Exploring the Benefits of CDMA in Optical Networks

Sharon Goldberg

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OCDMA Project Team

Princeton
Paul Prucnal, Ivan Glesk, Evgenii Narimanov
Camille Bres, Varghese Baby, Sharon Goldberg, Yue-Kai Huang, Bin Li

Hofstra
Wing Kwong

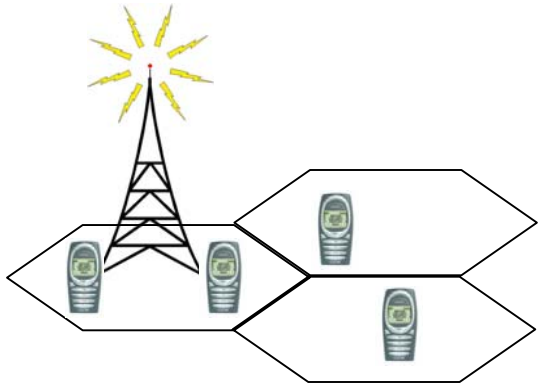
Telcordia
Robert Runser, Tom Banwell

Kambrook
Tom Curtis

DARPA
Jag Shah, Henryk Temkin

Code Division Multiple Access (CDMA)

Wireless CDMA

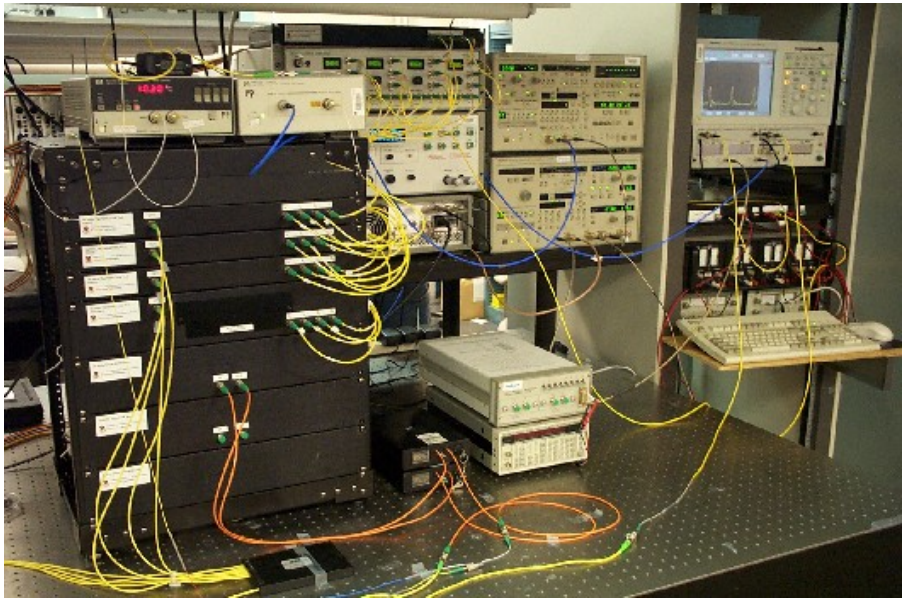


Cellular Systems

- Used in: (for example)
  - Wireless Cellular Systems
  - Unlicensed Spectrum Systems (2.4 GHz, 5.8 GHz)
- Allows:
  - Asynchronous multiple access
  - Frequency reuse
- Provides:
  - Immunity to interference
  - Variable QoS, Variable data rates
  - Soft blocking

