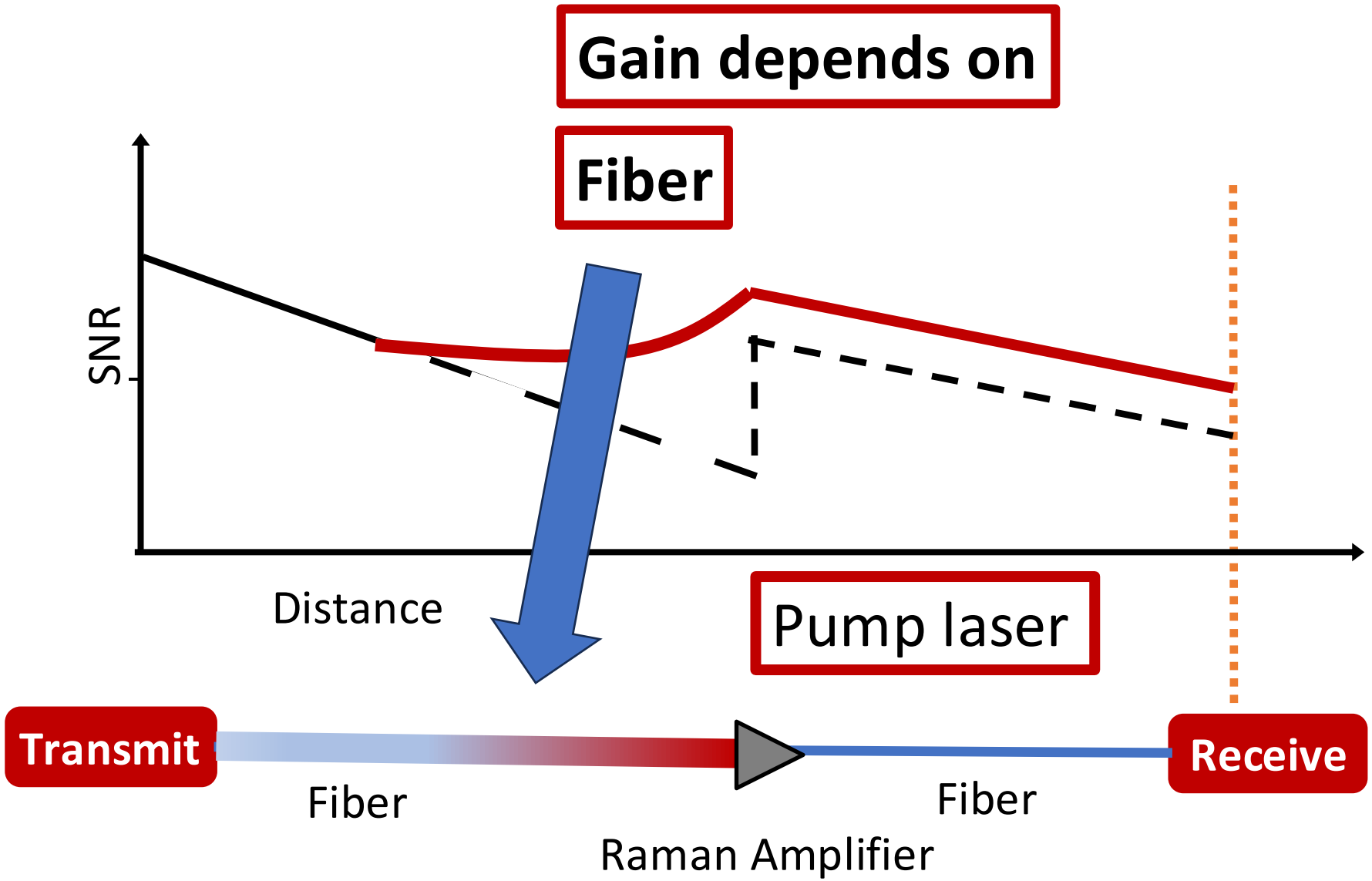

