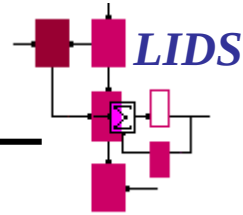


WDM Networks for Defense Applications

(DARPA Workshop, April 19, 2000)

by

Vincent W. S. Chan

Department of Aeronautics & Astronautics
Department of Electrical Engineering & Computer Science
Director, Laboratory for Information and Decision Systems
Massachusetts Institute of Technology
chan@MIT.edu

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
18 APR 2000	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
WDM Networking for Defense Applications	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

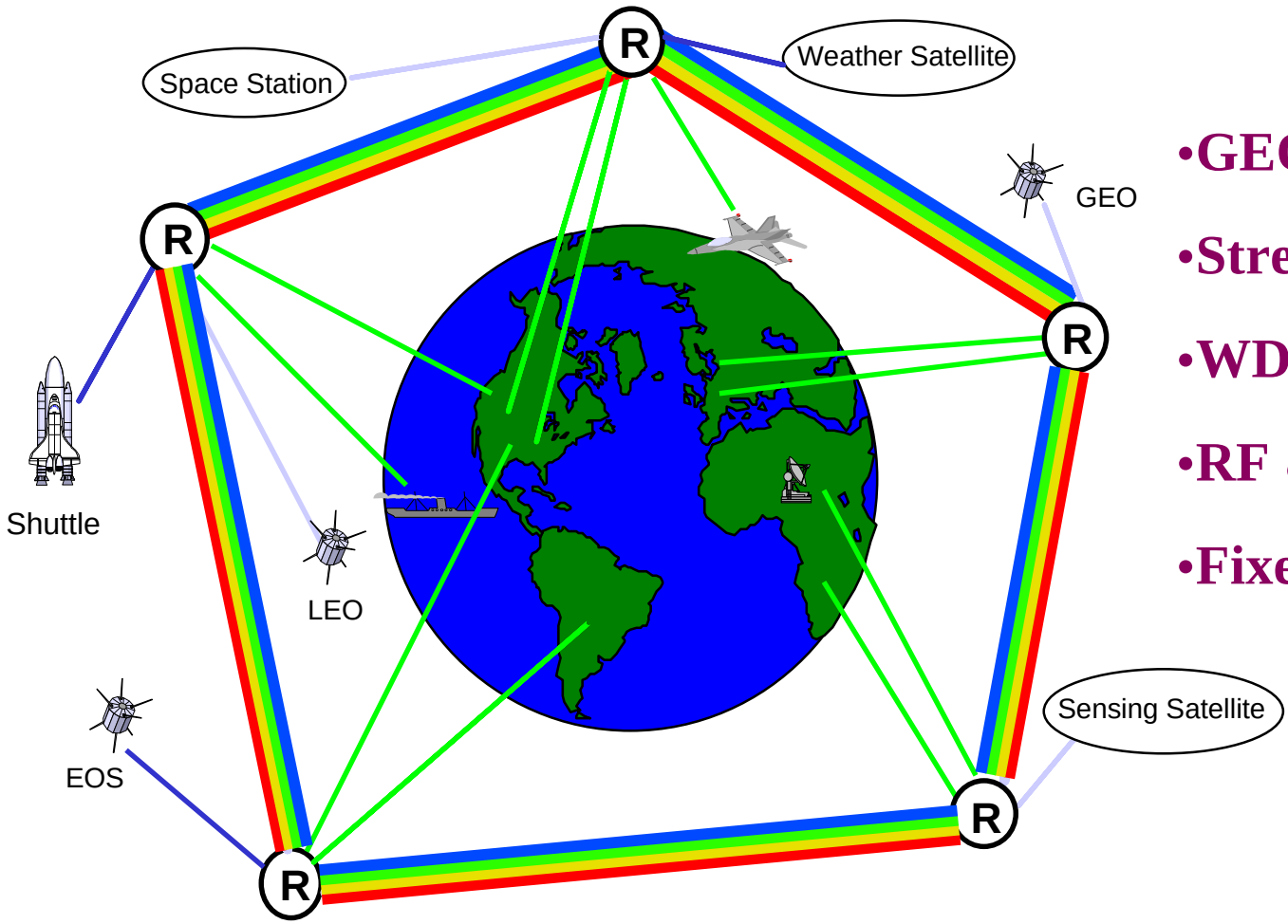
13. SUPPLEMENTARY NOTES
DARPA/MTO, WDM for Military Platforms Workshop held in McLean, VA on April 18-19, 2000, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**13**	

