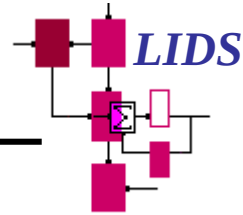

WDM Networks for Defense Applications

(DARPA Workshop, April 19, 2000)

by

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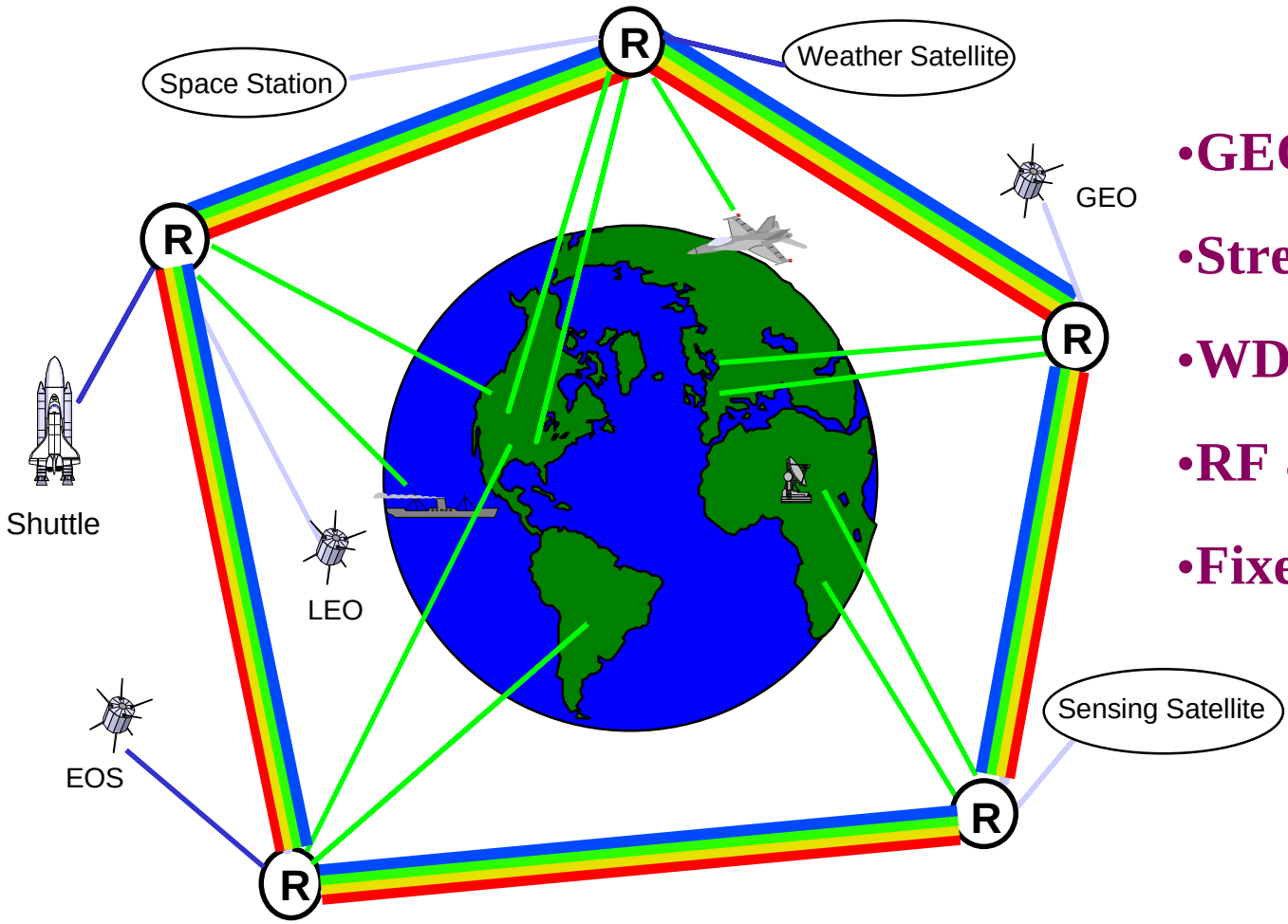
WDM Wide Area Network in Space



- GEO/MEO/LEO
- Streams & Packets
- WDM trunks
- RF & optical accesses
- Fixed/mobile users

