Module 5
Future Directions, Advanced Topics and a Question

What is

"Optical Internet?"

Read the suggested texts and references for this module

What is next?

On the the capacity limit and research directions

- Substantially unlimited capacity (Tera Hertz) in the future
    - Reduce spectral spacing
    - Optical spread spectrum transmission
    - Optical Time Division Multiplexing (OTDM)
    - Optical Code Division Multiplexing (OCDM)
    - Chirped WDM-TDM
    - Other
- **Bandwidth is no longer the issue**
- **Bandwidth Management is the challenge**

Data Networking Directions

Near-term:

Service layer and transport layer internetworking

- Optical Transport Networking
- More intelligence at the transport layer

Optical Technology Directions?

- Potential commercialization of hi speed optical logic arrays
- Potential development of high speed optical processors

Then in the long-term future

- All-Optical routers?

$$\sum_{\iota=1}^{N} \lambda \iota$$

What Is All-optical Internet? Some Thoughts and Views

Which of the following alternatives do you see?

1. **Mimic Electrical Internet**
    –   **Needs embedded labels (headers and trailers)**
    –   **Needs optical storage (flip-flops) and processors**
    –   **Far Future**

2. **Electronic routers with optical transport**
    –   **Today**

3. **Practical Vision**
    –   **No O/E/O conversion and electronic processing (except at edges of the Internet)**
    –   **Dynamically reconfigurable wavelength-based all-optical network**
    –   **Optical signaling**
    –   **Near-Term Future**

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An Optical Barcode Label Is Needed

- So we also need a barcode tag, a barcode reading mechanism, and preferably a barcode writing mechanism on each wavelength package.

- And we want this barcode on the package, not inside the package. This means on the optical channel and not in the electrical bit stream.

- That is the motivation behind the proposed optical wavelength tagging.

Need All-Optical Wavelength Channel Label and Channel Trace means

A Look at the UPS Tracking Mechanism

UPS Package Tracking - Netscape

File   Edit   View   Go   Communicator   Help

UNITED STATES
UPS
WORLDWIDE OLYMPIC PARTNER
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Service Guide | Download | Customer Service | About UPS | Site Guide

TRACK   SHIP   QUICK COST   TRANSIT TIME   PICKUP   DROP-OFF   SUPPLIES
TRACKING NUMBER | REFERENCE NUMBER

Tracking Detail

Status:	**Delivered**
Delivered on:	Jan 15, 2001 12:13 P.M.
Location:	MC BOY
Delivered to:	MIDDLETOWN, NJ, US
Shipped or Billed on:	Jan 12, 2001
Tracking Number:	1Z 086 30E 03 4096 945 7
Service Type:	GROUND
Weight:	5.50 Lbs

PACKAGE PROGRESS

| Date	Time	Location	Activity
Jan 15, 2001	12:13 P.M.	TINTON FALLS-RED BNK, NJ, US	DELIVERY
	8:17 A.M.	TINTON FALLS, NJ, US	DESTINATION SCAN
	5:43 A.M.	TINTON FALLS, NJ, US	ARRIVAL SCAN
Jan 13, 2001	4:03 A.M.	PARSIPPANY, NJ, US	DEPARTURE SCAN
	2:46 A.M.	PARSIPPANY, NJ, US	LOCATION SCAN
	12:51 A.M.	PARSIPPANY, NJ, US	UNLOAD SCAN
Jan 12, 2001	10:53 P.M.	PARSIPPANY, NJ, US	ARRIVAL SCAN
	10:23 P.M.	SADDLEBROOK, NJ, US	DEPARTURE SCAN
	7:12 P.M.	SADDLEBROOK, NJ, US	ORIGIN SCAN
	3:05 P.M.	US	PICKUP MANIFEST RECEIVED

Tracking results provided by UPS: Jan 16, 2001 3:47 P.M. Eastern Time (USA)

NOTICE: UPS authorizes you to use UPS tracking systems solely to track shipments tendered by or for you to UPS for delivery and for no other purpose. Any other use of UPS tracking systems and information is strictly

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What Is an Optical Barcode?