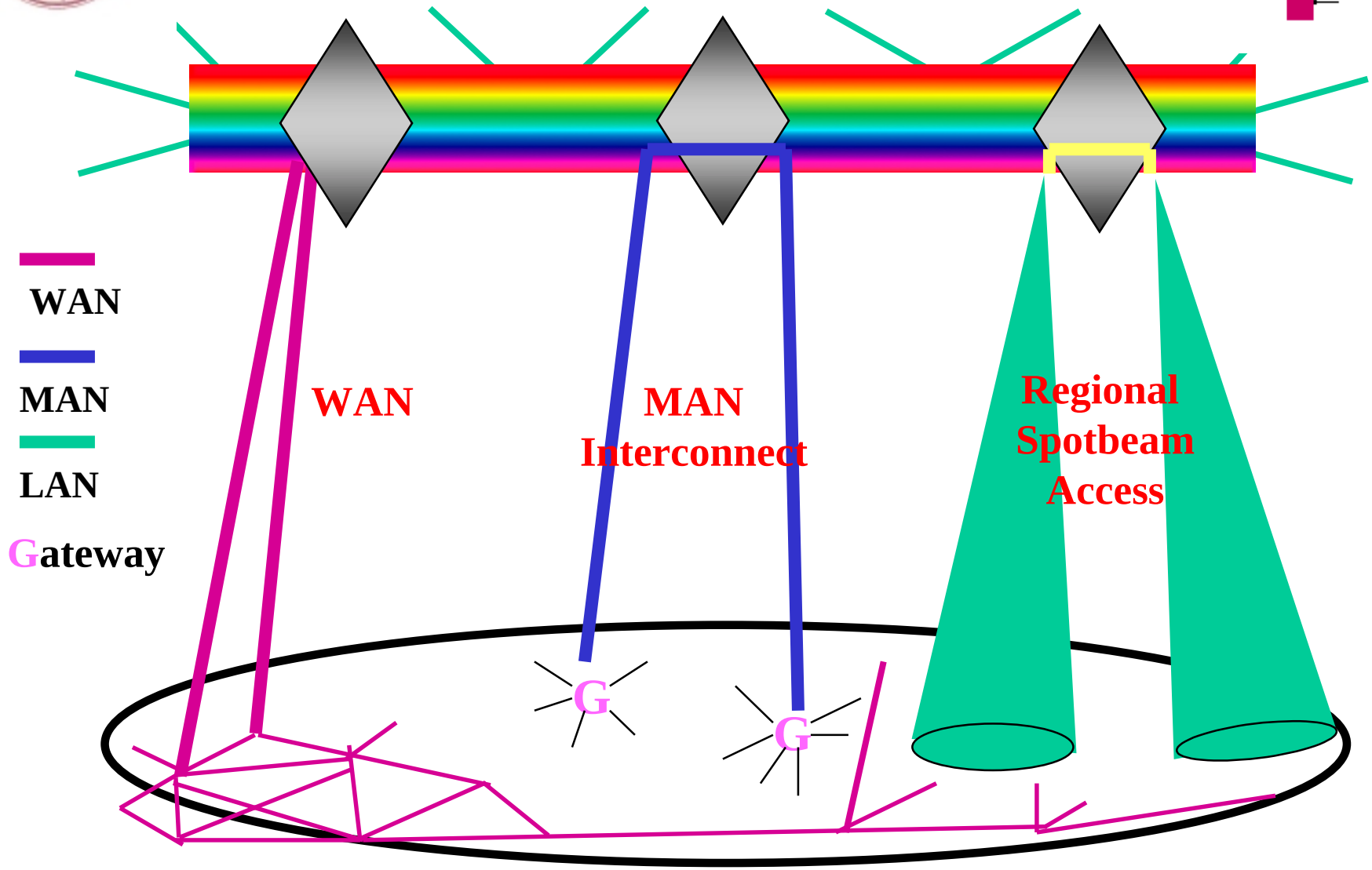
WDM Wide Area Network in Space



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

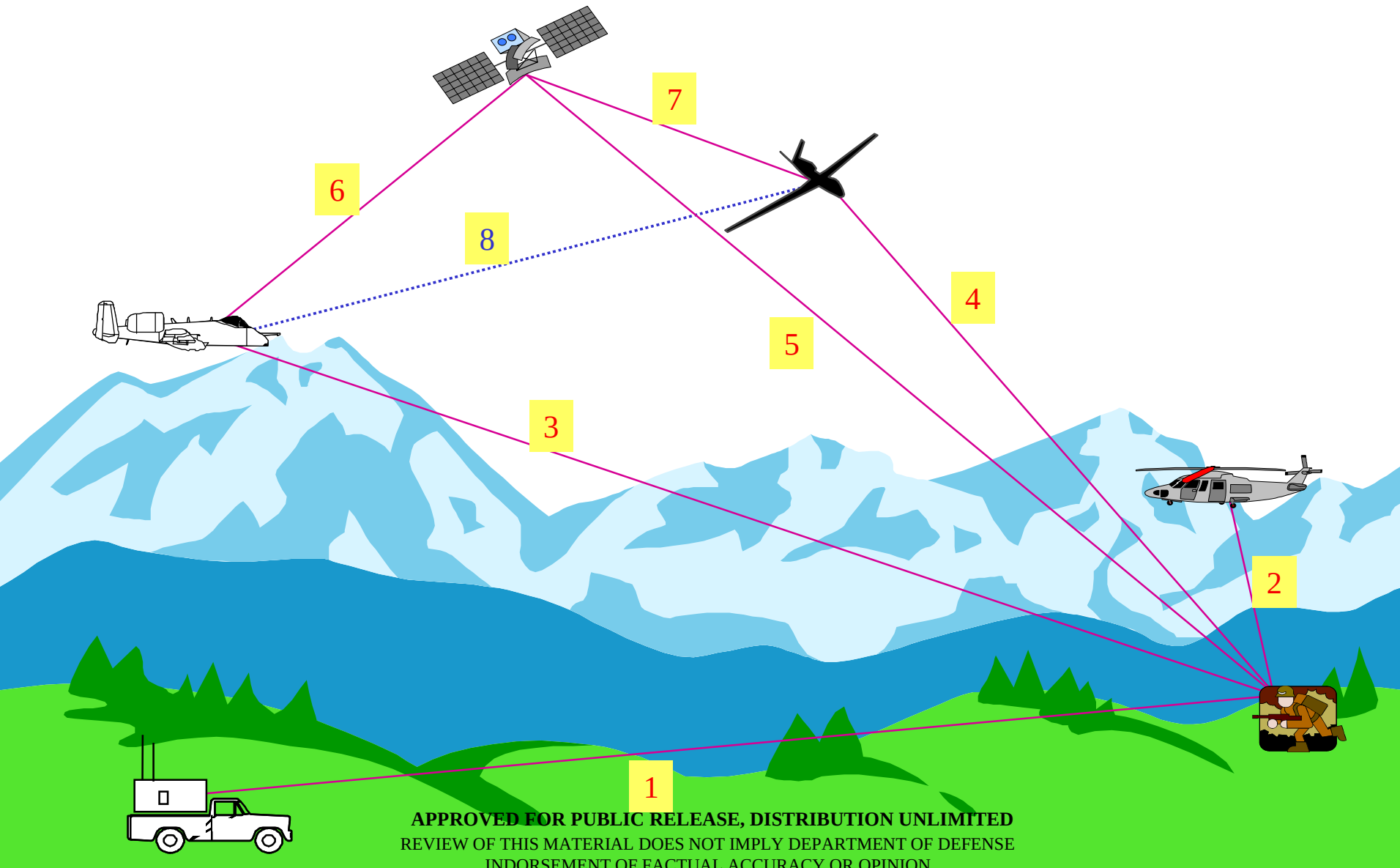
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