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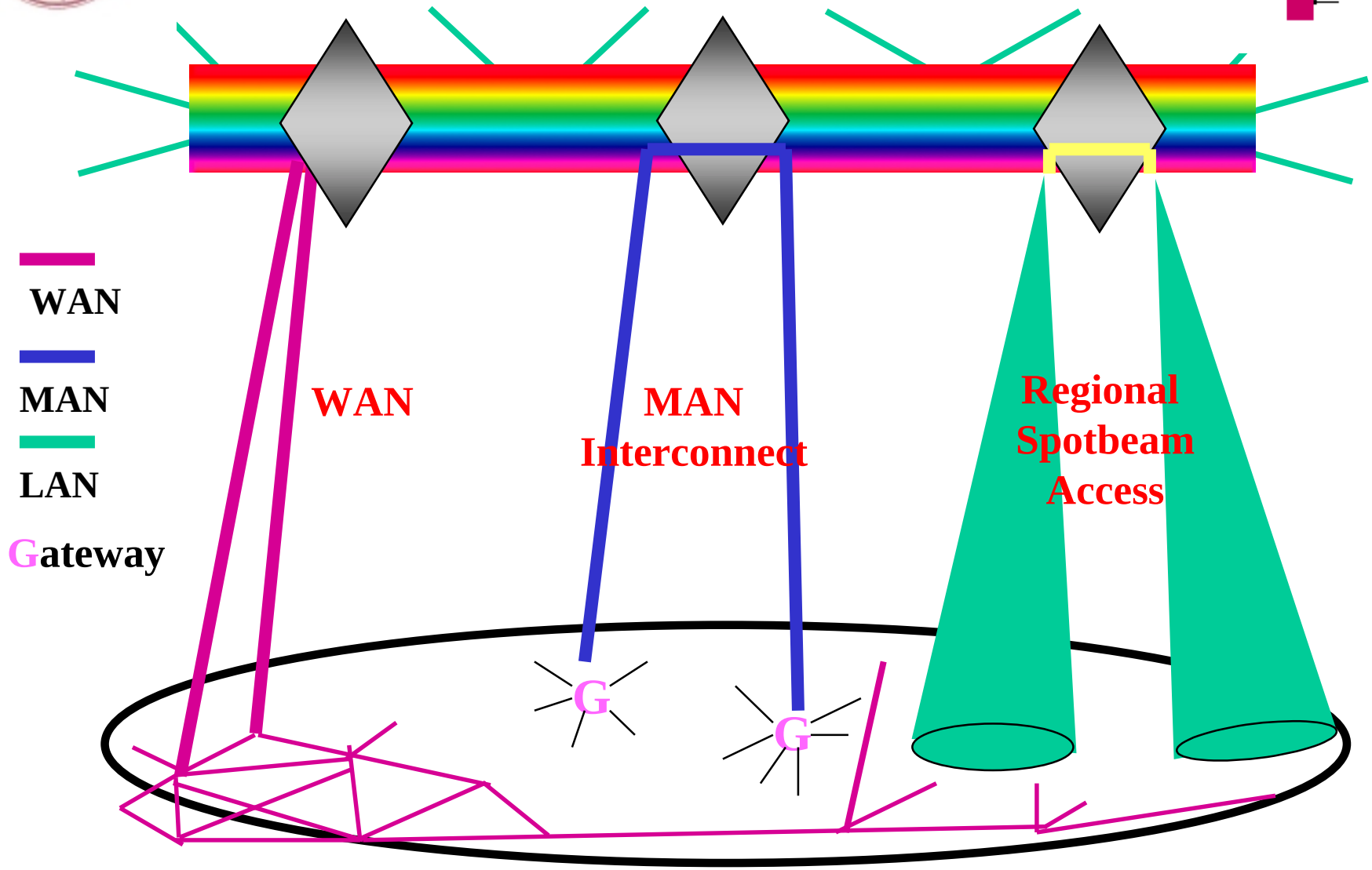
4-D Global Network



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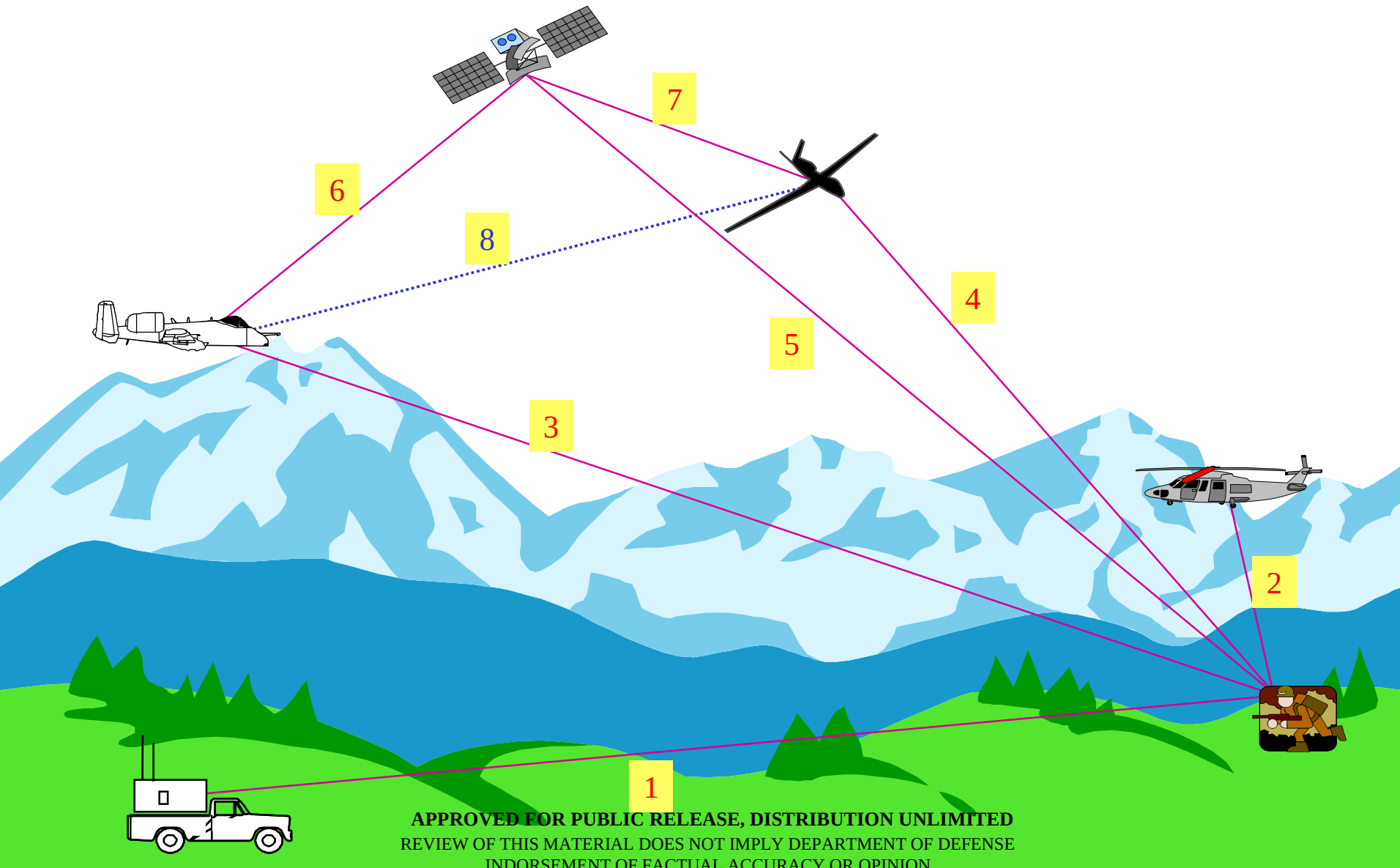
Battlefield Communications and Networking