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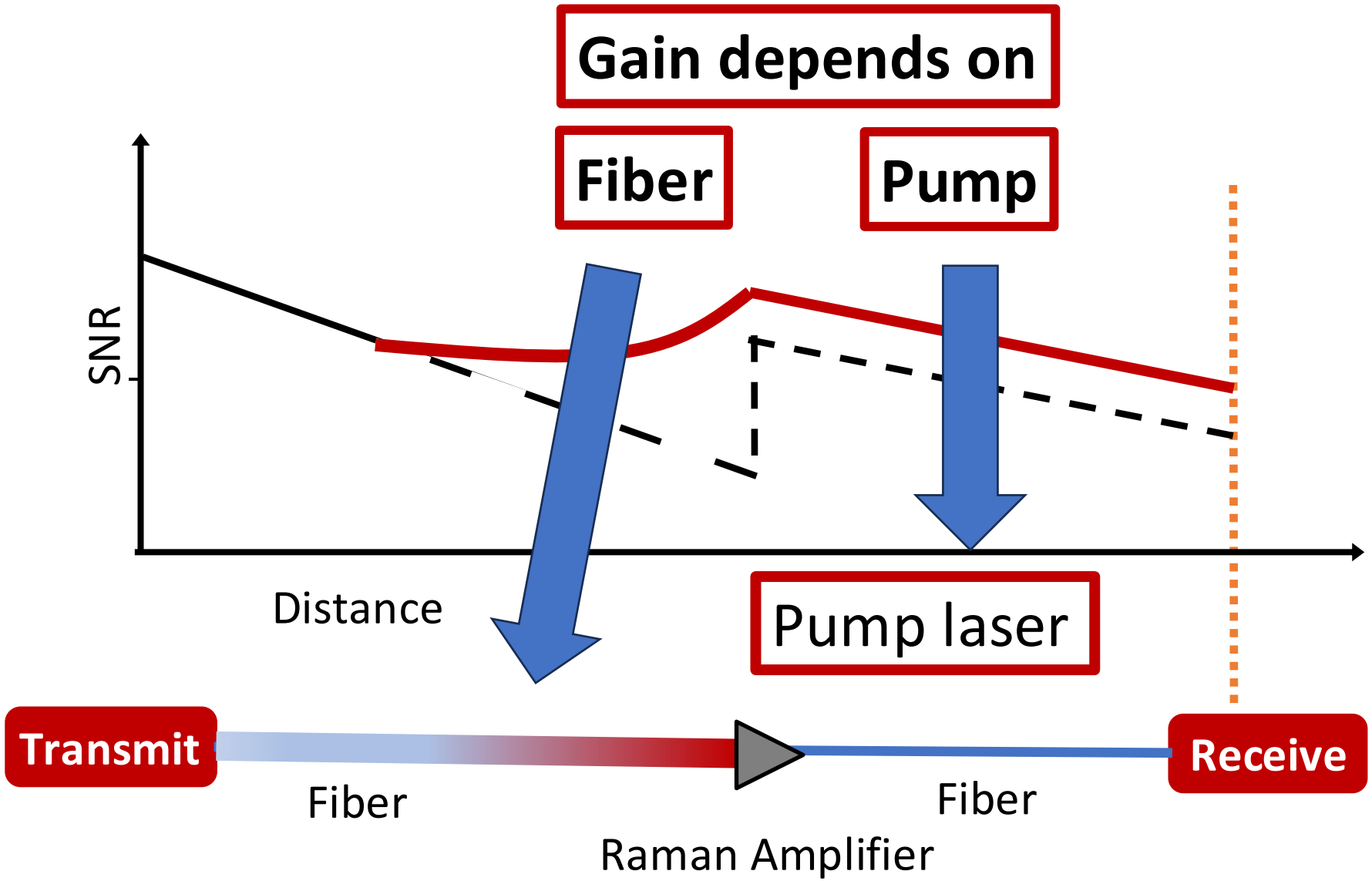