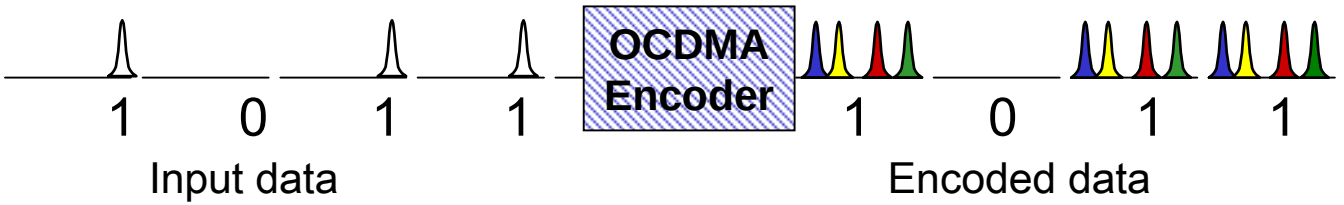
Optical CDMA

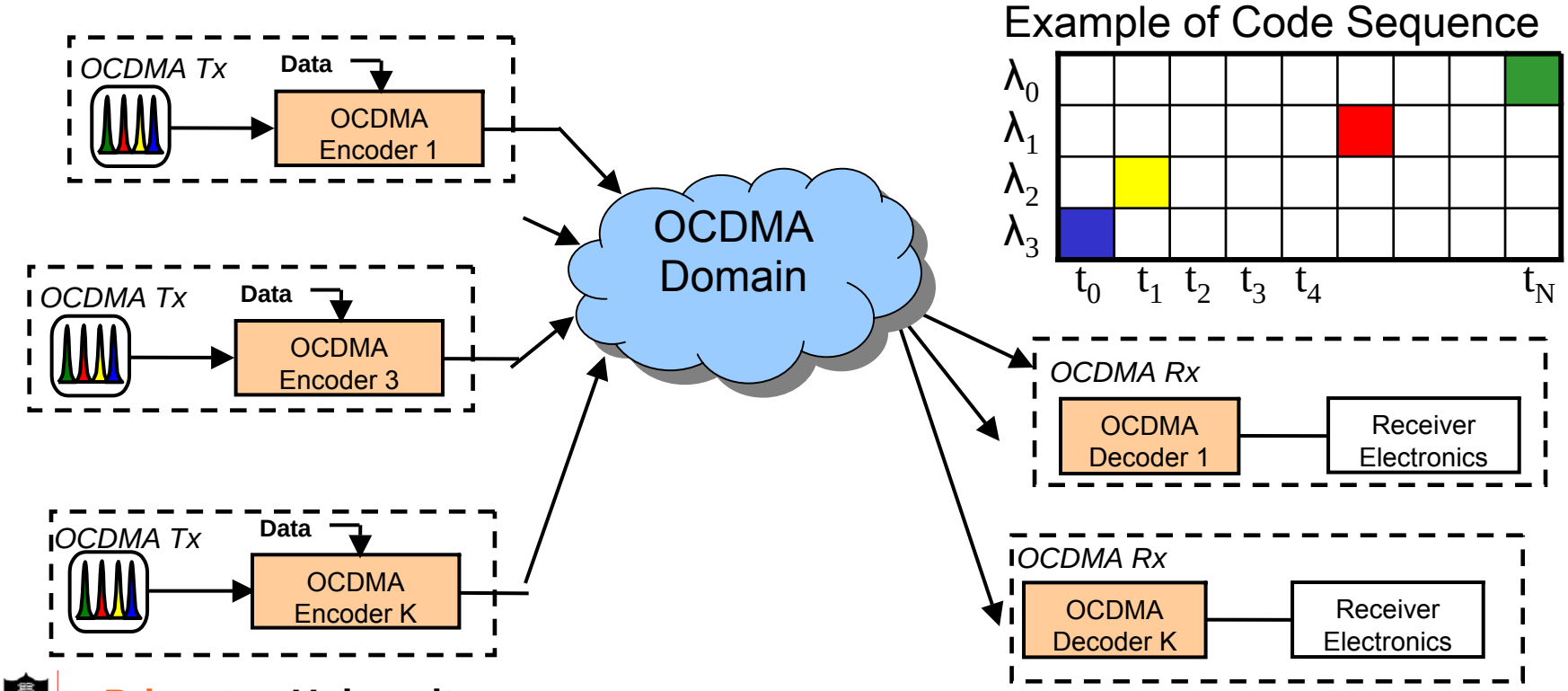
- Apply concept of wireless CDMA to optical domain
- Incoherent Coding
  - Time-Amplitude
  - Spectral-Amplitude
  - **Wavelength-Time**
- Coherent Coding
  - Temporal-Phase
  - Spectral-Phase



Incoherent (Wavelength-Time) Optical CDMA

Each user is assigned one or more unique code sequences.