4-D Global Network



APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

Battlefield Communications and Networking



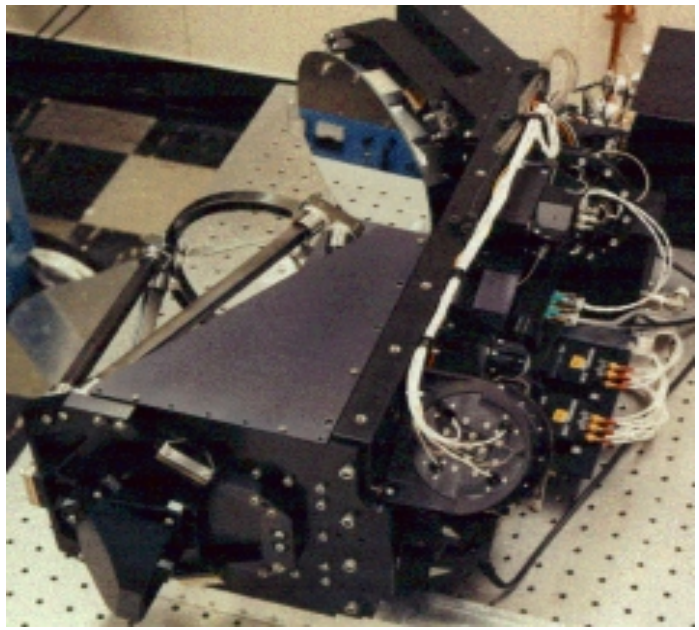
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

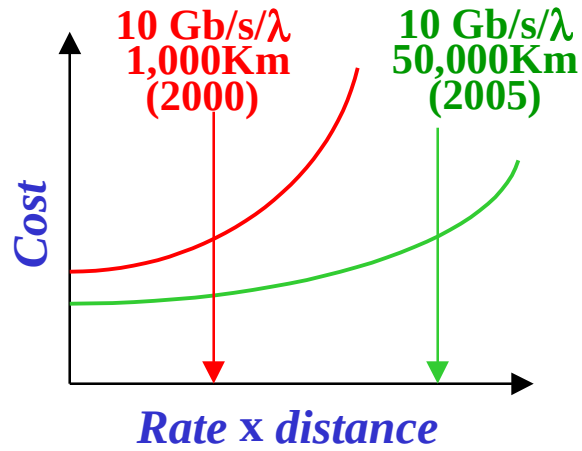
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