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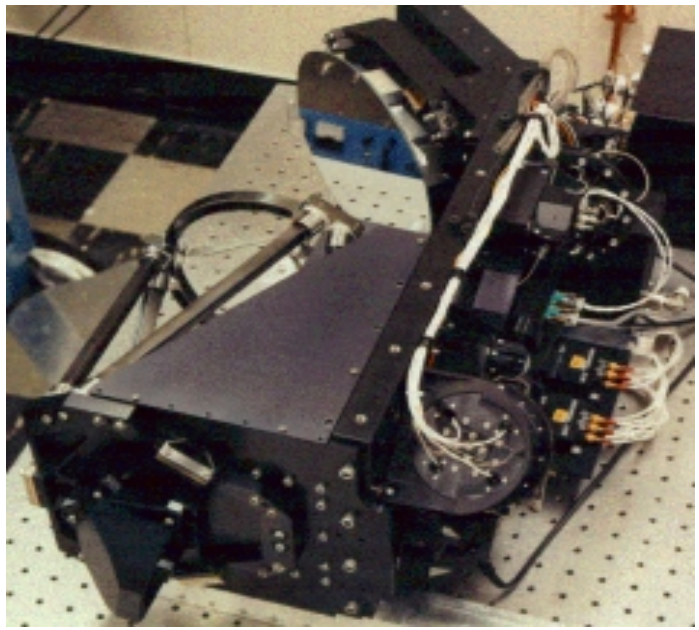
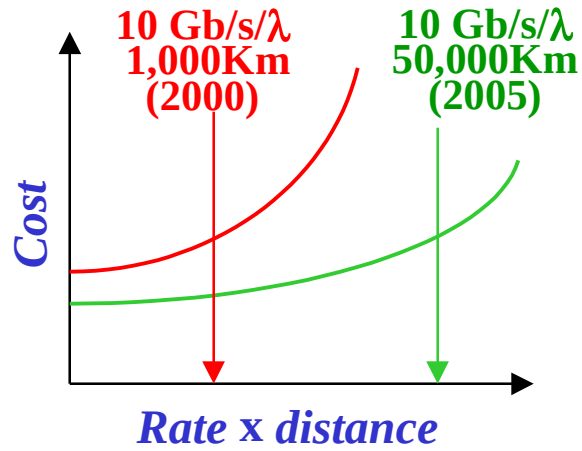
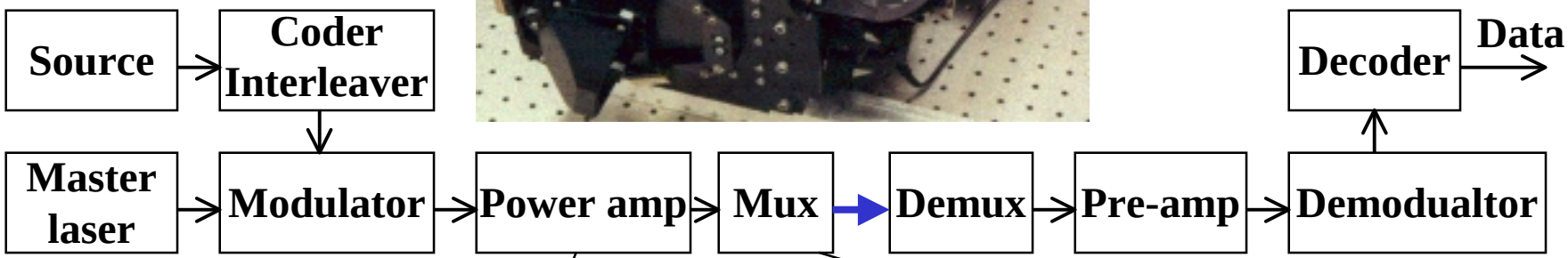
Optical Space Cross-Link

