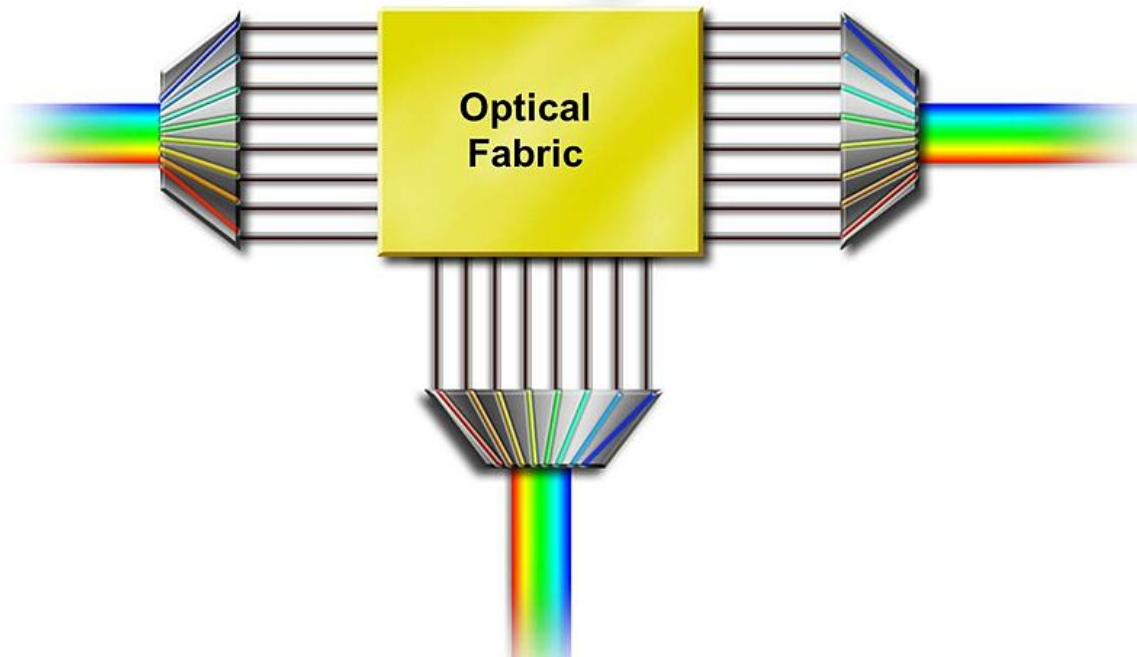


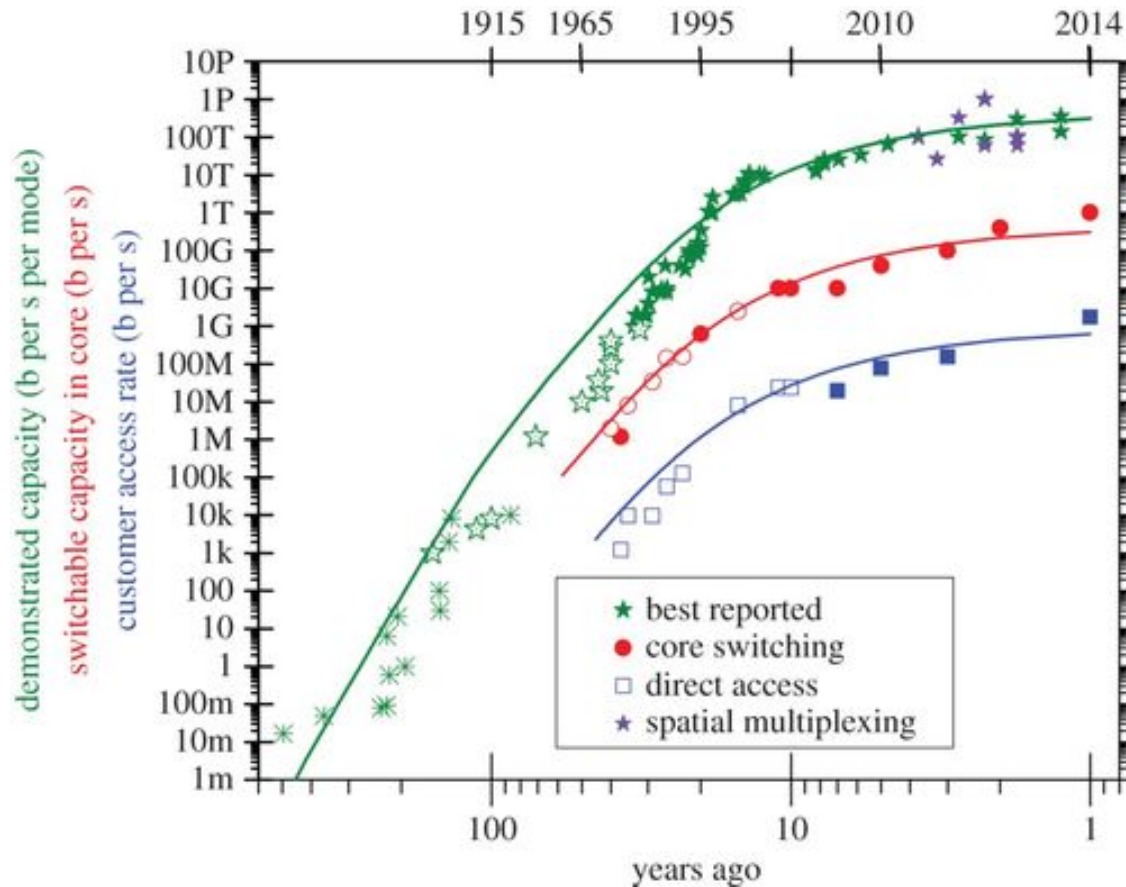
# Fiber Optic Communications

## Lecture 11: Networking Growth

- Upgrading existing network hardware
- Improved communications protocols
- Novel network concepts



# Network Capacity over Time



A.D. Ellis et al., *Phil. Trans. Roy. Soc. A* **374**, 2062 (2016).

# Upgrading Existing Hardware

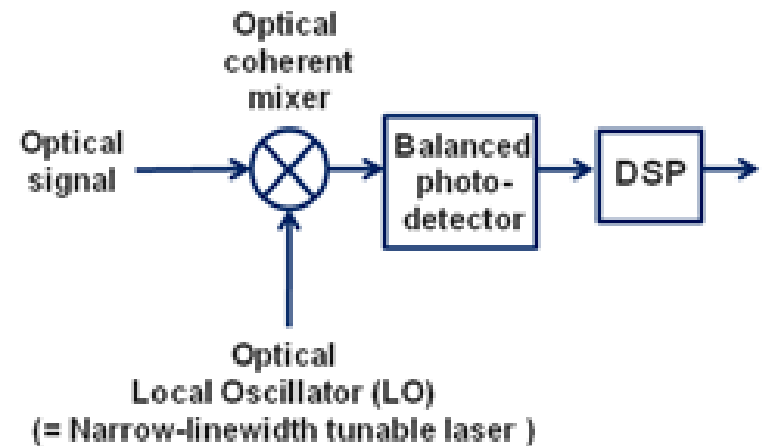
- Polarization Multiplexing
- Coherent Detection
- Dispersion-Compensated Fibers
- Multimode Fibers
- Digital Processing

# Dispersion-Compensated Fibers

- Implemented by splicing a short length to make up for longer stretches of opposite sign of dispersion
- As discussed previously, can great increase bandwidth for long-haul telecommunications

# Coherent Detection

- Mixes transmitted signal with a reference signal to create a radio-frequency output
- Increases sensitivity, capacity, dispersion compensation, and signal-to-noise ratio
- Also enables broad class of other improved components