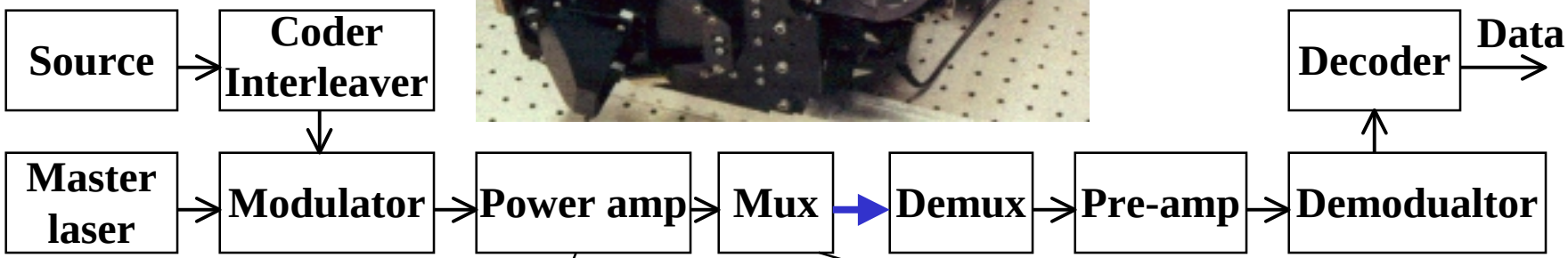
Optical Space Cross-Link

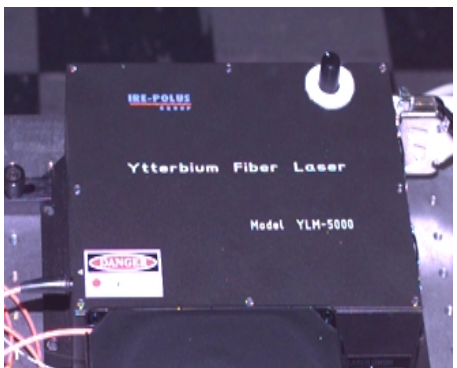
LIDS

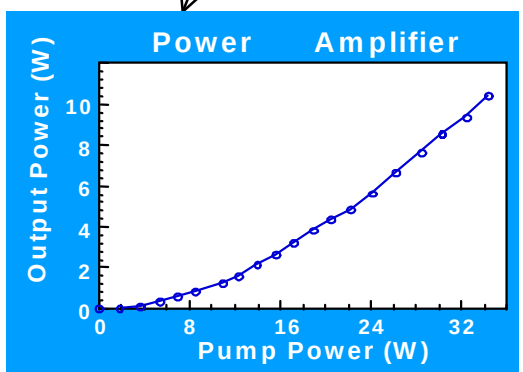
- Space backbone
- Digital or analog
- On-board demod
- Transponded
- E/O routed