- We need:

Payload or content
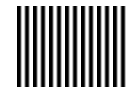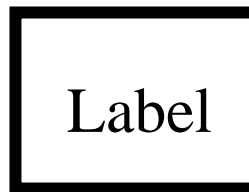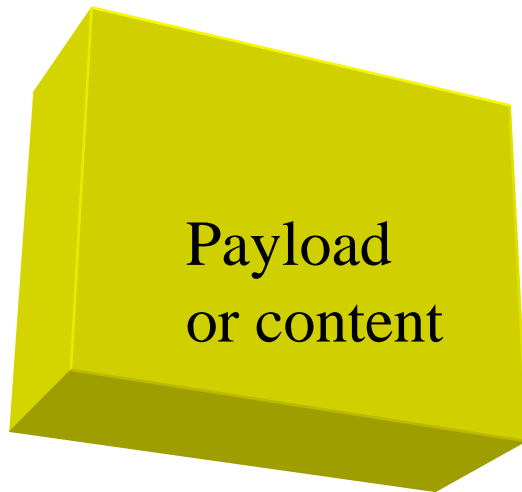
Label

Barcode tag

Label generator/writing tool

Label reading/writing tool

Digital high-speed payload

LF tones

LS digital tag

Low-cost reader/writer

$$\sum_{\iota=1}^{N} \lambda\iota$$

Signaling for Path Setup and Removal

- **Labels are effective in carrying optical signaling for wavelength reconfiguration.**

  - **Optical labels can be placed in-band (e.g., Digital Wrapper) but would require O/E/O conversion - limits transparency.**

  - **Other signaling techniques, such as a separate network (e.g., SS7), or a separate wavelength is also possible (cost/speed tradeoff).**

Network Architecture Vision for an All-Optical Internet

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$$\sum_{\iota=1}^{N} \lambda \iota$$
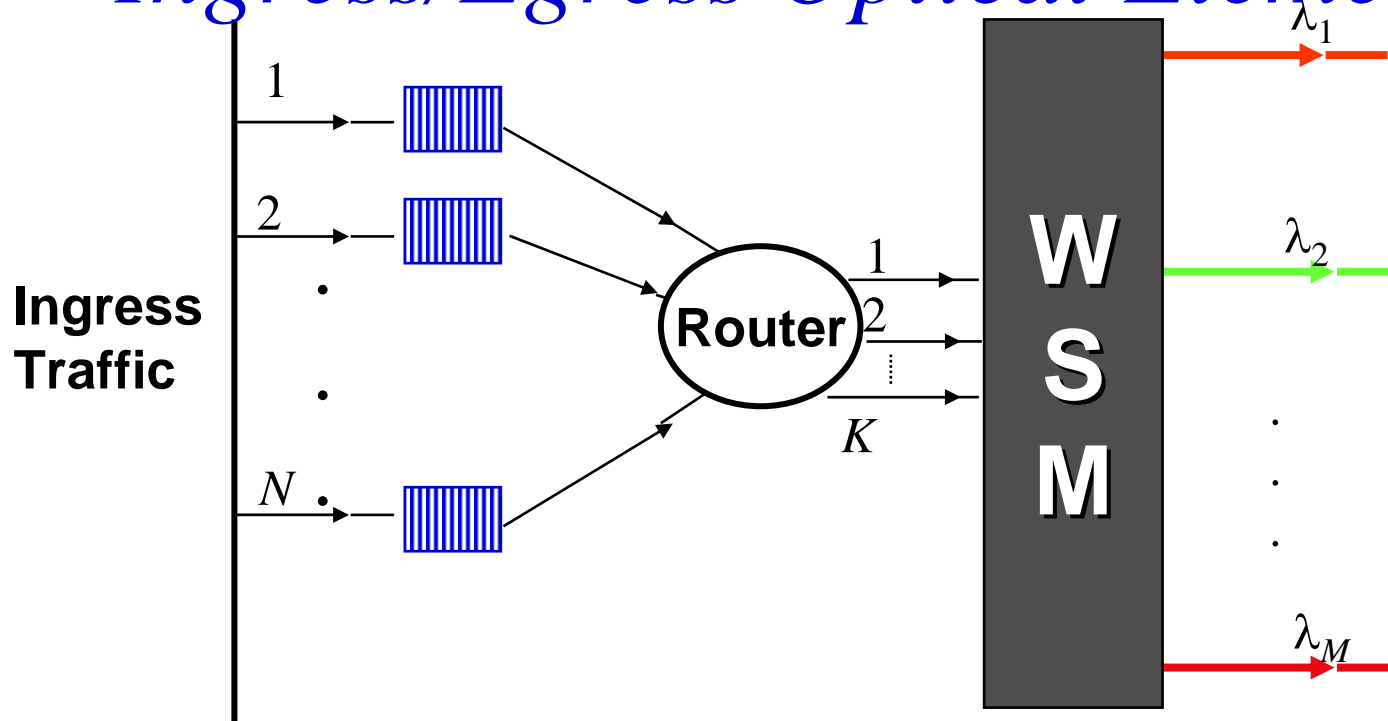
A Proposed Optical Label