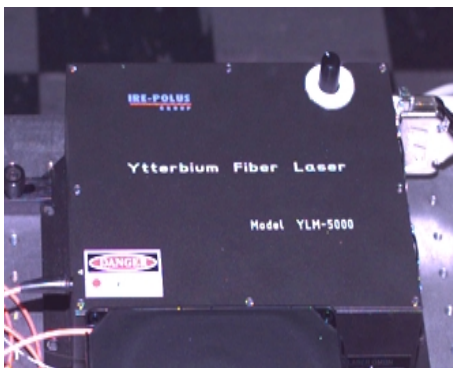
LIDS

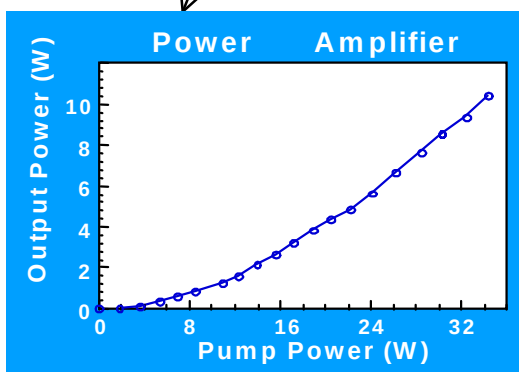
- Space backbone
- Digital or analog
- On-board demod
- Transponded
- E/O routed

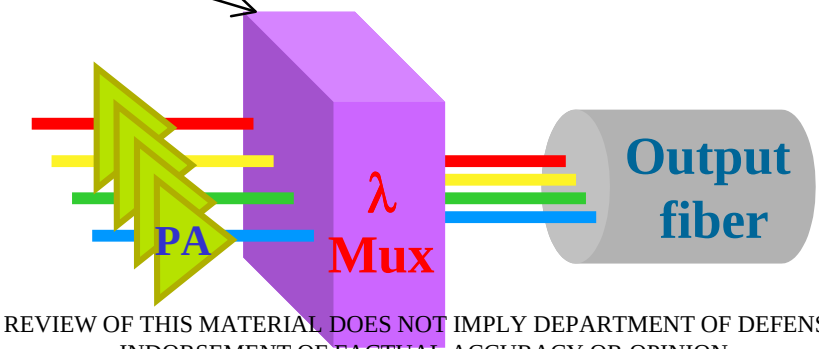












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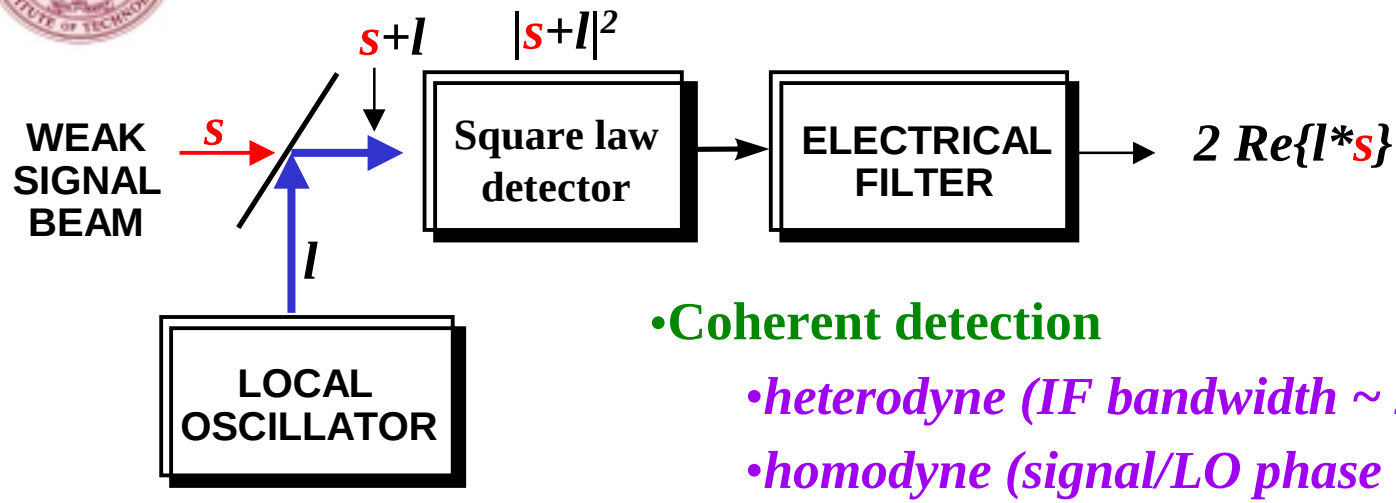
Structured Receivers



- **Coherent detection**
  - *heterodyne (IF bandwidth ~ 2 x data rate)*
  - *homodyne (signal/LO phase lock required)*
  - *30-50dB gain, quantum limit easily achieved*

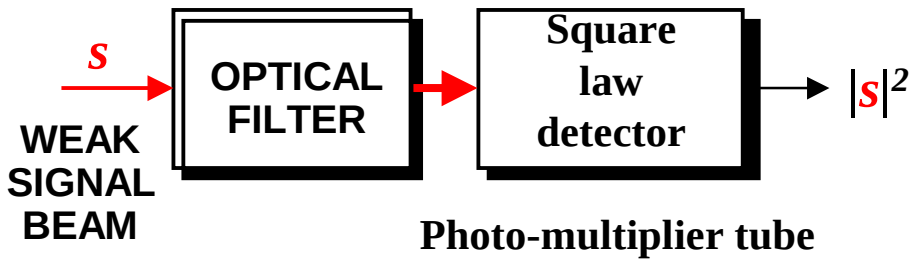


Photo-multiplier tube
Avalanche photo-detector
PIN-FET receiver

- **Direct detection**
  - *simple*
  - *noisy gain other PMT*
  - *PMT can achieve quantum limit (BW and QE limited)*