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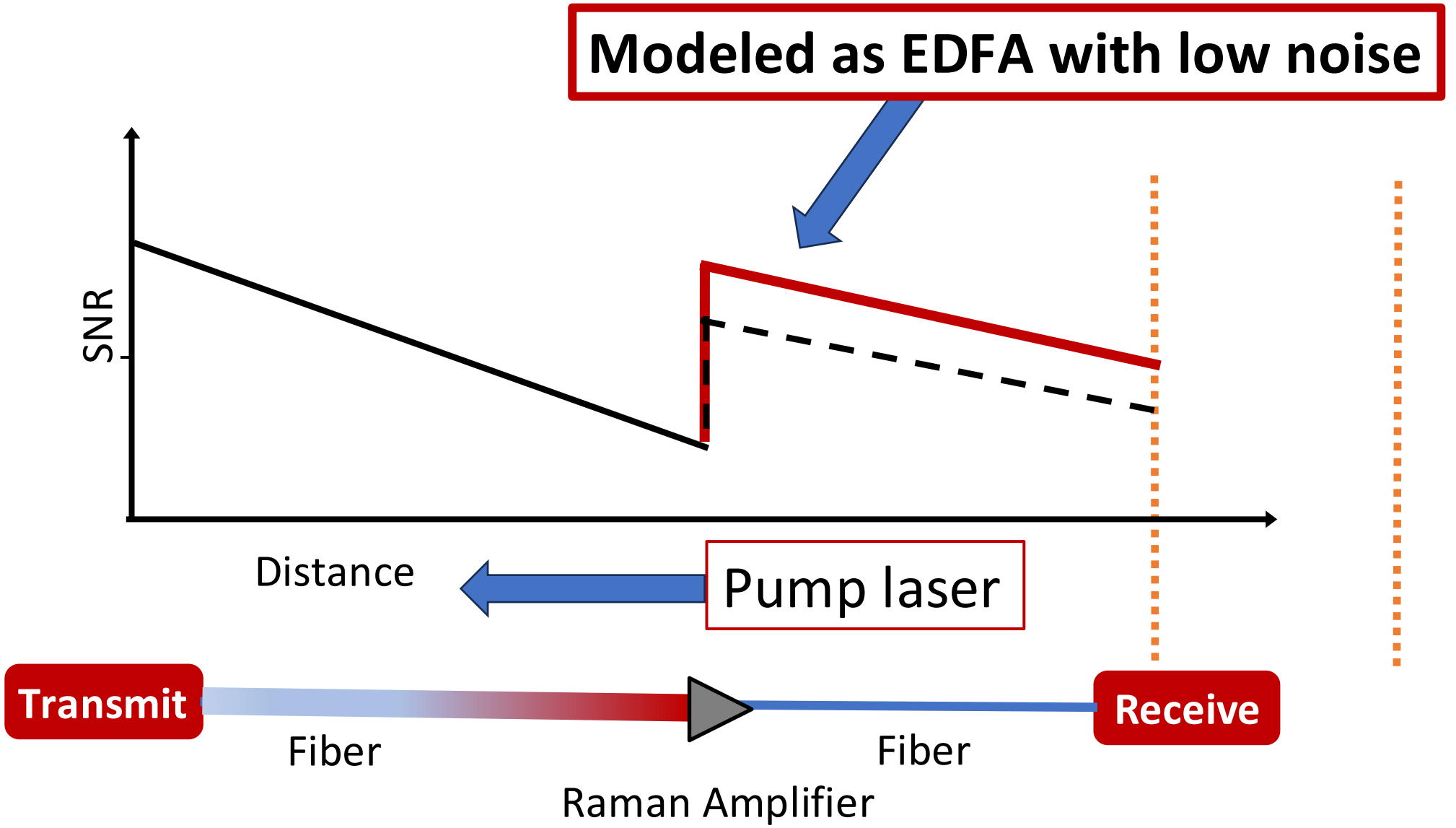

# Hurdles in modeling the network

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# Hurdles in modeling the network

- **Heterogeneous equipment –** Many components, varied parameters
- **Proprietary device behavior –** Missing vendor specific information
- **Modeling RAMAN amplifier –** Proprietary pump characteristic

# Modeling accuracy

| Channel | Direction | Model (dB) | Measured (dB) | Error |
|---|---|---|---|---|
| 193.35 THz | Syr → NYC | 15.56 | 15.5 | **0.4%** |
| 193.50 THz | Syr → NYC | 14.93 | 15.1 | **1.1%** |
| 193.75 THz | Syr → NYC | 15.07 | 15.2 | **0.9%** |
| 193.35 THz | NYC → Syr | 15.06 | 14.7 | **2.4%** |
| 193.50 THz | NYC → Syr | 14.39 | 13.9 | **3.5%** |
| 193.75 THz | NYC → Syr | 14.46 | 14.1 | **2.6%** |