# Polarization Multiplexing

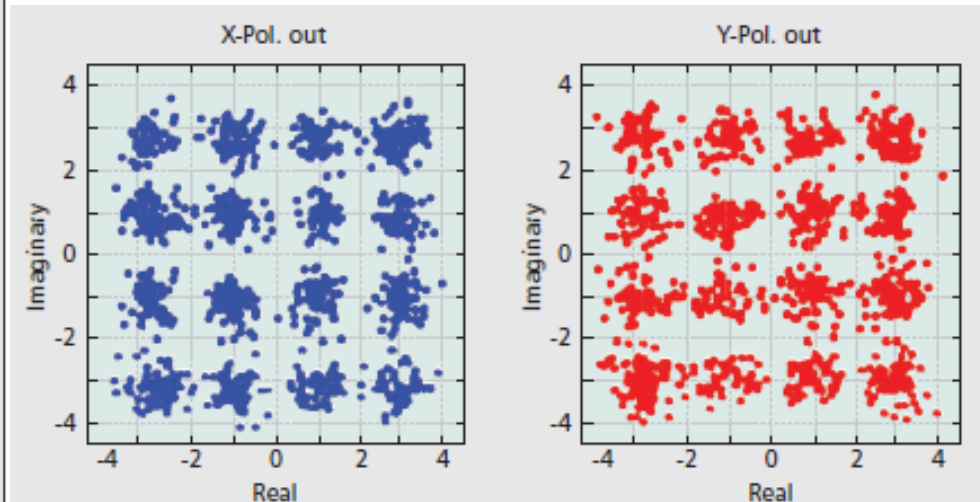
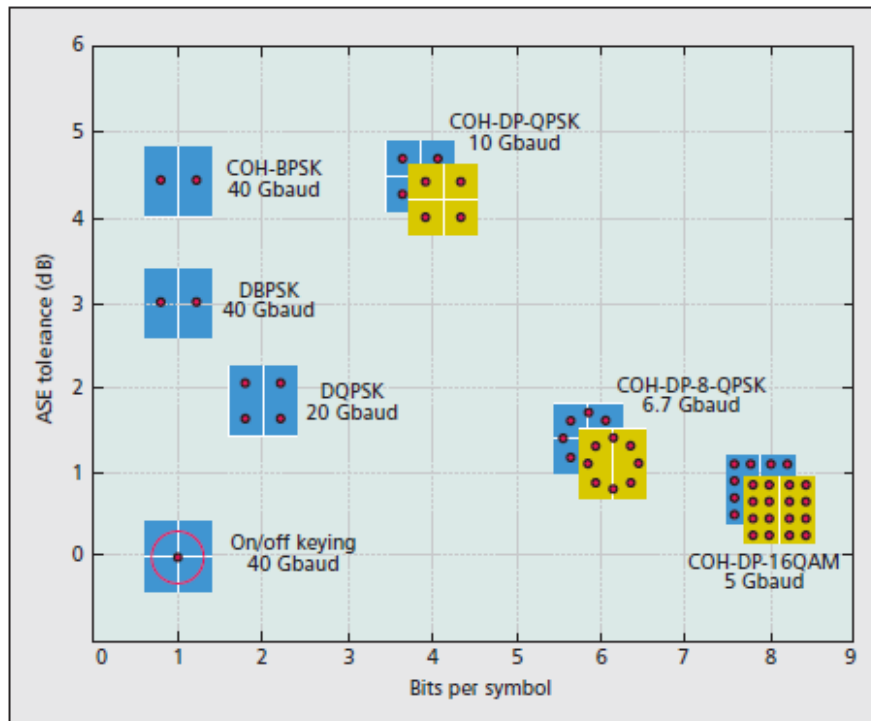
- Allows two channels of information on the same fiber and carrier frequency by transmitting separate left and right circularly polarized light beams
- Challenges include drifts in polarization states
- Can be addressed by advanced coding techniques, to be discussed later

# Multimode Fibers

- Originally dropped for the simplicity of single-mode fibers
- May be revived using several tricks:
  - working just above single-mode V-number (aka few-mode fibers)
  - Limiting bending and twists
  - Applying MIMO or digital signal processing