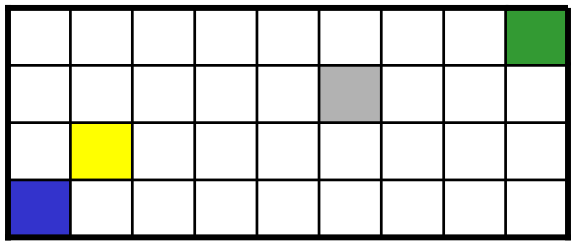


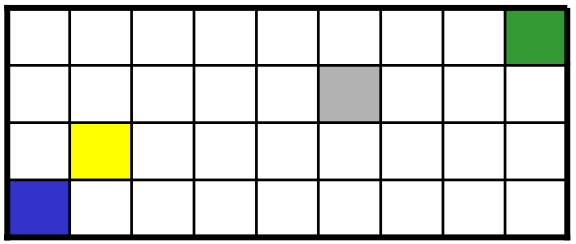


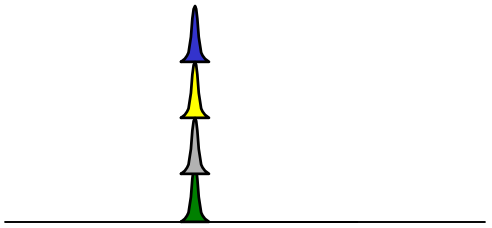
Wavelength-Time Optical CDMA Decoding

Recover data using optical correlator; a peak indicates code match.

- Amplitude of peak increases with number of wavelengths.
- For clock & data recovery, codes are designed with minimal autocorrelation side lobes.





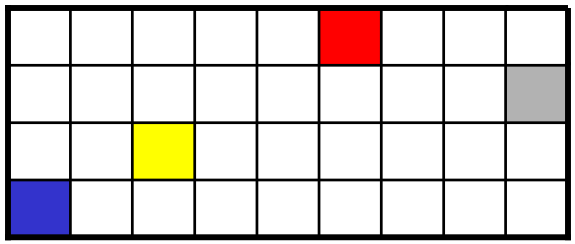


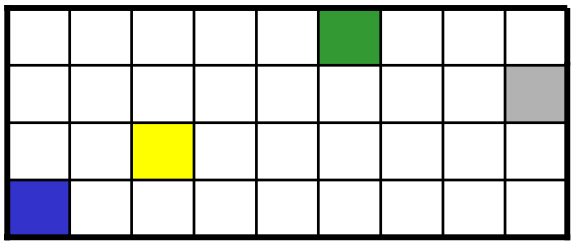
autocorrelation

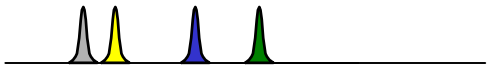
Codes are designed to have bounded cross-correlation (≤ 1) for any timeshift between codewords