- **Unique LF tone insertion on each wavelength at the edge WSM.**

- **The tone subcarriers are modulated with low speed signaling information**

- **At each network element, labels may be:**
    - **read/written**
    - **removed**
    - **replaced**
    - **regenerated**

- **Also Needed for OXC Connection Verification**
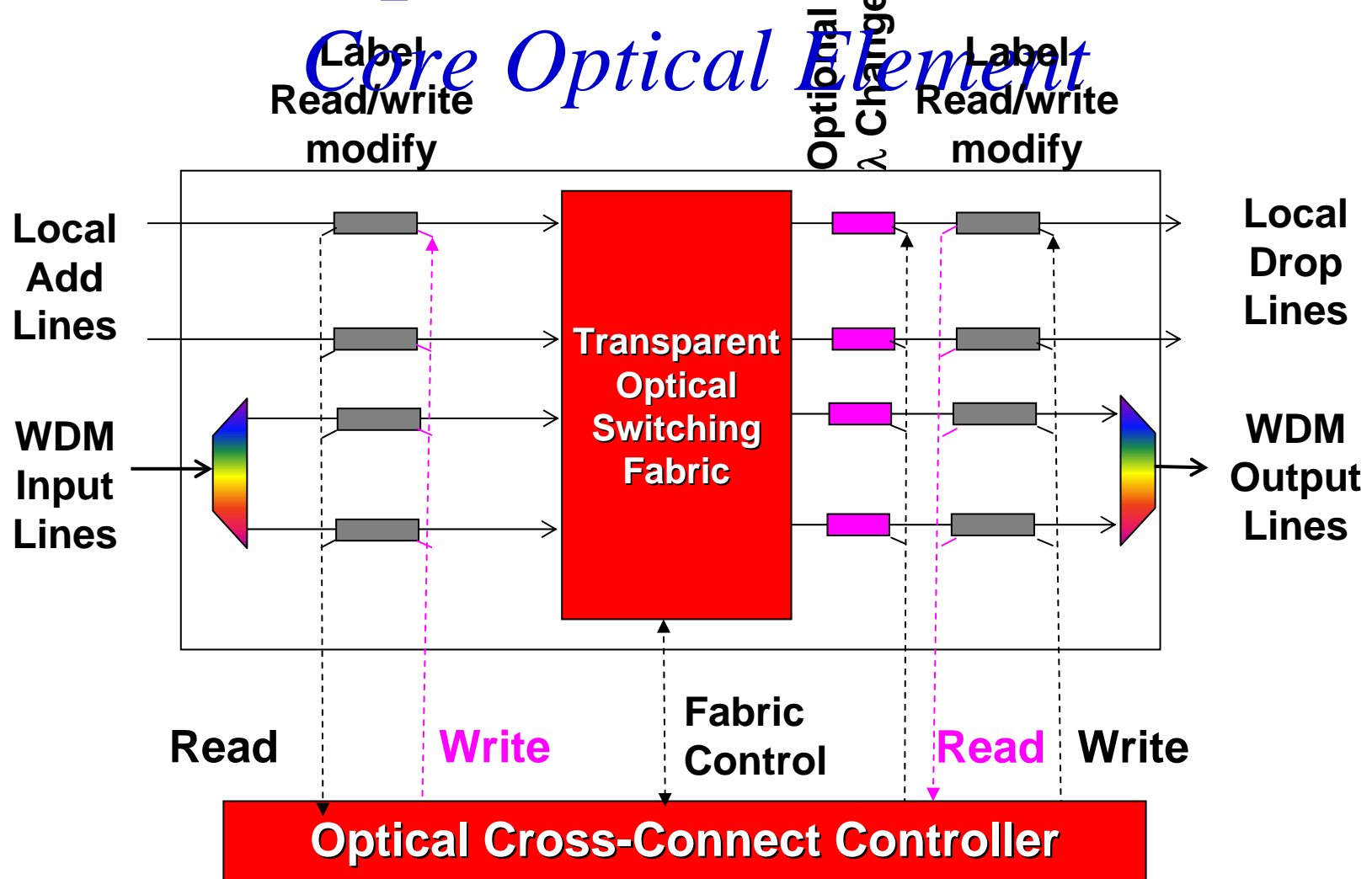
Reference: Read NFOC96 paper

$$\sum_{i=1}^{N} \lambda_i$$

Wavelength Selection/Multiplexing

Ingress/Egress Optical Element

$$\sum_{\iota=1}^{N} \lambda\iota$$

All-Optical Router (OXC)