Error

**< 4%**

Across all channels and both directions

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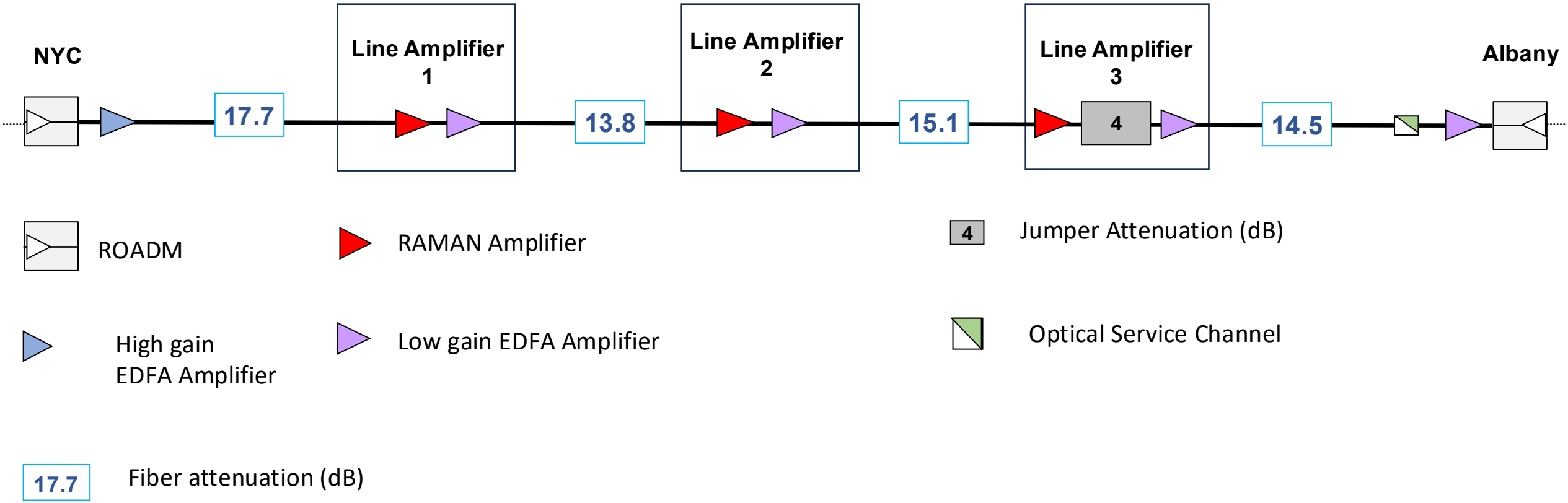

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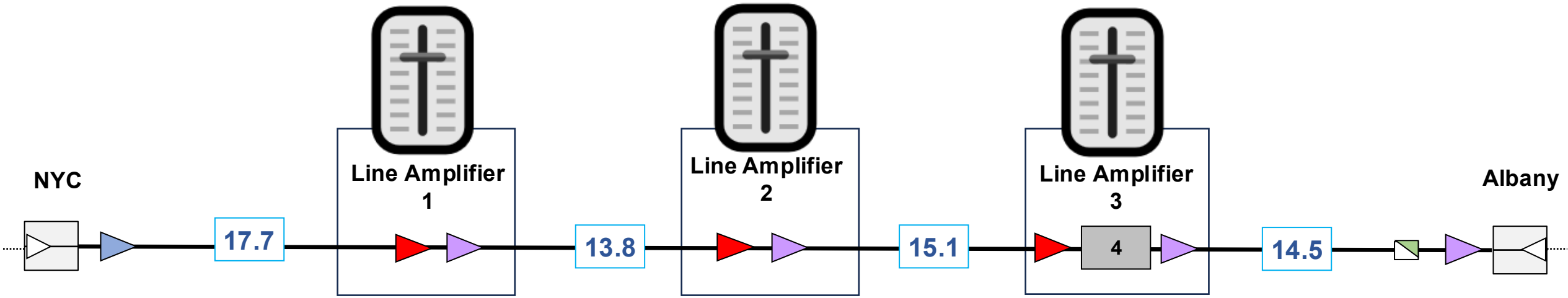