But quantum receivers are just over the horizons

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Bit Error Rate Performance

Signal Set	Direct Detection	Heterodyne Detection	Homodyne Detection	Quantum Optimum
On-off Signal	$2N_s$	$N_s/2$	N_s	$2N_s$
Orthogonal Signal (PPM, FSK)	N_s	$N_s/2$	N_s	$2N_s$
Antipodal Signal (PSK)	Not Applicable	N_s	$2N_s$	$4N_s$

Receiver performance comparison; probability of detection error, $\Pr[\varepsilon]$ for binary signaling

[1] Exponent θ of tightest exponential bound, $\Pr[\varepsilon] = e^{-\theta}$

[2] N_s = average number of detected photons per bit

Detection Scheme	Direct Detection	Homodyne Detection
Computation Cut-off Rate, R_0	1 nat/photon	1 nat/photon
Capacity, C	∞	2 nat/photon

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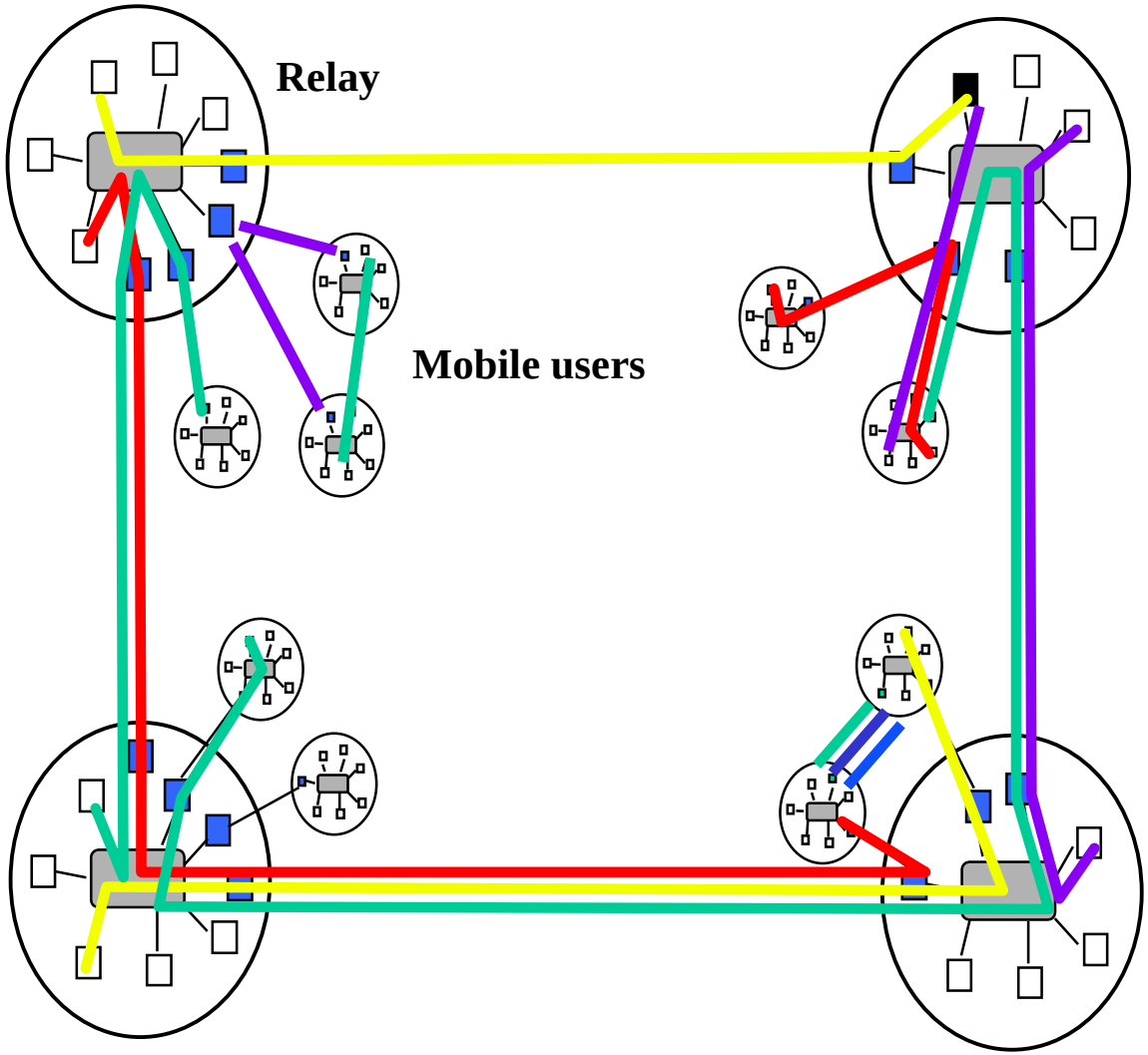
Node Concepts