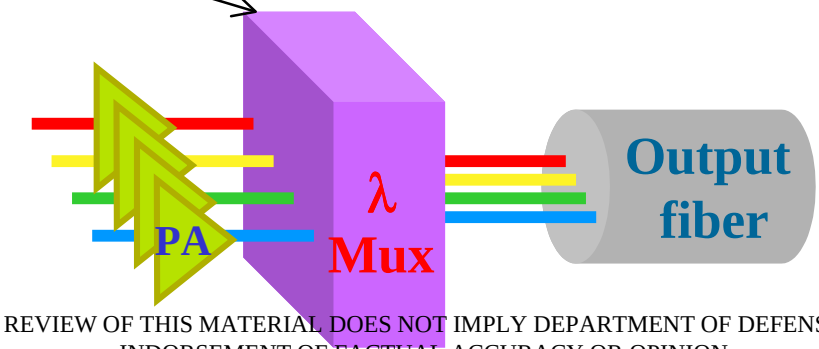






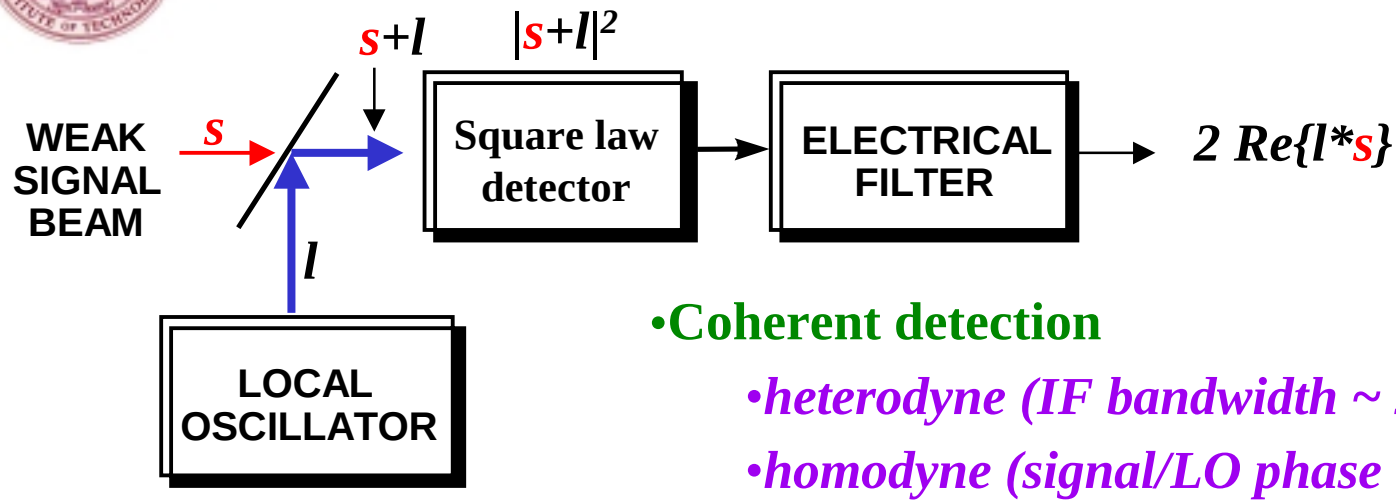






REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

Structured Receivers



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

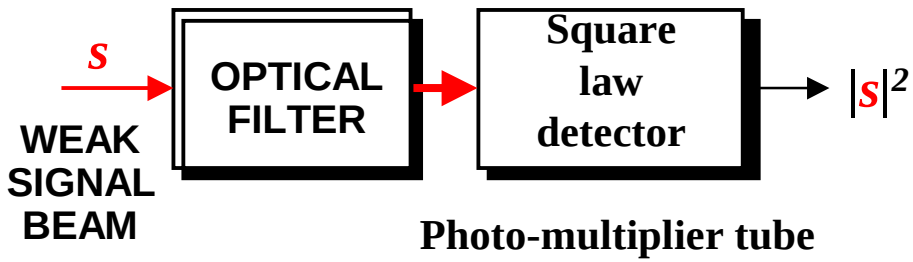


Photo-multiplier tube
Avalanche photo-detector
PIN-FET receiver

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

But quantum receivers are just over the horizons

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE INDORSEMENT OF FACTUAL ACCURACY OR OPINION

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

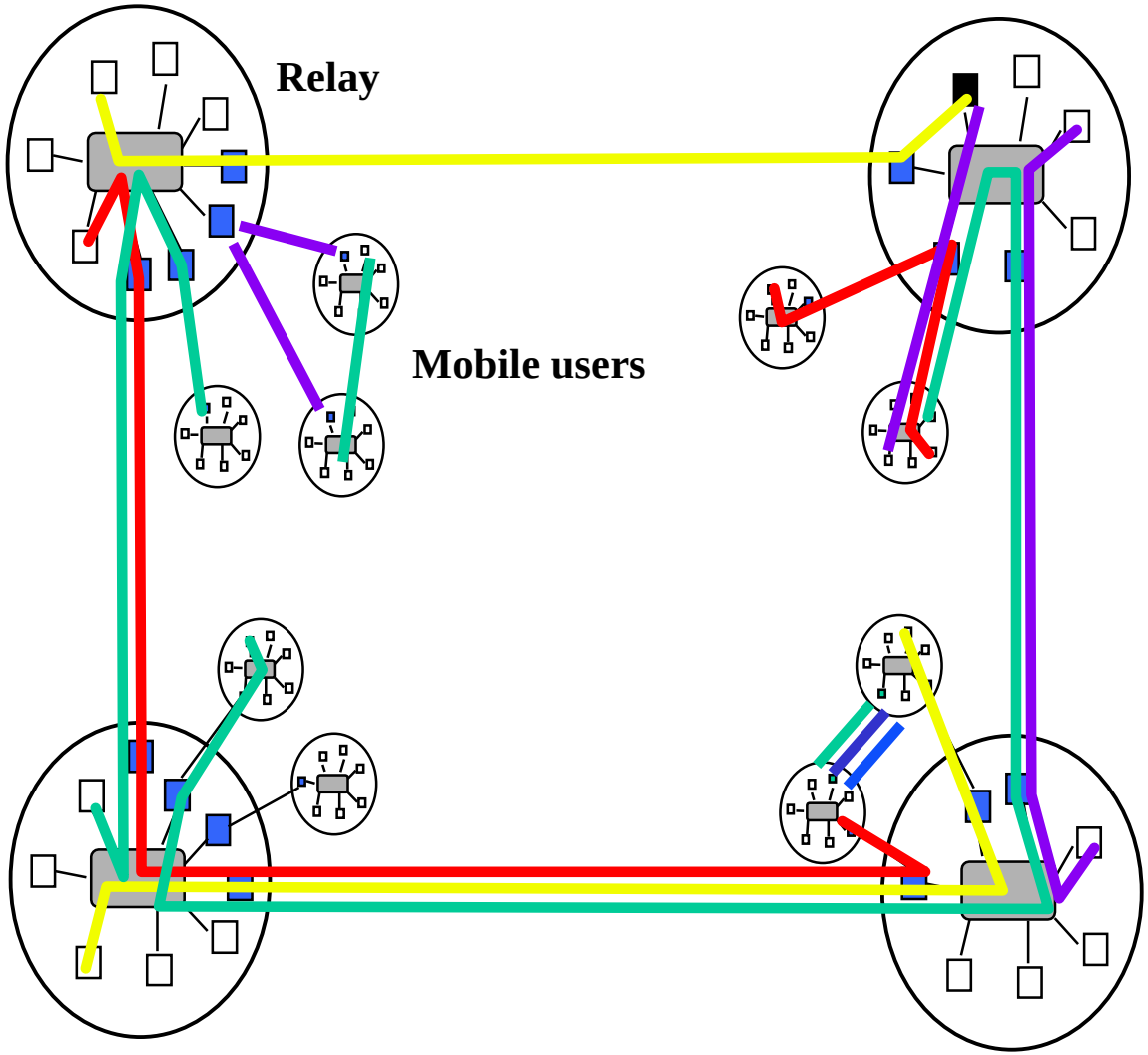
[1] Exponent θ of tightest exponential bound, $\Pr[\varepsilon] = e^{-\theta}$