# Digital Signal Processing

Tradeoff between digital signal complexity and tolerable noise levels



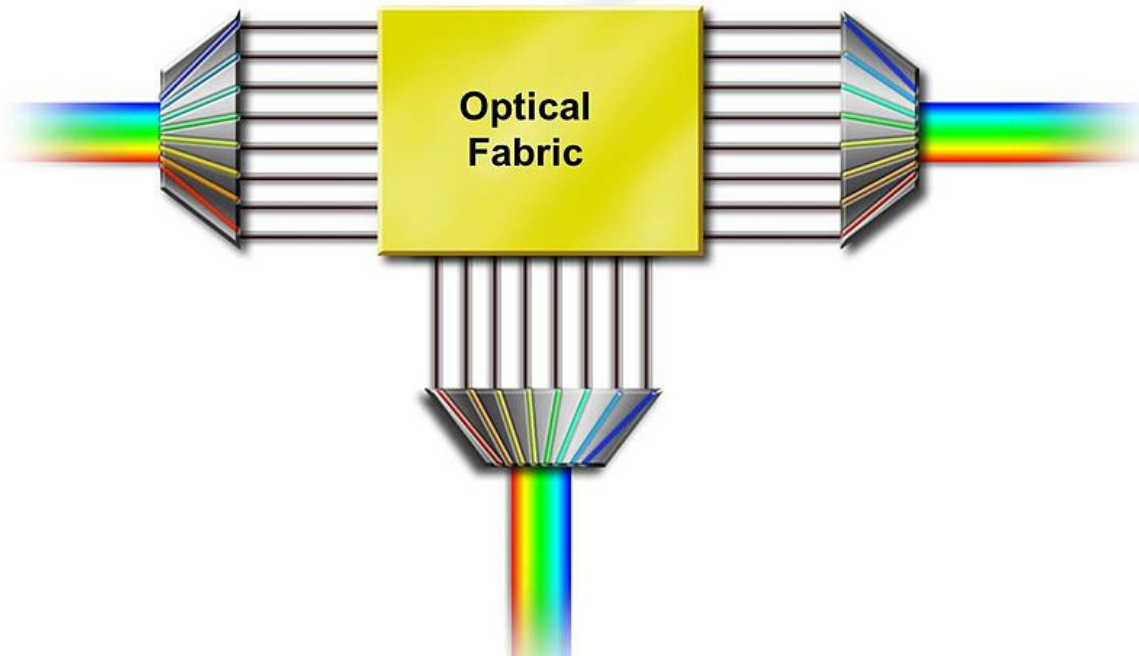
K. Roberts et al., IEEE Comms. Mag. (2010).



# Fiber Optic Communications

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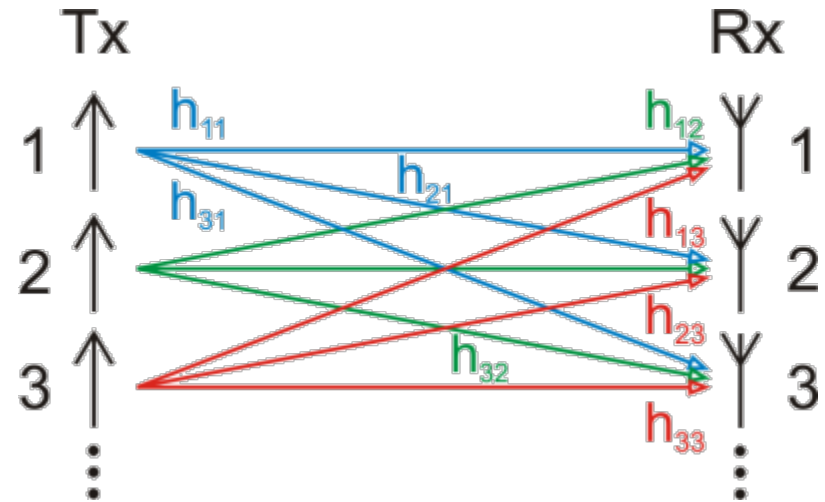


# Improved Communications Protocols

- Multiple-Input Multiple-Output (MIMO)
- Space-Division Multiplexing

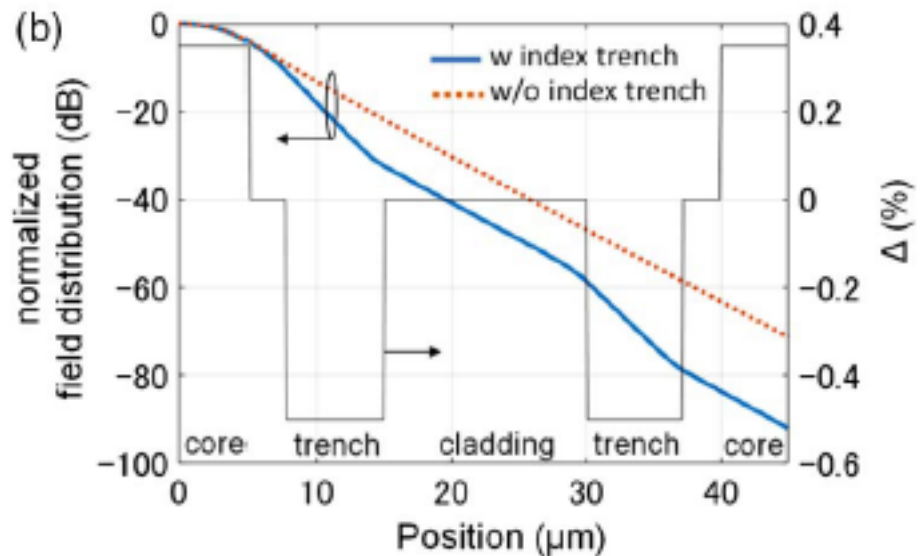
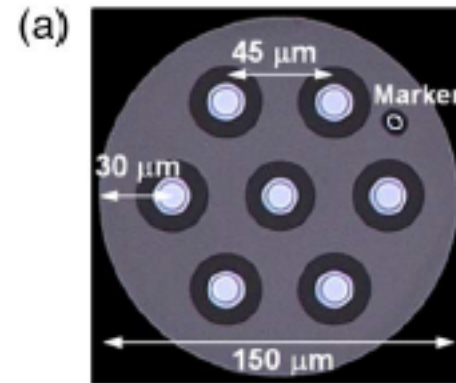
# Multiple-Input Multiple-Output (MIMO)