- e/o switching/routing
- Streams/packets
- Interconnect with RF
- Analog links

= S/C LAN

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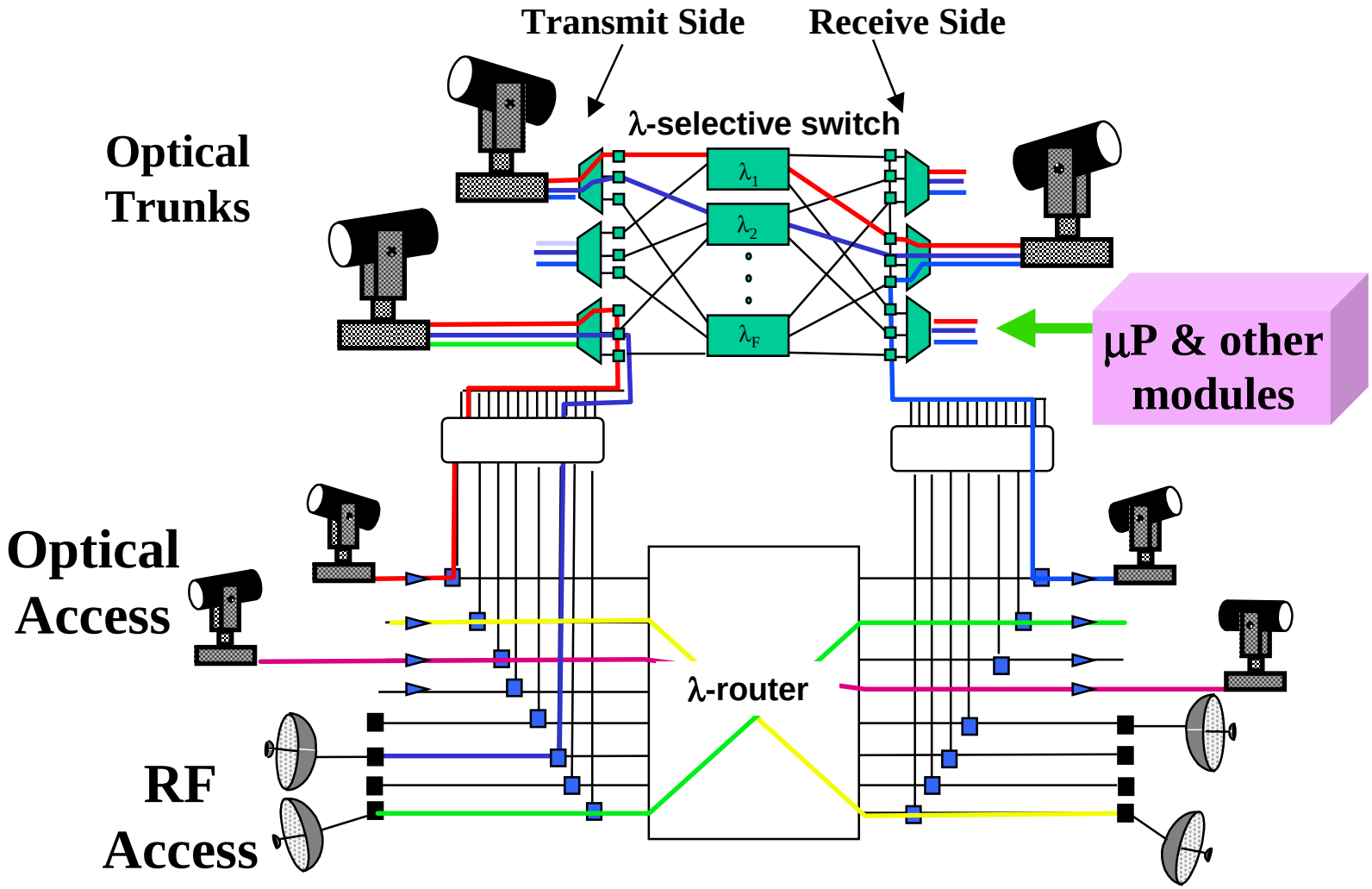
Spacecraft LAN Architecture



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ONRAMP Regional Access Network
Physical Architecture