[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

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

Node Concepts

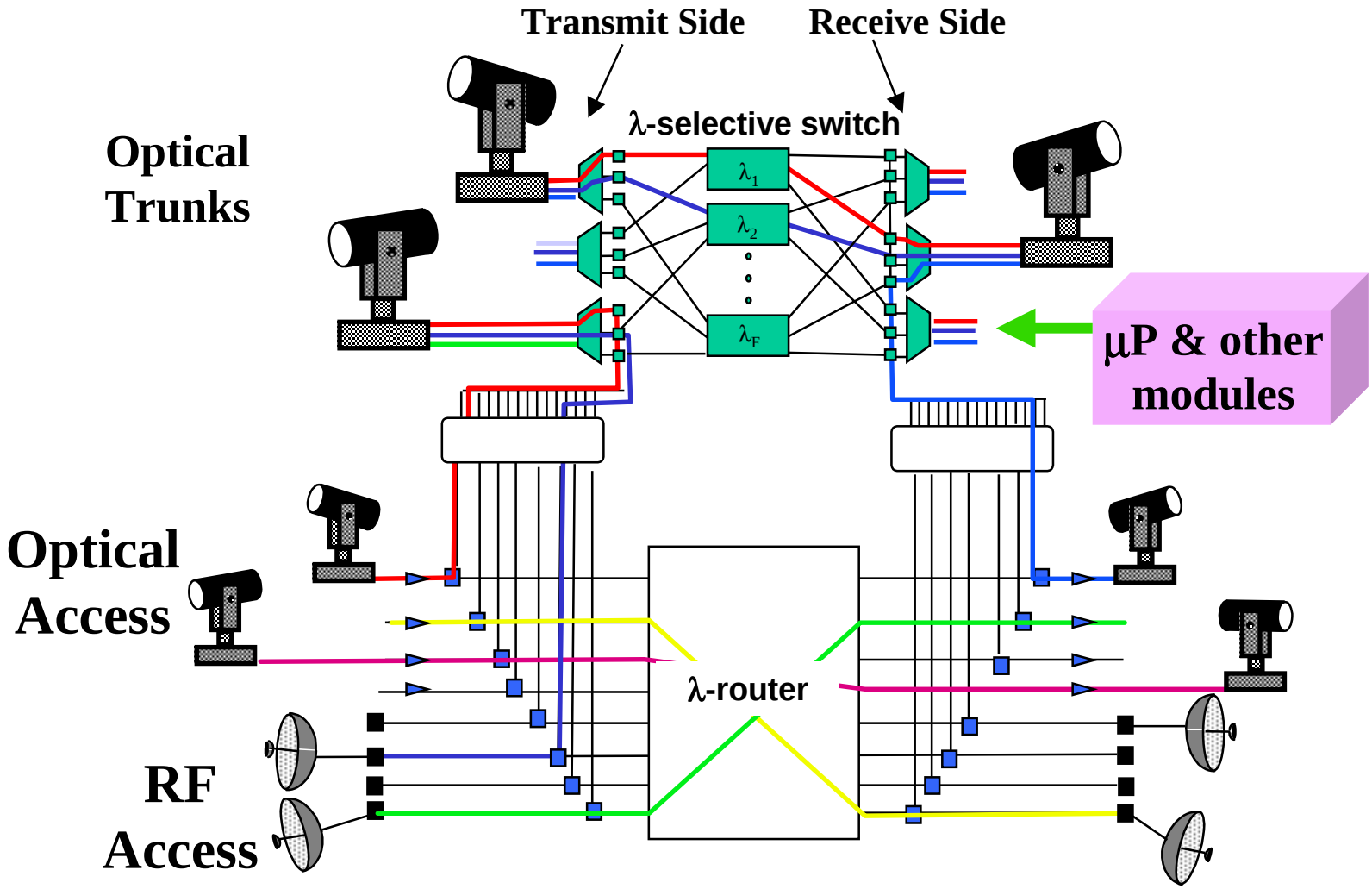


- e/o switching/routing
- Streams/packets
- Interconnect with RF
- Analog links

= S/C LAN

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

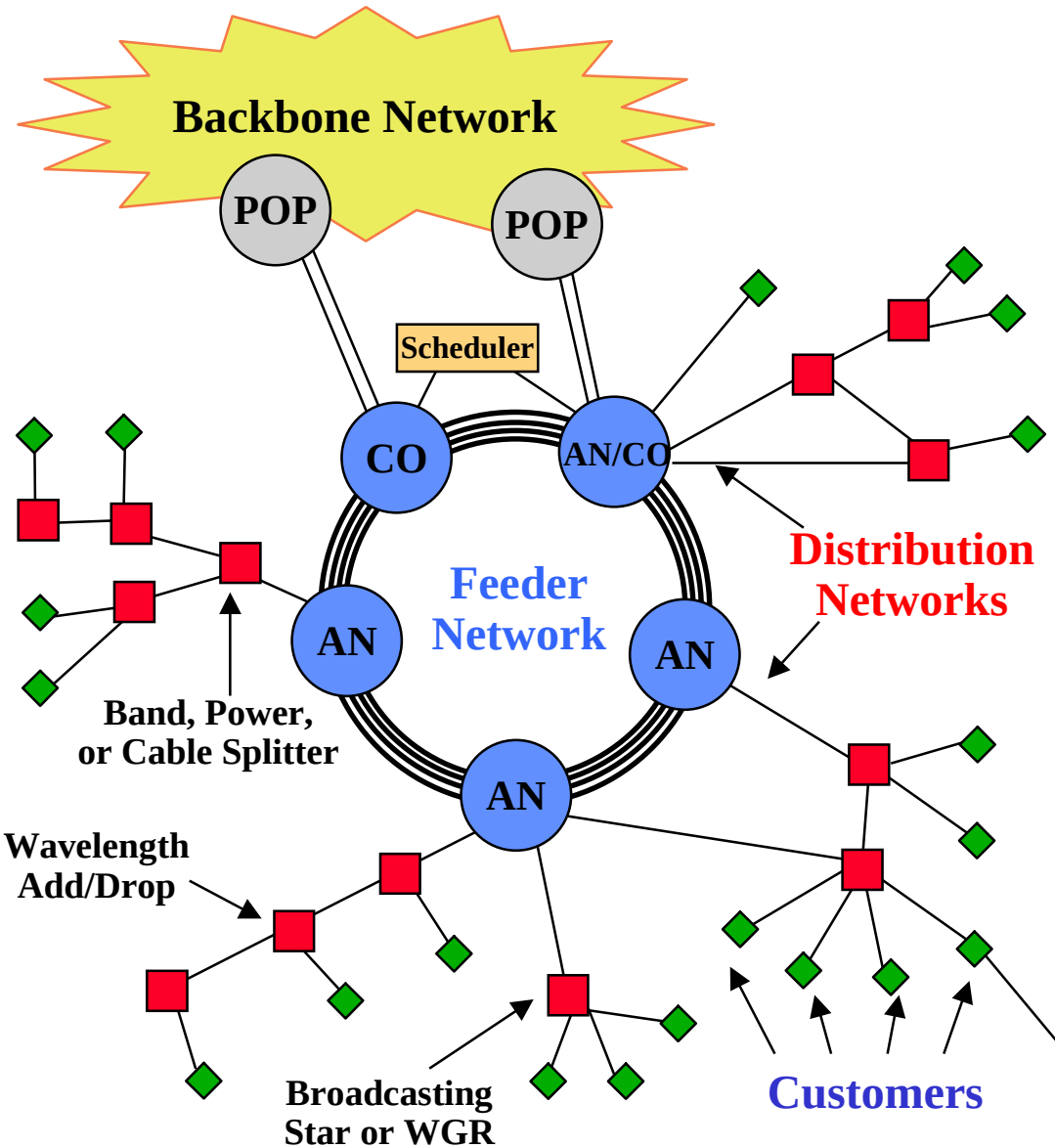
Spacecraft LAN Architecture



APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

ONRAMP Regional Access Network