ROADM

RAMAN Amplifier

4 Jumper Attenuation (dB)

High gain EDFA Amplifier

Low gain EDFA Amplifier

Optical Service Channel

17.7 Fiber attenuation (dB)

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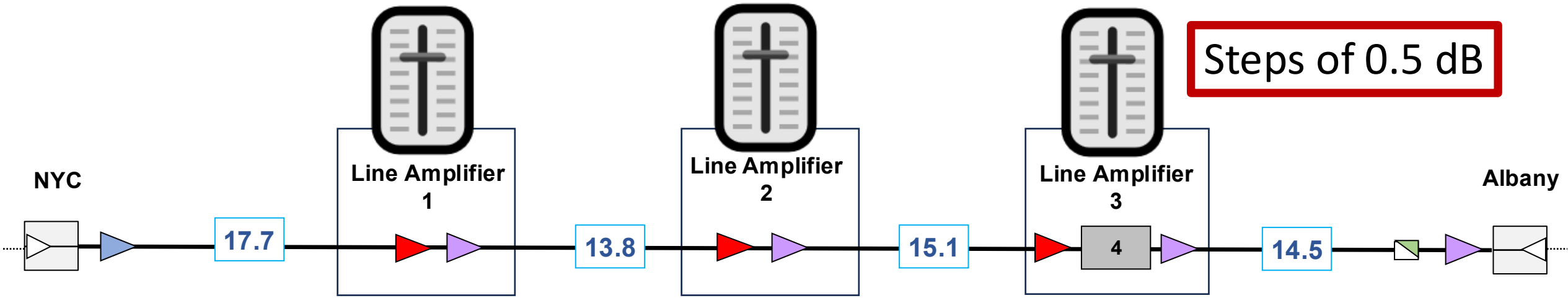


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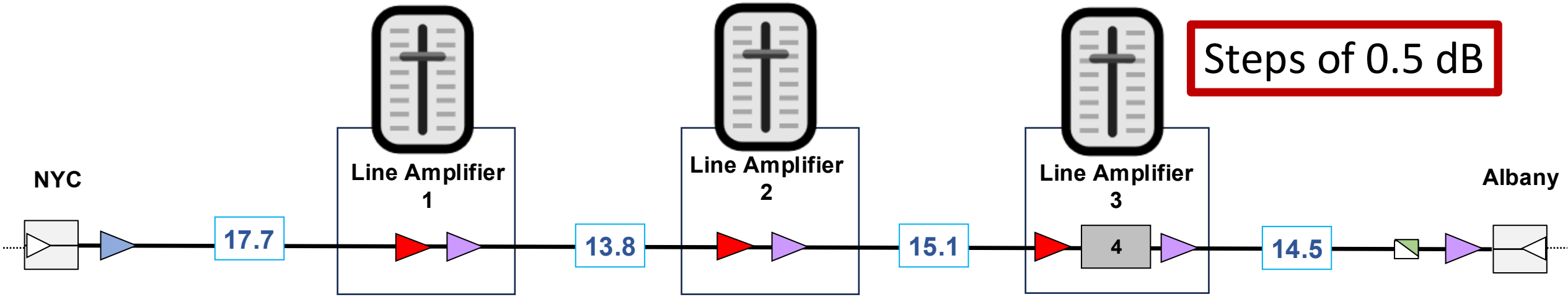
# Optimization constraints

Limited to safe values

Steps of 0.5 dB

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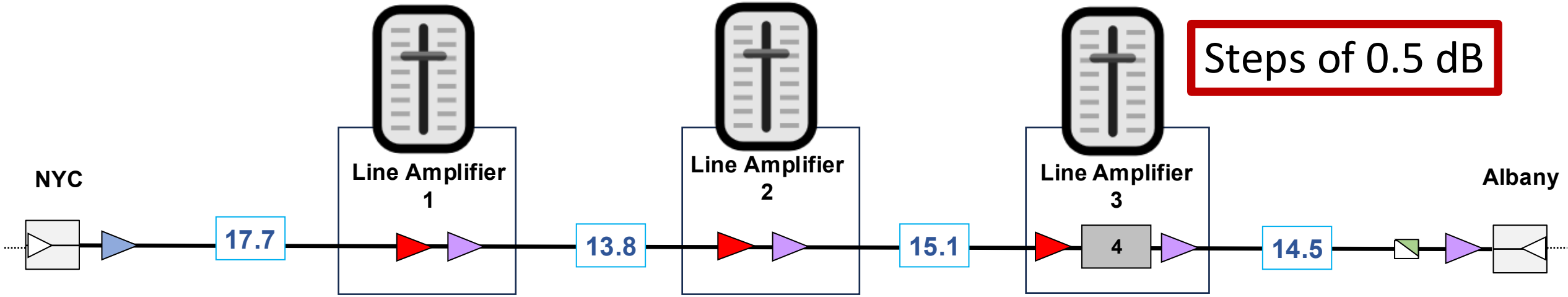