- Uses multiplexing inputs and outputs to increase bandwidth
- Concept originally developed to exploit the principle of multiplexing gain
- Works well with digital signal processing



# Space-Division Multiplexing

- Exploits spatial degree of freedom in multicore fibers
- Must track crosstalk, loss, and cutoffs across a range of scenarios

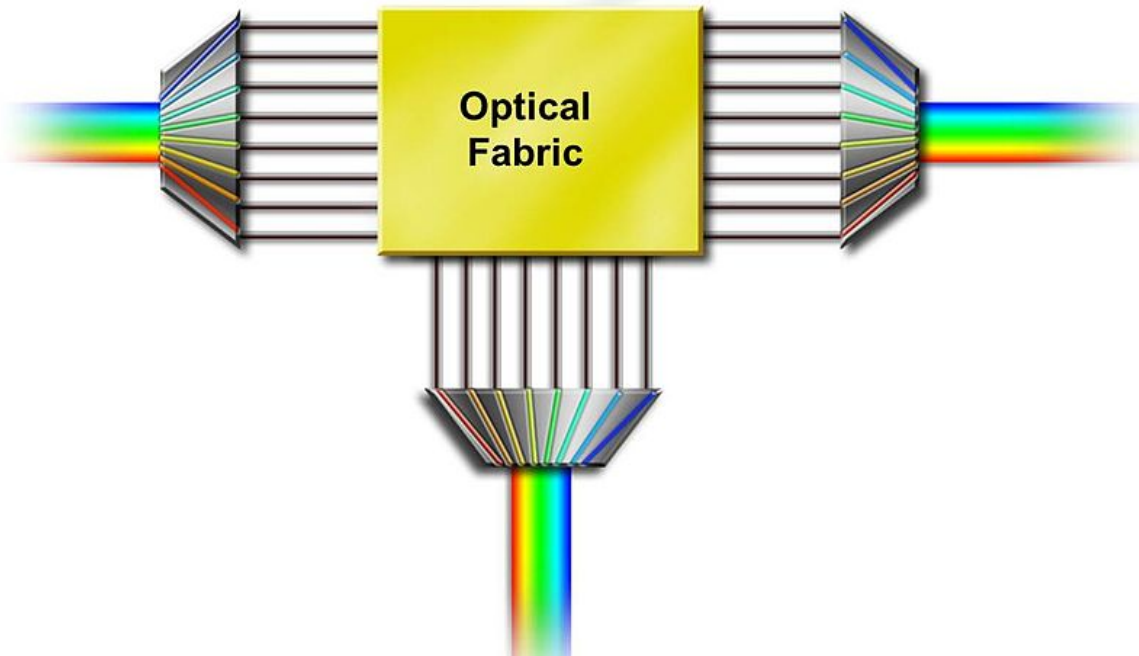


Klaus et al., J. Opt. Commun. Networks (2017)