Physical Architecture

REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION

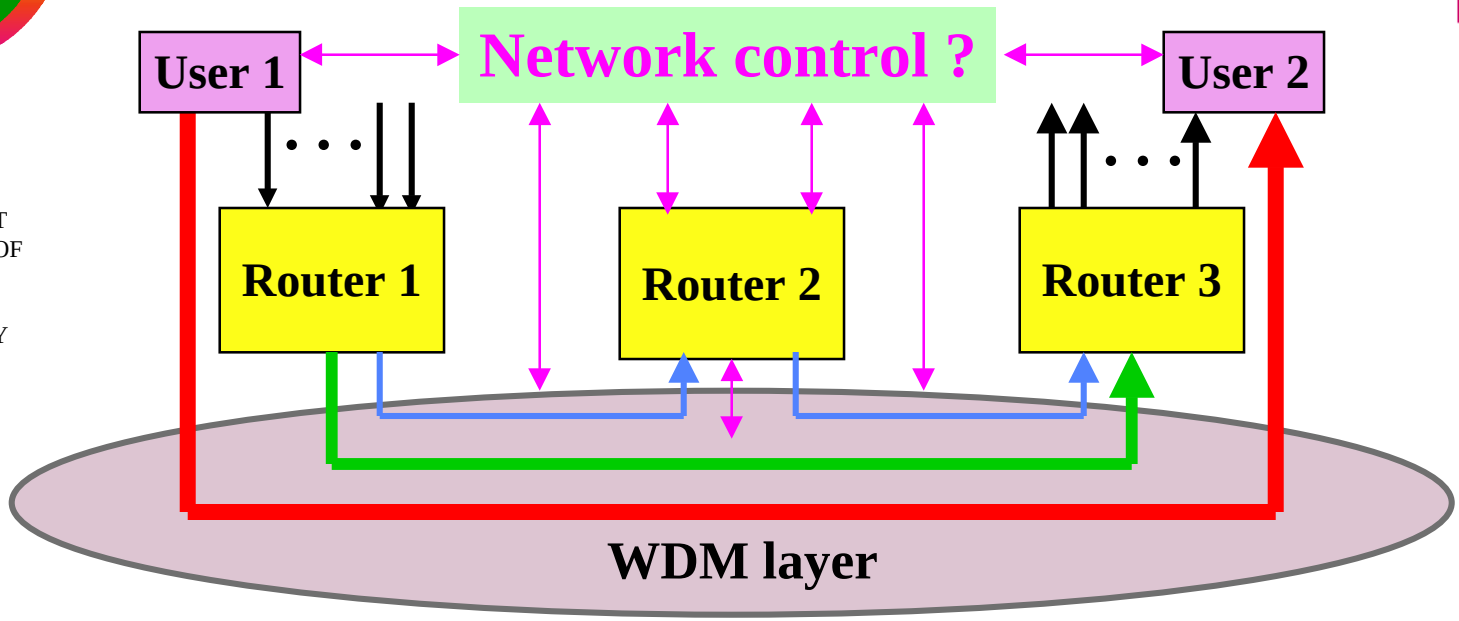


- **Feeder network**
  - *Active*
  - *Multi-fiber WDM*
  - *Configurable access nodes*
  - *Banded add/drop*
  - *Full restoration*
- **Distribution network**
  - *Passive*
  - *WDM*
  - *Tree/Bus/Ring topology*
- **End-to-end light paths**
  - *MAC protocol setup*
  - *Local/global coordination*
 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