Core Optical Element

Label Read/write modify

Optical λ Changers

Label Read/write modify

Local Add Lines

WDM Input Lines

Transparent Optical Switching Fabric

Local Drop Lines

WDM Output Lines

Read   **Write**   Fabric Control   **Read**   Write

Optical Cross-Connect Controller

Optical Labeling/Signaling

Network Example

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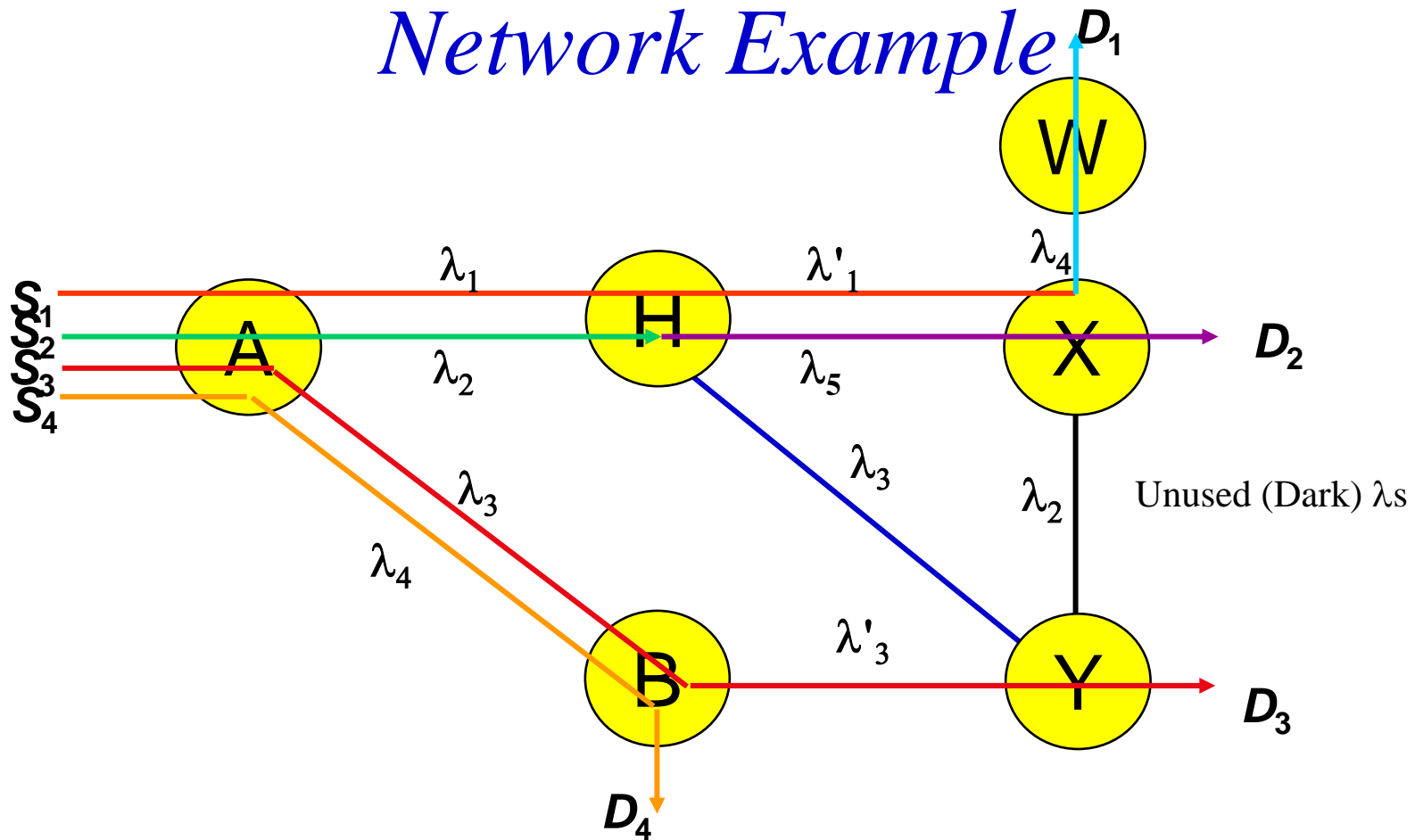
Optical Labeling/Signaling
Implementation of Write Function

Intensity Modulator

Modulation depth control (m) (e.g., $m = 0.05$)