ROADM

RAMAN Amplifier

Fixed at max gain value

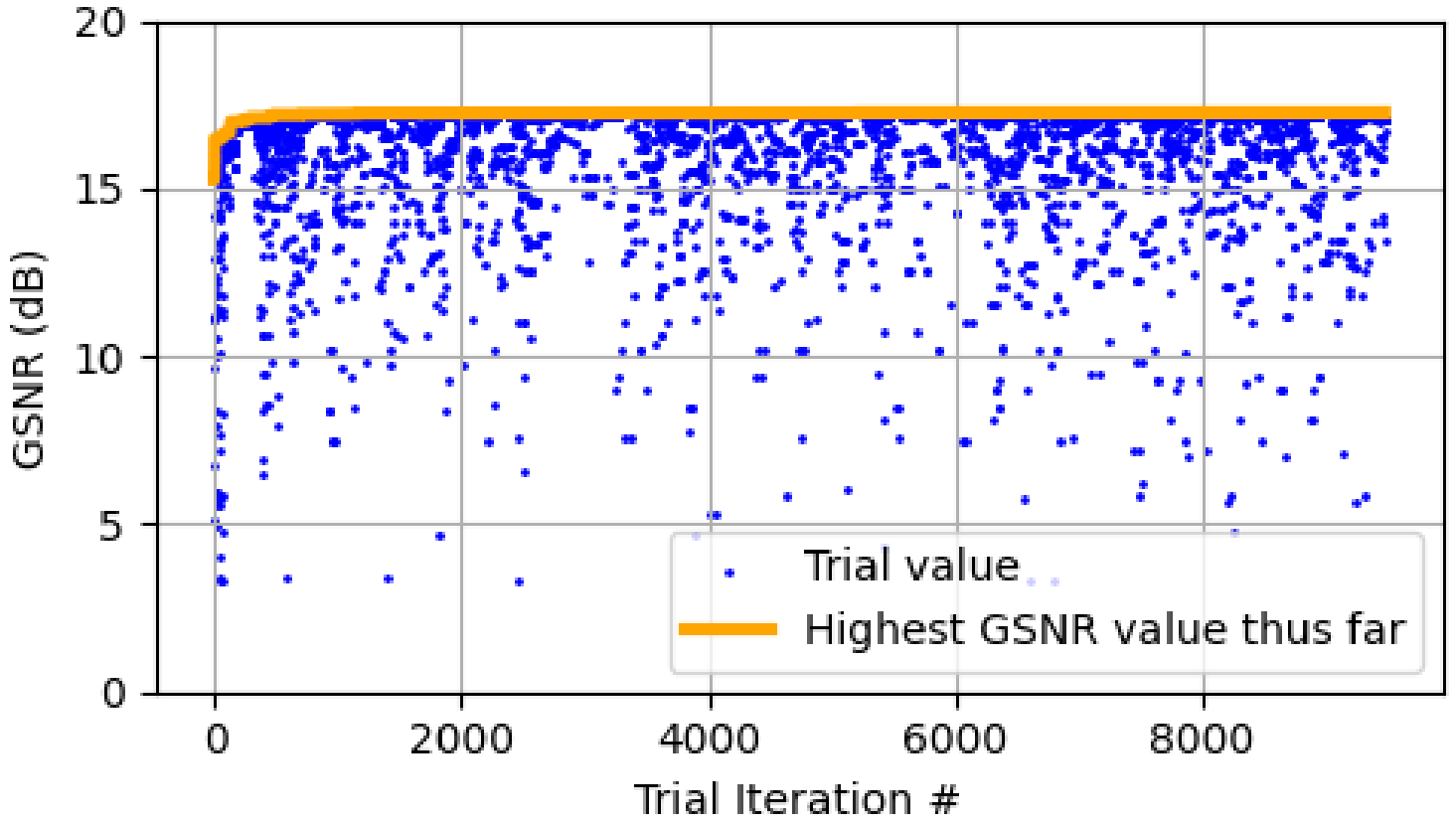
High gain EDFA Amplifier

Low gain EDFA Amplifier

Optical Service Channel

17.7 Fiber attenuation (dB)

# Hyperparameter search




**Takeaway:** Search finds the gain setting for highest feasible end-to-end SNR

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# Deploying to production: phased and cautious