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

Optical Flow Switching and Bypass

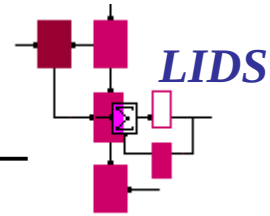
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE INDORSEMENT OF FACTUAL ACCURACY OR OPINION



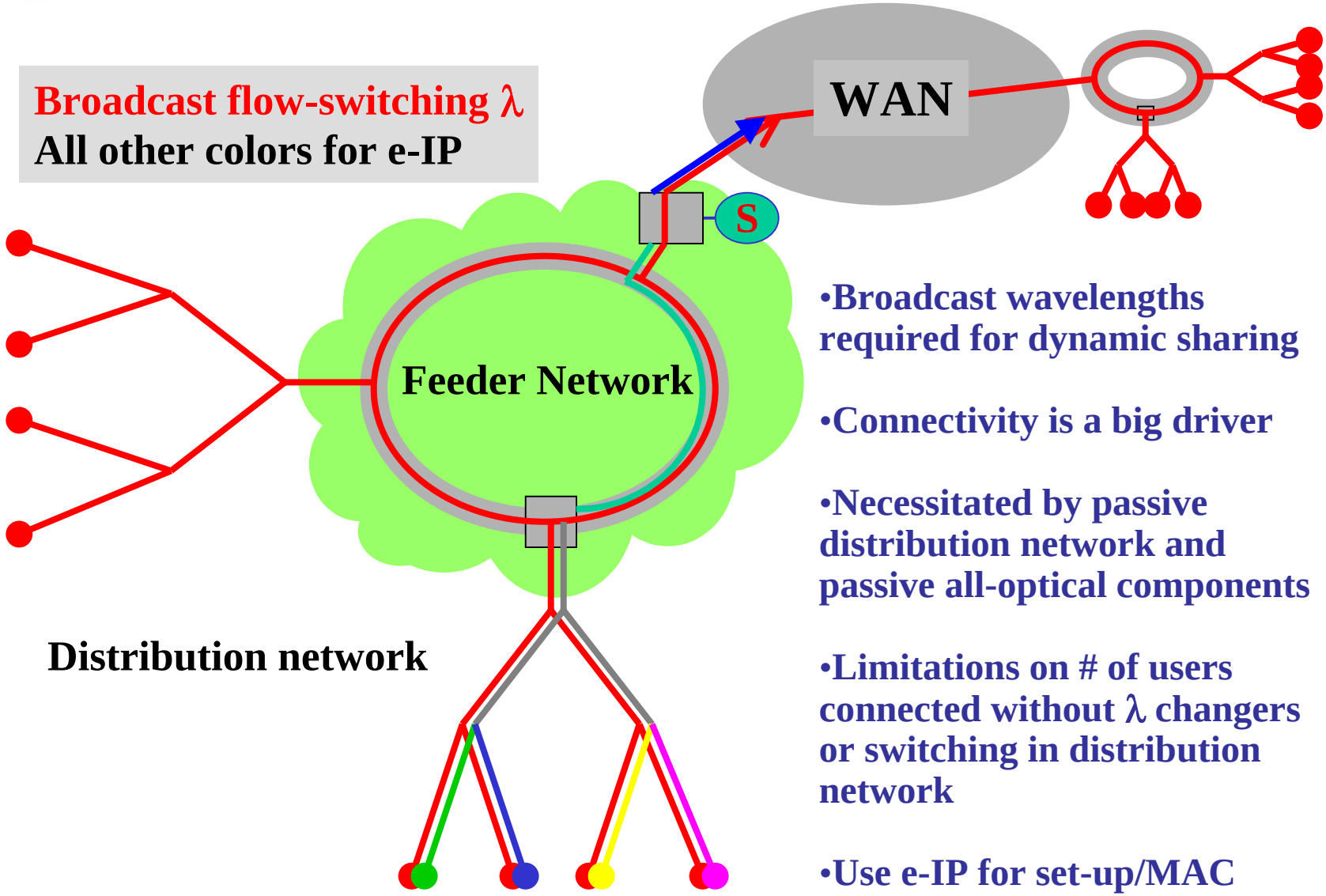
- **Conventional packet routing**
- **Optical bypass of intermediate routers for high volume traffic**
- **End-to end (user-to-user) flow of entire file bypassing routers**
  - *~ 1 S duration or longer via fast end-to-end scheduling*
  - *MAC protocol for reservation request*
  - *Scheduling time ~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

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

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

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE INDORSEMENT OF FACTUAL ACCURACY OR OPINION

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

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE
INDORSEMENT OF FACTUAL ACCURACY OR OPINION