⇒ users can transmit asynchronously

⇒ low multiple access interference

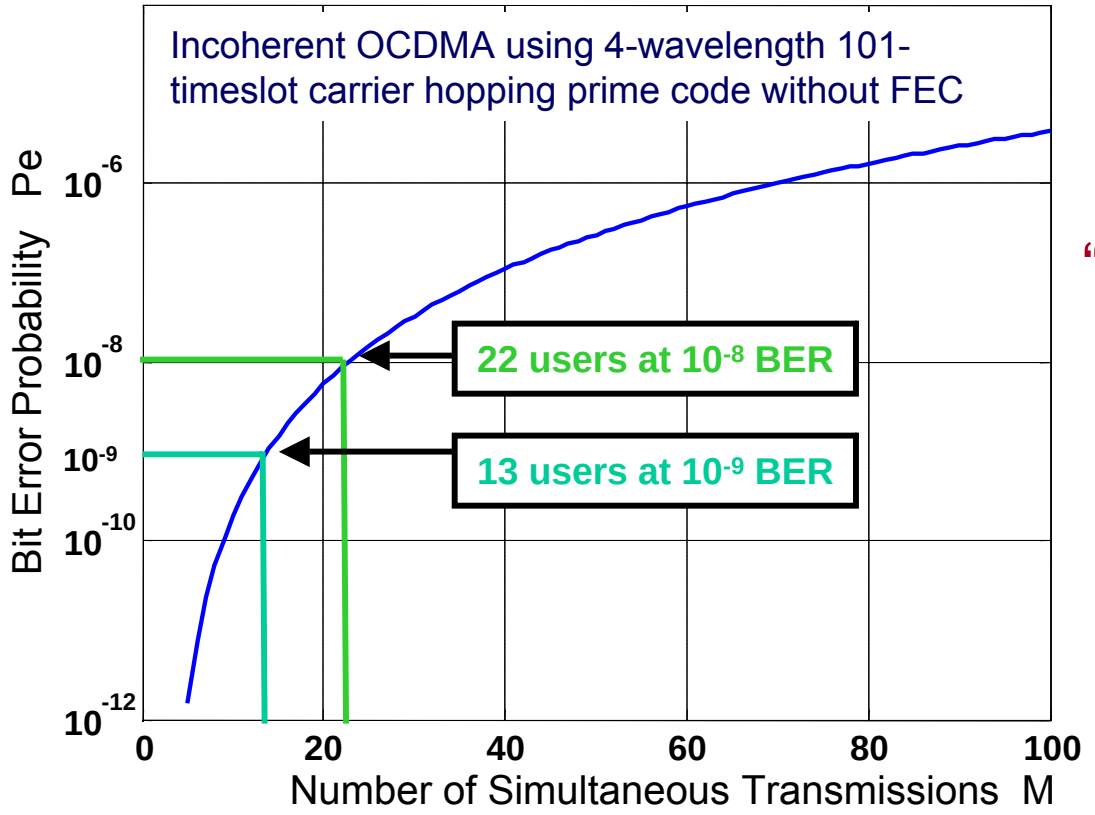






crosscorrelation

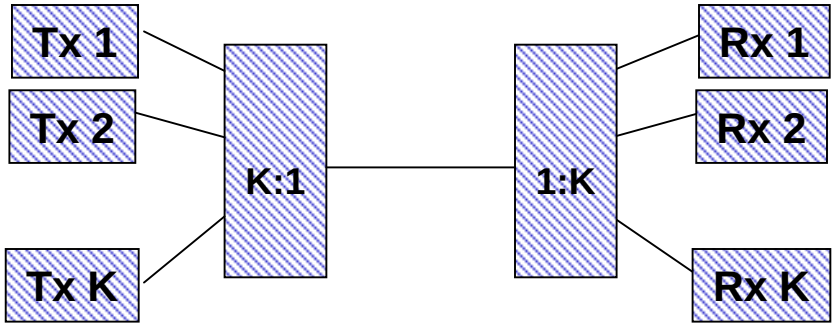
Bandwidth on demand: Trading BER for Capacity



"Soft blocking"

- Additional users can be accommodated at the cost of increased BER
  - For traditional schemes (WDM, TDM) once limit is reached, no other users can be added on the network

Capacity Analysis*: OCDMA vs Wavelength Routed Network



We compare broadcast-and-select networks with K = 32 subscribers where

- Calls connected on a circuit-by-circuit basis.
- Each circuit is active (carries data) with probability *p*.

OCDMA:

Define max BER threshold of 10^{-9}

⇒ System admits M = 13 simultaneous transmissions

⇒ When M > 13, BER degrades causing an *outage*.

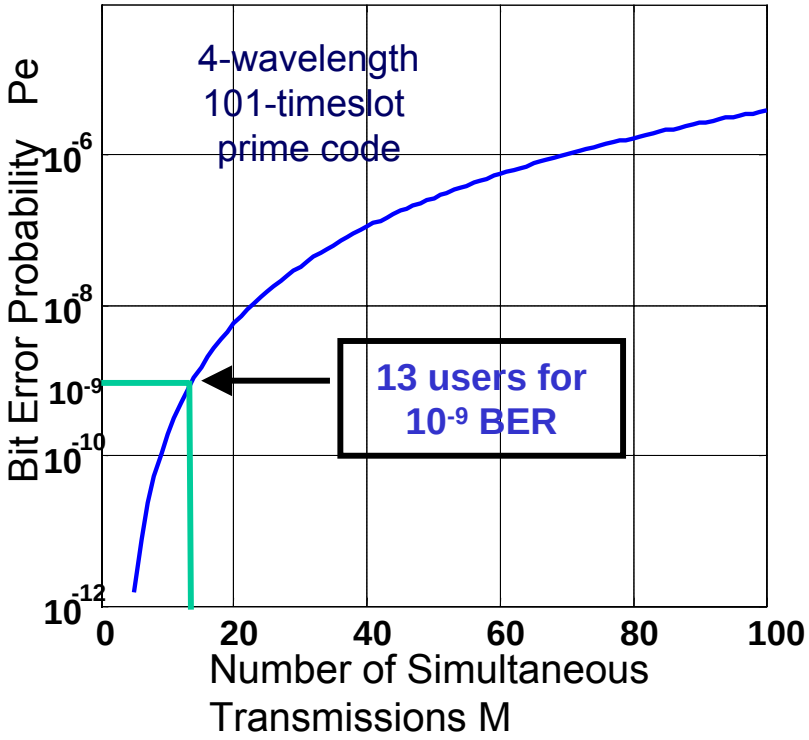
⇒ Ensure that outages occur with probability < 10^{-3}

WRN:

Assume a WRN with 13 wavelengths

⇒ When 13 circuits are connected, new calls are *blocked*.