LF Tone Osc/Modulator (f_k)

Low-Speed Label Data (S_k)
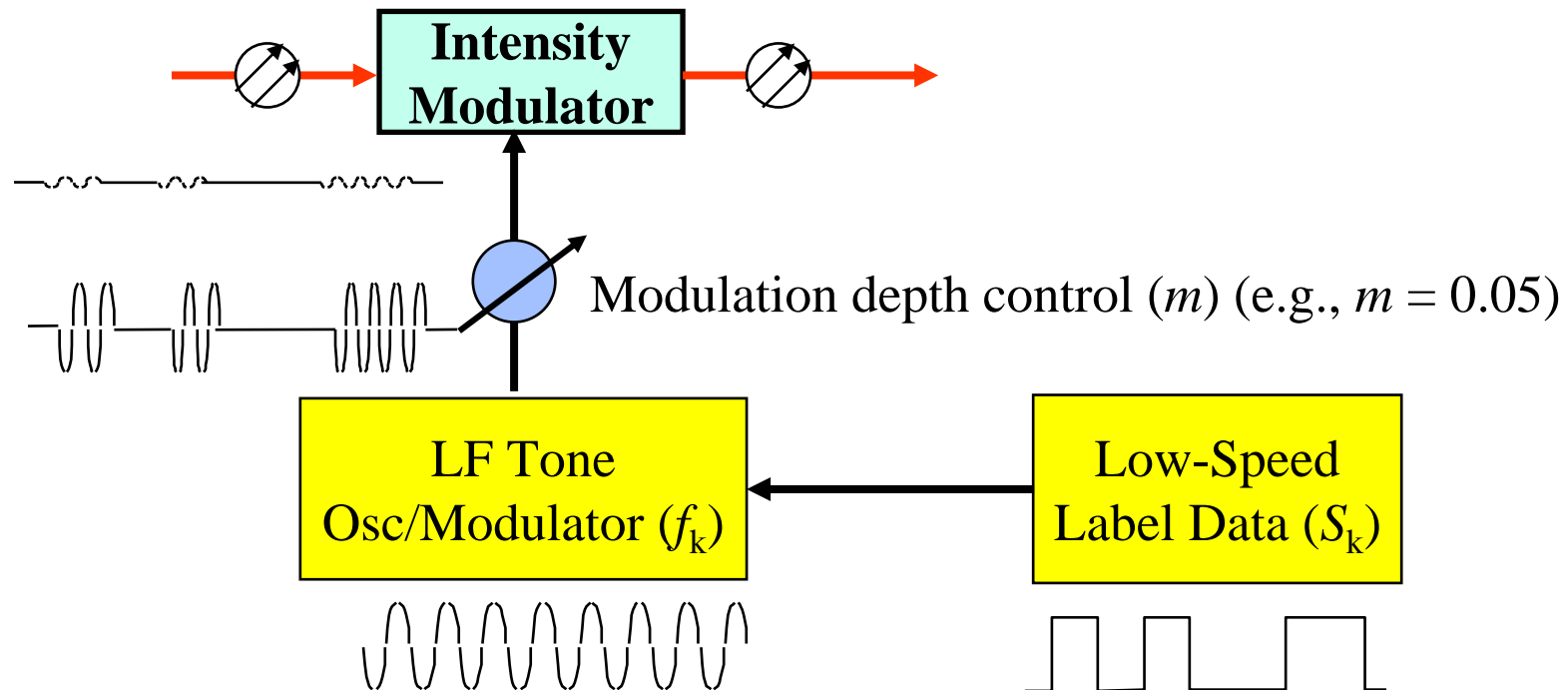
Optical Labeling/Signaling