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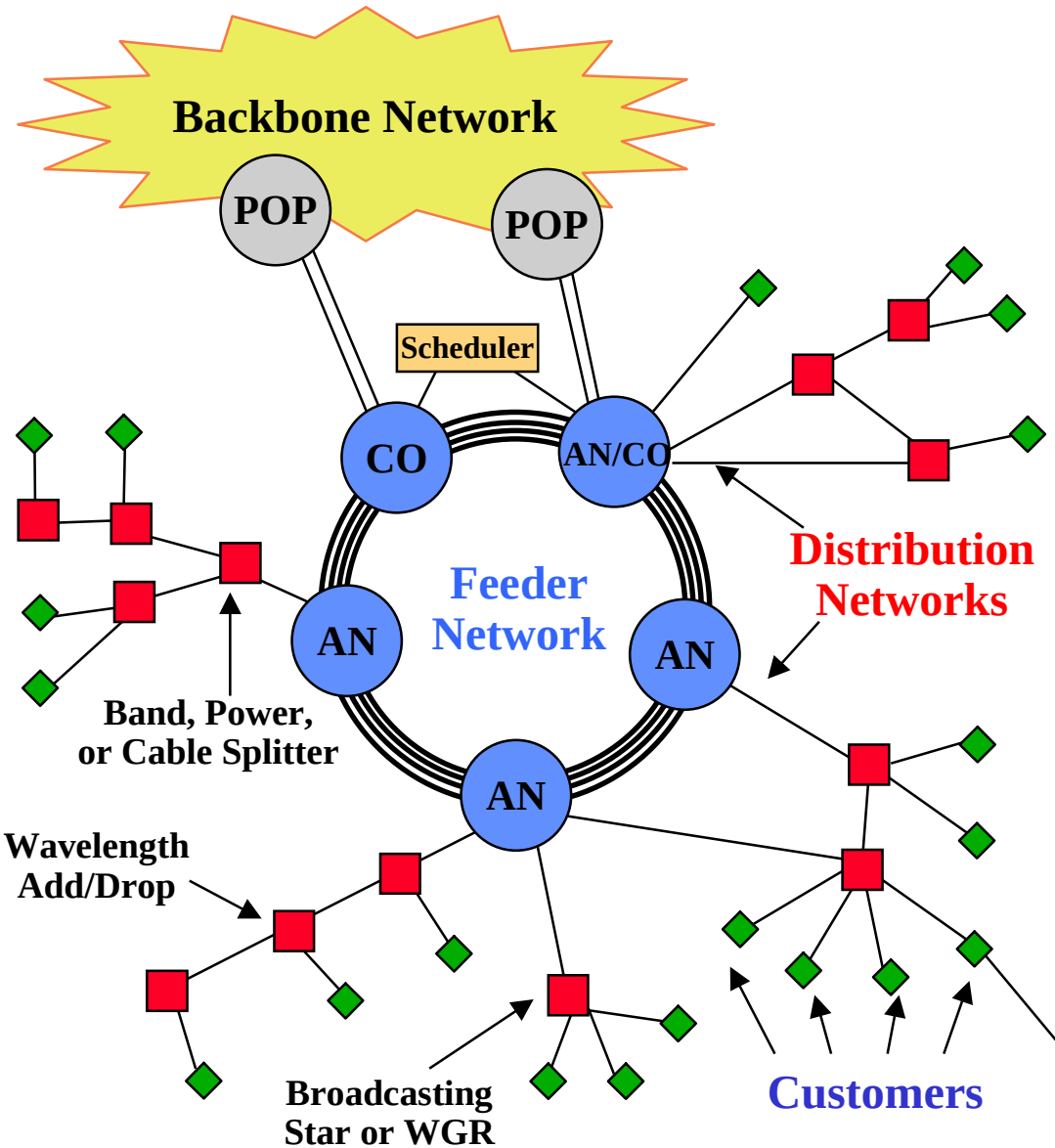

- **Feeder network**
  - *Active*
  - *Multi-fiber WDM*
  - *Configurable access nodes*
  - *Banded add/drop*
  - *Full restoration*
- **Distribution network**
  - *Passive*
  - *WDM*
  - *Tree/Bus/Ring topology*
- **End-to-end light paths**
  - *MAC protocol setup*
  - *Local/global coordination*
  - *Efficient multicasting*

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Optical Flow Switching and Bypass

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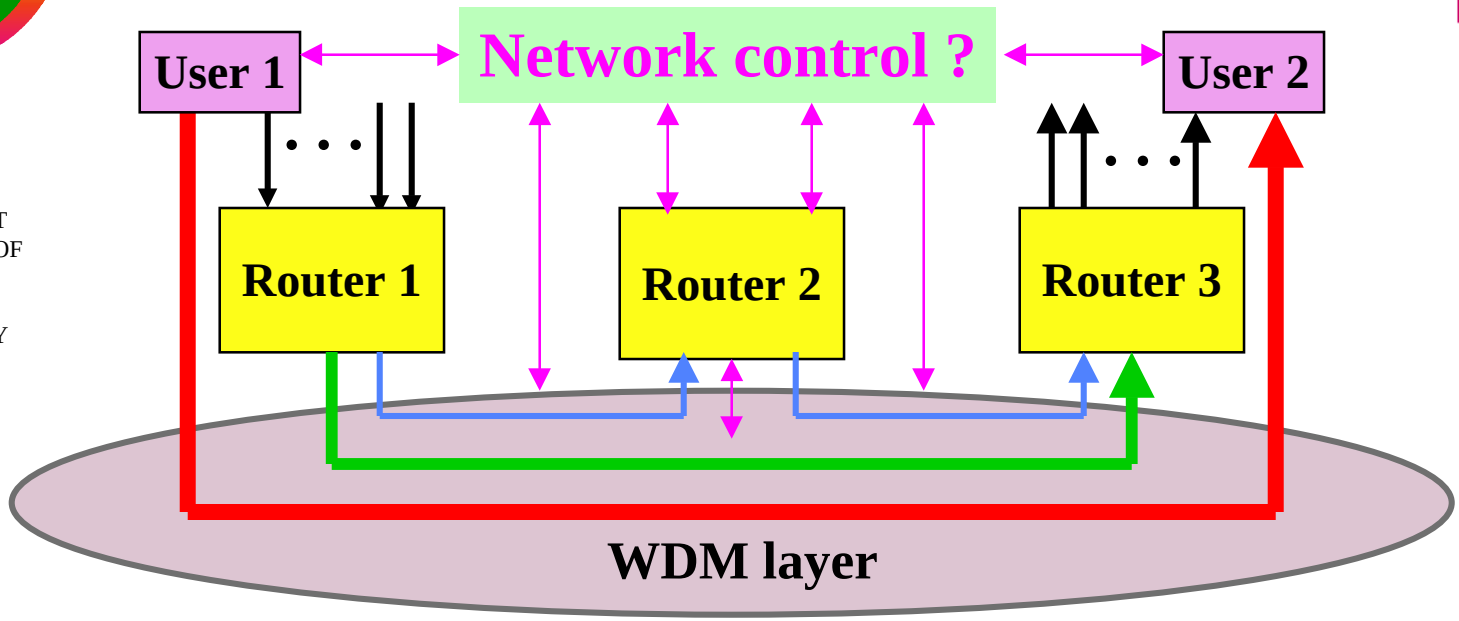