⇒ Ensure that blocking occurs with probability < 10^{-3}.



* Goldberg, Prucnal, "On the teletraffic capacity of optical CDMA", in submission.

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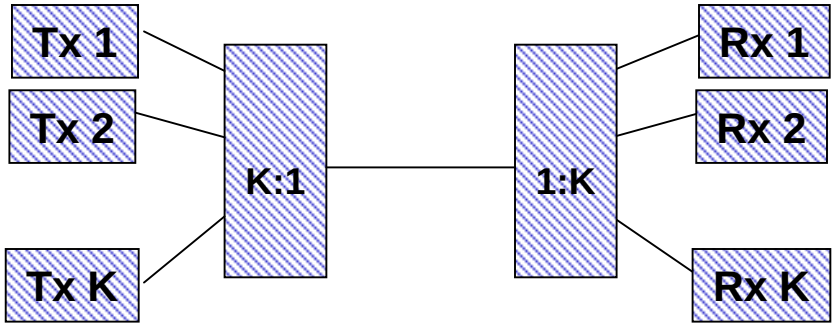

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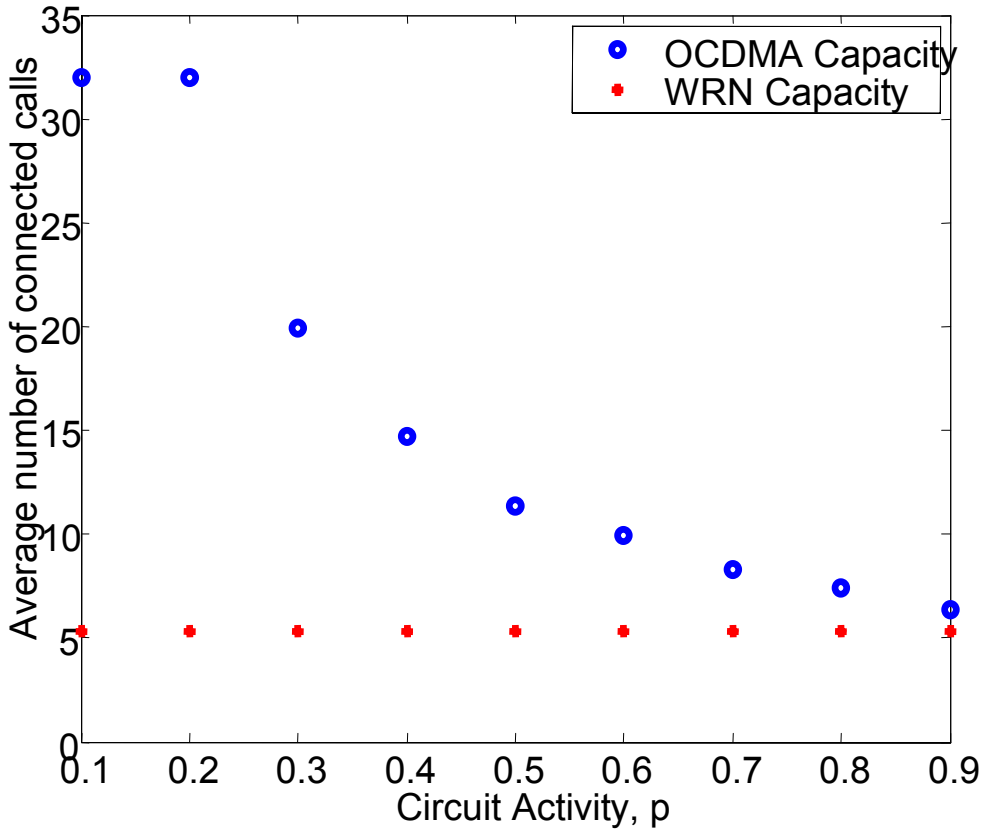
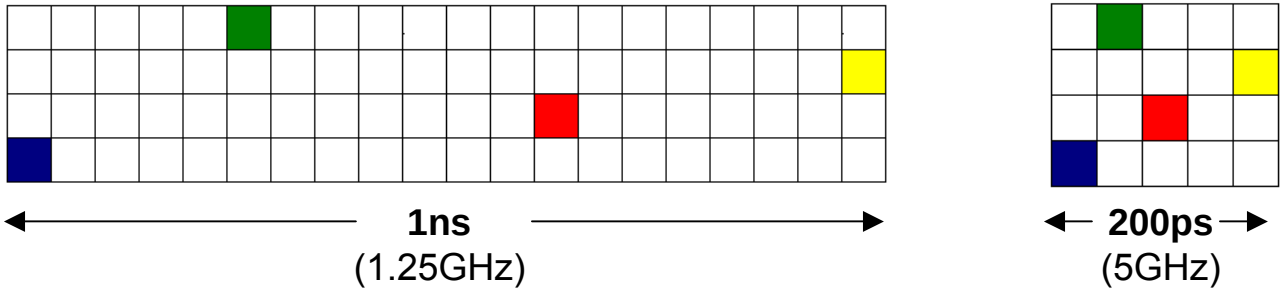
Capacity of OCDMA and WRN:
Average number of connected calls