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- Maintenance window with operator supervision

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# Deploying to production: phased and cautious

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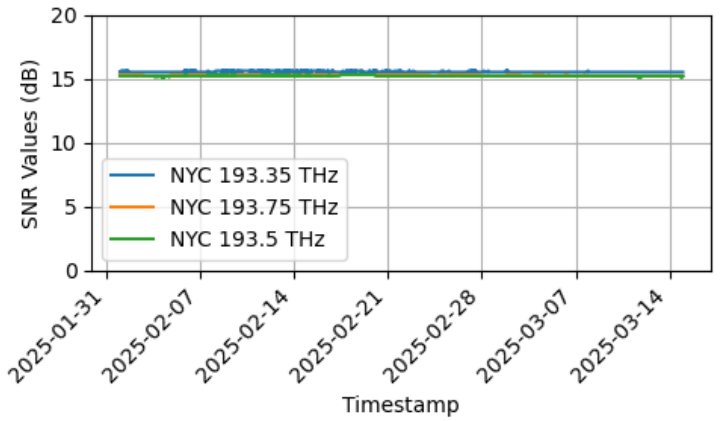
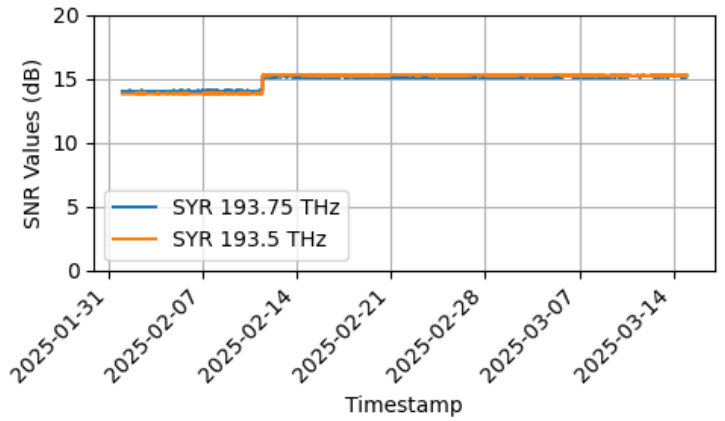
- 0.5 dB phased gain changes
- 1-hour monitoring after each step
- Rollback if needed
- Follow-up measurements confirm stability

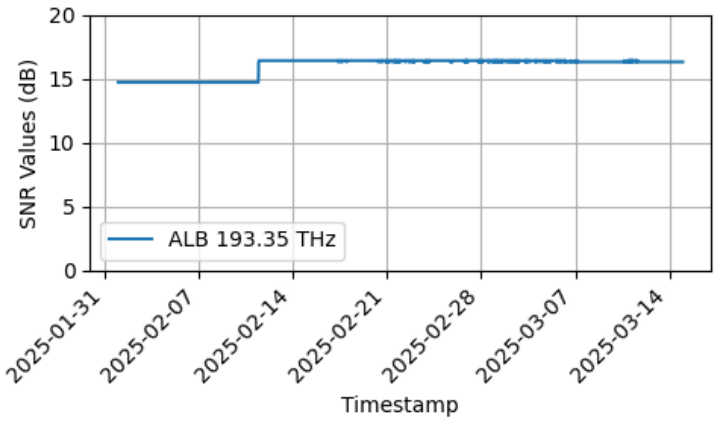
# Results: measured improvement in the production network




**Tx Node: NYC**




**Rx Node: SYR**




**Rx Node: ALB**

**+4.2 dB**

total across 3 wavelengths

**+10.4%**

Capacity gain (Shannon-Hartley)

**+60 Gbps**

Capacity increase

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**Thank you!**

Bhaskar Kataria (bk478@cornell.edu)