- **Conventional packet routing**
- **Optical bypass of intermediate routers for high volume traffic**
- **End-to end (user-to-user) flow of entire file bypassing routers**
  - *~ 1 S duration or longer via fast end-to-end scheduling*
  - *MAC protocol for reservation request*
  - *Scheduling time ~ 100 mS*
- **Application and TCP/IP layers implications and modifications**
- **Network management and control**

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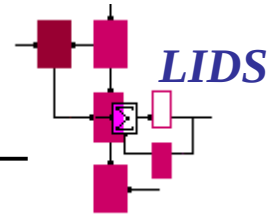
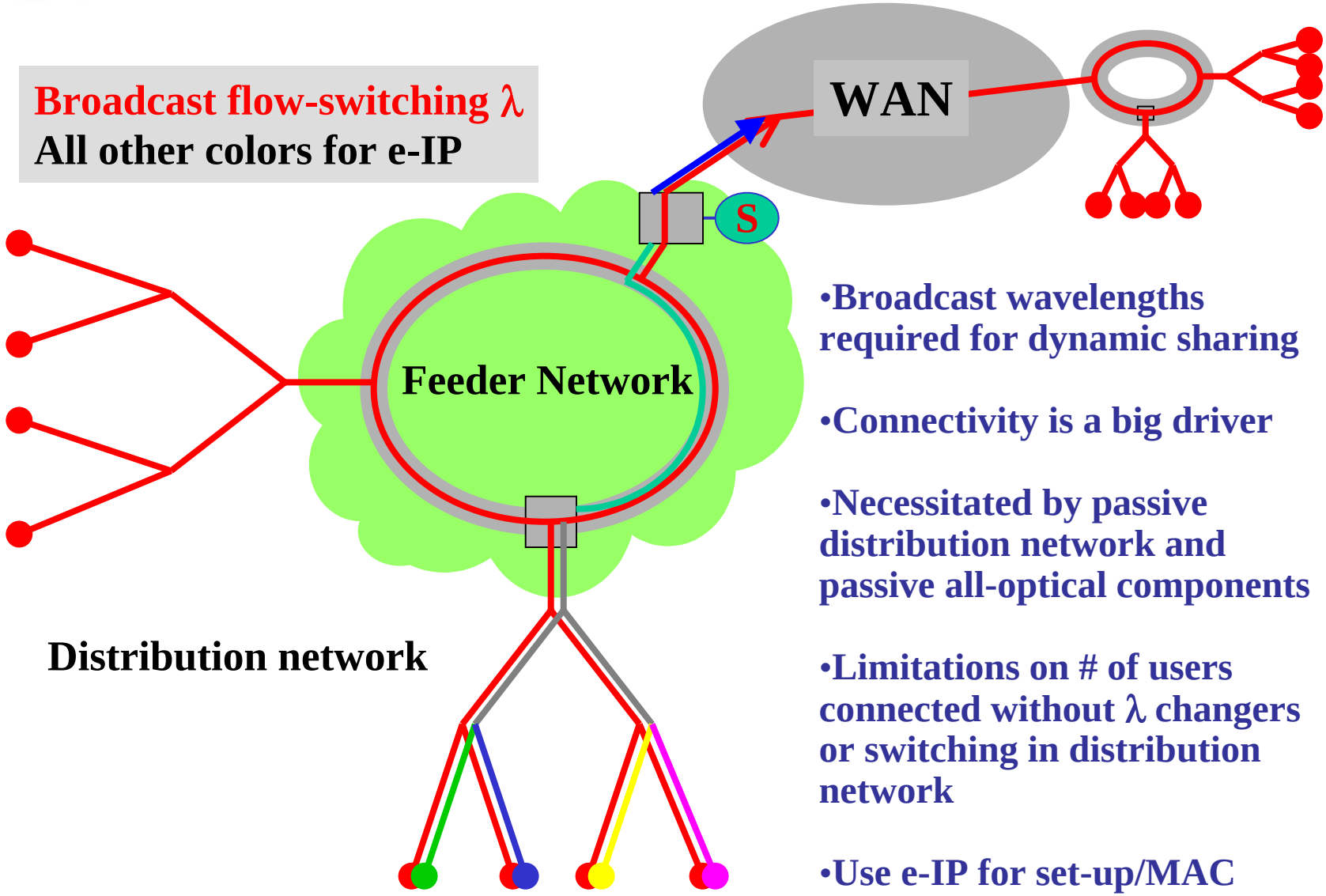
Flow Switching Physical Layer Architecture



Broadcast flow-switching λ
All other colors for e-IP



- **Broadcast wavelengths required for dynamic sharing**
- **Connectivity is a big driver**
- **Necessitated by passive distribution network and passive all-optical components**
- **Limitations on # of users connected without λ changers or switching in distribution network**
- **Use e-IP for set-up/MAC**
  Bounded jitter required

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LIST

1. High power efficient fiber amp (>20W)
2. Ultra-low loss WDM combiner (<0.1db)
3. Low-loss, low-crosstalk WDM components (>30db)
4. Photon counting receiver
5. Analog transmitter/receivers/amplifiers

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