Implementation of Read Function

Single- or multi-wavelength
optical signal line

Tap

| Low-Speed O/E | → | *Optional* LPF | → | Carrier DeMod(s) (f_k) |

Label Information Receiver (S_k)
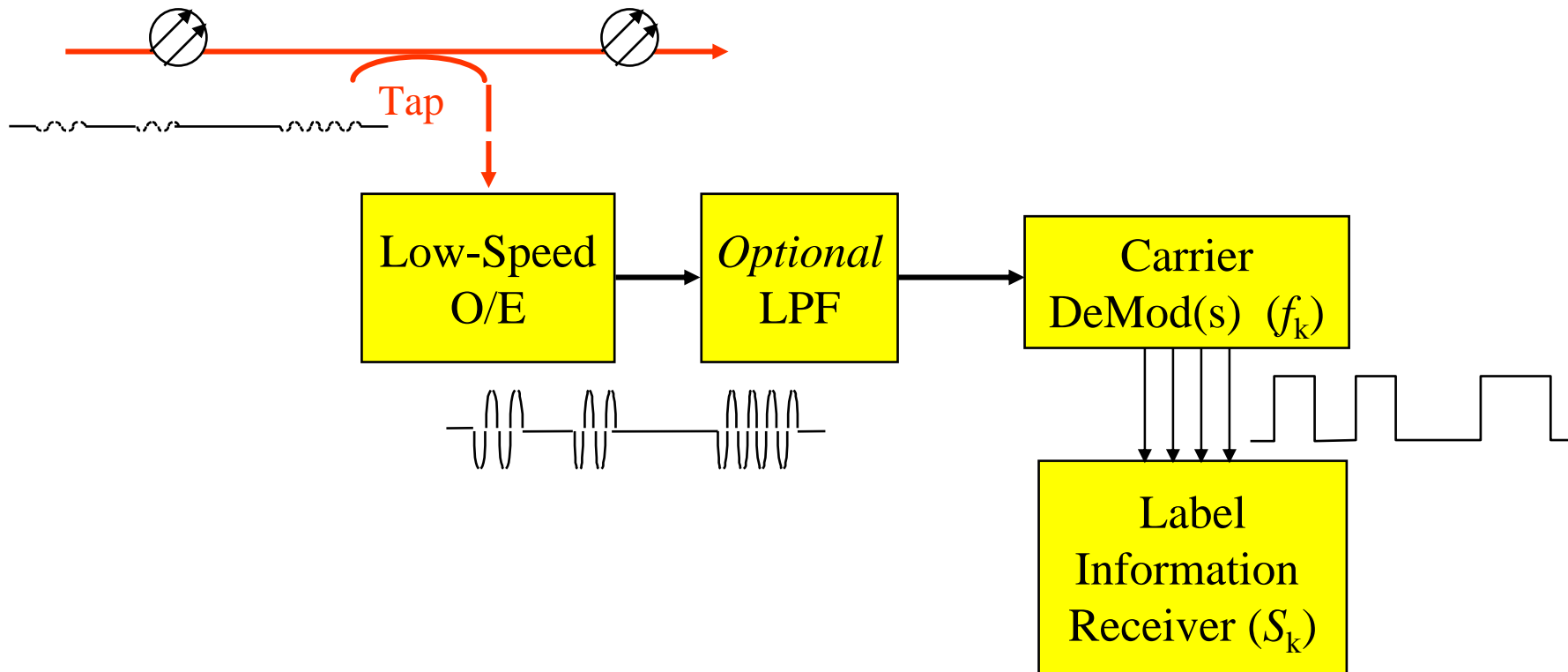
Optical Label Replacement
Feed-Forward Implementation

Single wavelength signal line (optical)

Intensity Modulator

Tap

Low-Speed O/E (f_i)

Error Signal

Modulation depth control (m) (e.g., $m = 0.05$)

LF Tone Osc/Modulator (f_k)

New Low-Speed Label Data (S_k)