# Fiber Optic Communications

## Lecture 11: Networking Growth

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# Novel Networking Concepts

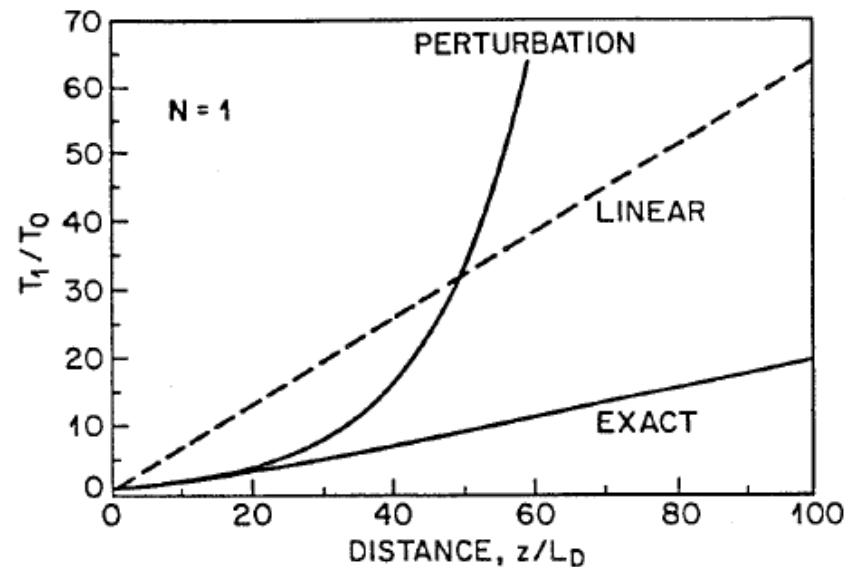
- Solitons
- Air/Space-Based Telecommunications
- Quantum Networks

# Solitons

- A stable nonlinear mode that can travel a long distance. Represented as solutions to:

$$i \frac{\partial u}{\partial \xi} + \frac{1}{2} \frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = 0.$$

- Broadening can be substantially below linear case



# Air/Space-Based Telecommunications

New unmanned aerial vehicles can maintain continuous telecommunication links

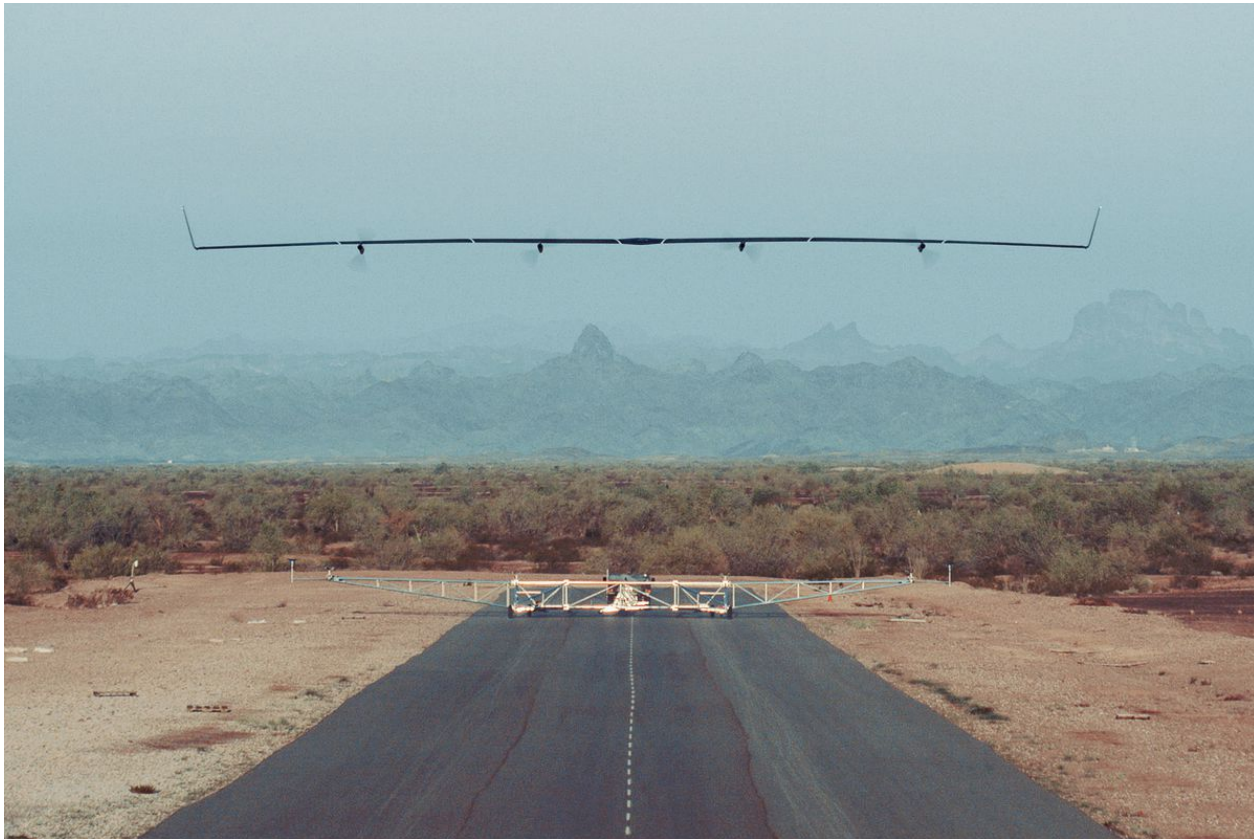
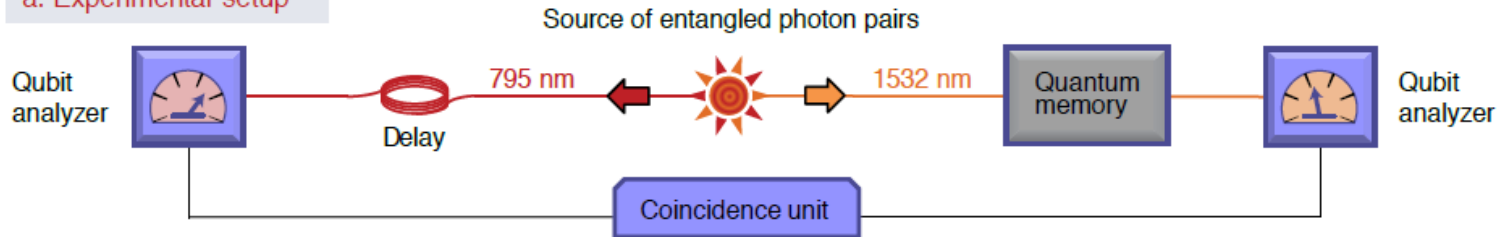