$$\sum_{\iota=1}^{N} \lambda \iota$$
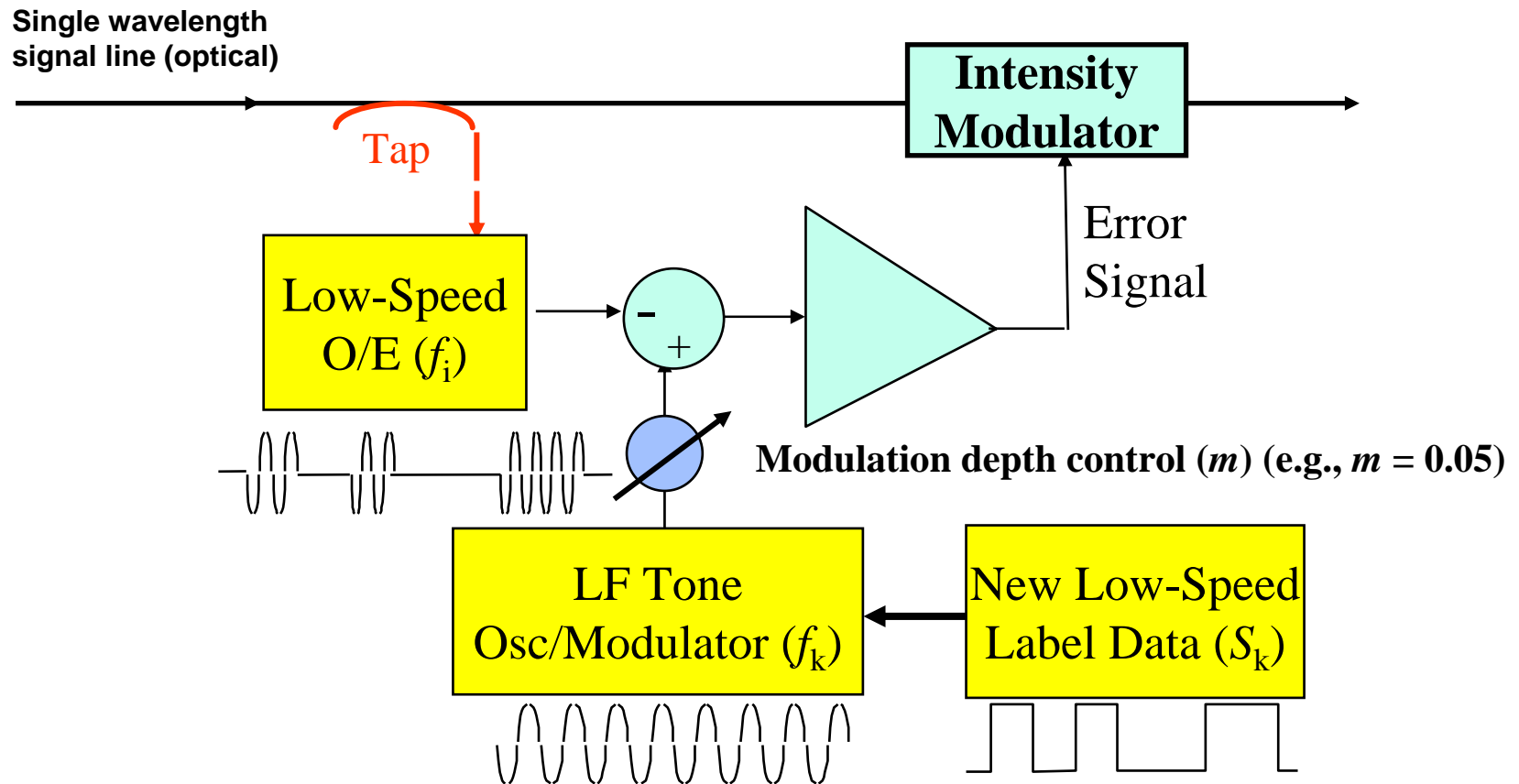
Optical Label Replacement
Feedback Implementation

Intensity Modulator

Tap

Error Signal

Low-Speed O/E (f_i)

Modulation depth control (m) (e.g., $m = 0.05$)

New Low-Speed Label Data (S_k)

LF Tone Osc/Modulator (f_k)

$$\sum_{\iota=1}^{N} \lambda \iota$$
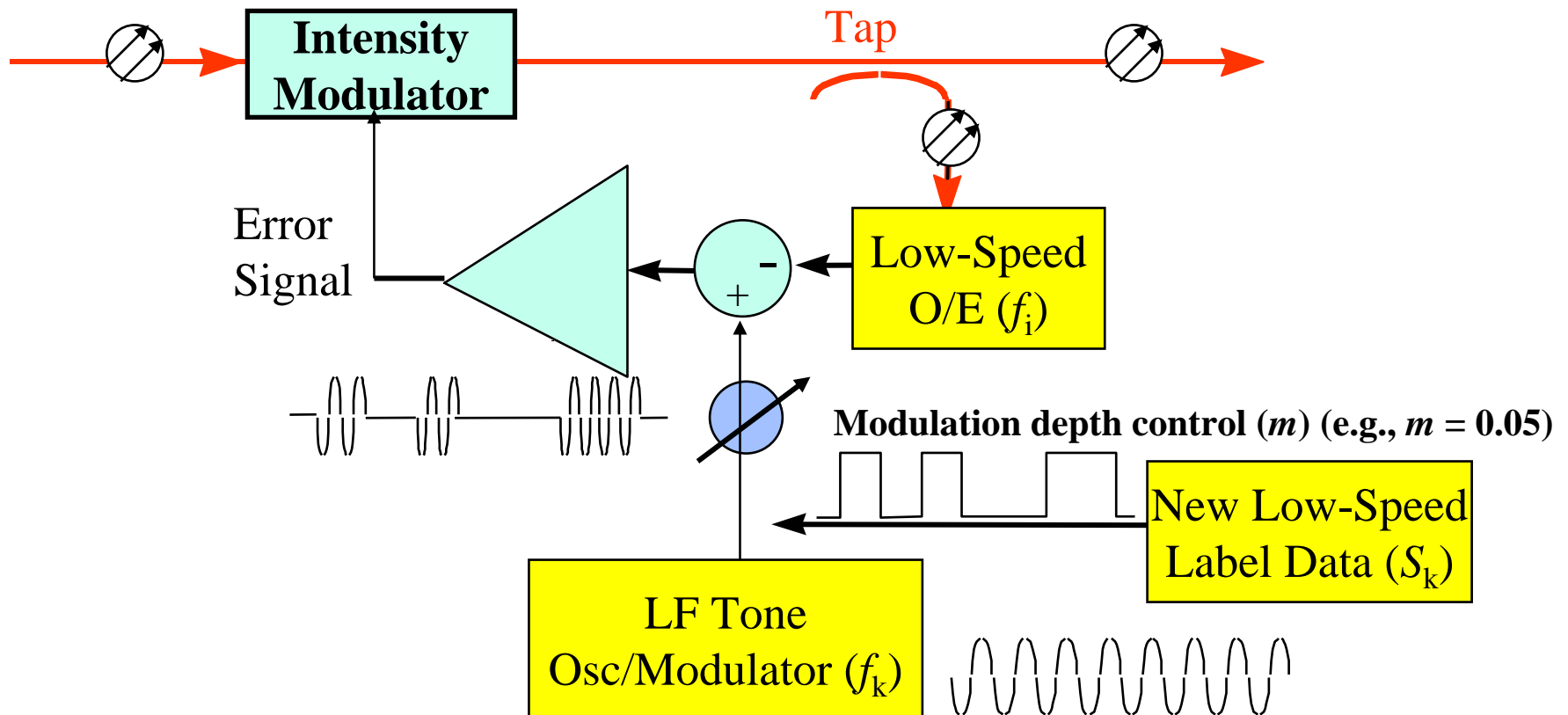
Optical Labeling/Signaling
Signaling for Path Setup/Removal

- **Labels are effective in carrying optical signaling for wavelength reconfiguration**

  – Optical labels can be placed in-band (e.g., Digital Wrapper) but would require O/E/O conversion - limits transparency.

  – Other signaling techniques, such as a separate network (e.g., SS7) or a separate label-bearing wavelength, are also possible (cost considerations)

- **Can be used for network restoration in case of node/link failures (mesh/ring, etc.)**

- **Reconfiguration/restoration priorities are determined by the QoS carried on the optical label**

$$\sum_{\iota=1}^{N} \lambda\iota$$

Optical Labeling/Signaling
Signaling for Path Setup/Removal

Path Service Request (PSR)

| Source WSM/OXC Address	Destination WSM/OXC Address	λ_1 At Source WSM/OXC	λ_2 At Source WSM/OXC	. . .	Path QoS

Pending PSR

Original /Source WSM/ OXC Address	Destination WSM/OXC Address	Wavelength at Source WSM/OXC	Path QoS	First OXC Address	Wavelength At First OXC	Second OXC Address	Wavelength At Second OXC	. . .

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Optical Labeling/Signaling
Wavelength Assignment/Allocation

- **Traffic observation & wavelength allocation assignment performed over predetermined intervals:**

  - **Scheduled:** based on daily/hourly fluctuations

  - **Unscheduled:** based on parameters such as channel utilization, buffer size, etc.

λ_1

λ_2

$\vdots$

λ_N

$$\sum_{\iota=1}^{N} \lambda \iota$$
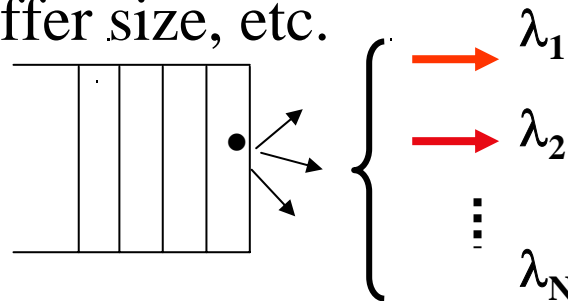
Optical Labeling/Signaling
Summary

- **Practical network architecture for an "all-optical" internet**

- **Optical labels using subcarrier-modulated low-frequency tones:**
  - **Feedback architecture for optical label read/write/replace**

- **Signaling messages for network reconfiguration**
  - **Wavelength (re-)allocation based on traffic observations**

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