Photo courtesy of Facebook Corporation

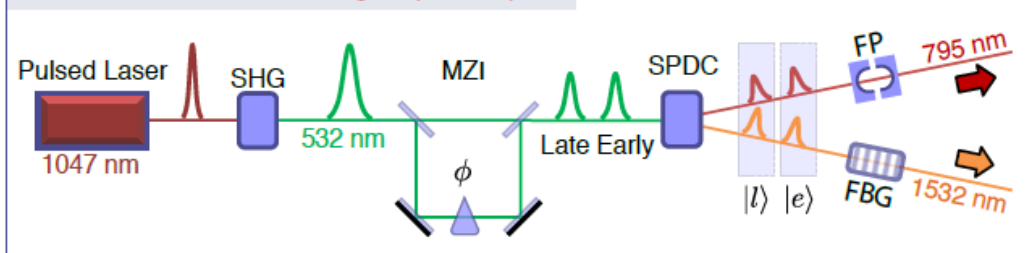


# Quantum Networks

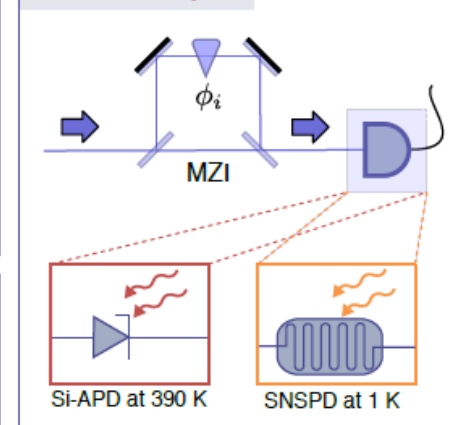
a. Experimental setup



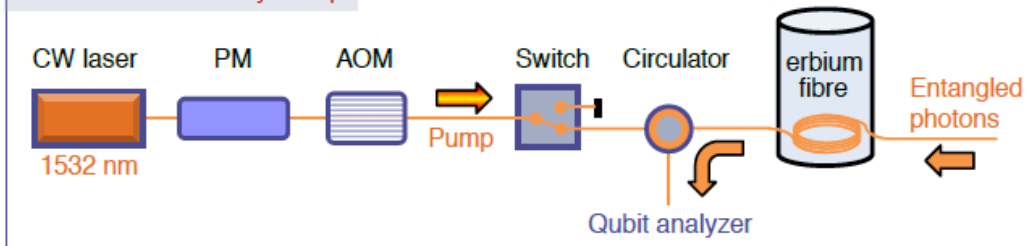
b. Source of time-bin entangled photon pairs



c. Qubit analyzer



d. Quantum memory setup



Legend

 : Mirror
  : Beam splitter

Saglamyurek et al., Nature Photonics 9, 83-87 (2015).