Differentiated Services with OCDMA

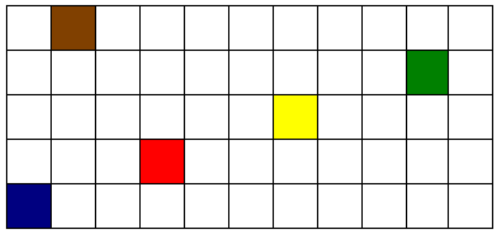
Variable Rate

- Exploit the variable length property (cross-correlation ≤ 1 for any rate)
- Support users transmitting at different rates at the physical level

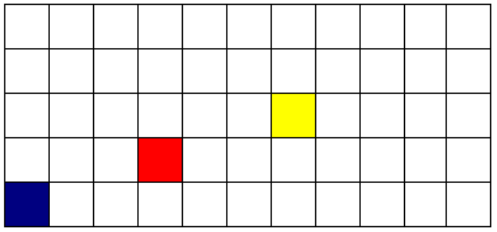


Variable QoS

- Exploit the variable weight property (cross-correlation ≤ 1 for any weight)
- Higher code weight (more λ's) improves BER but uses more resources
- Priority channels can occupy more λ's – variable QoS at the physical level



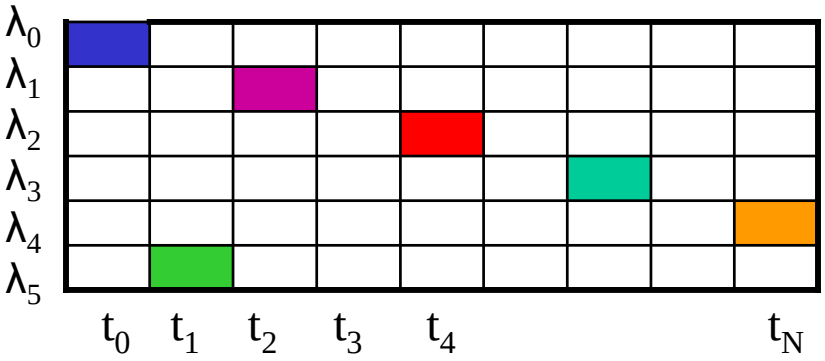
(5,11) codeword
Lower BER



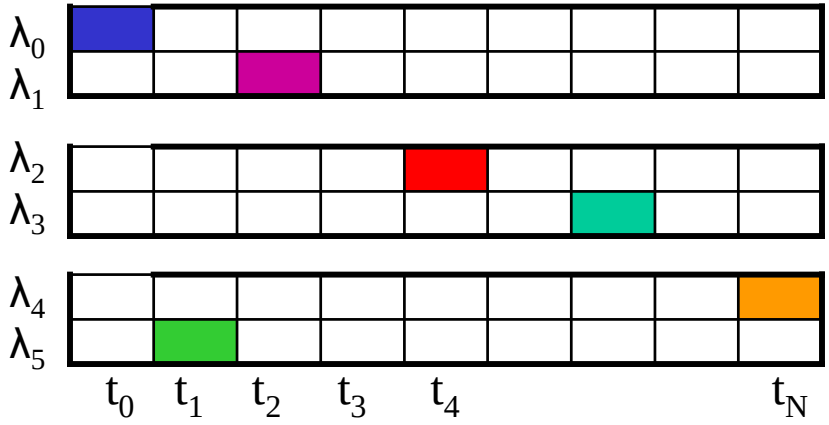
(3,11) codeword
Higher BER

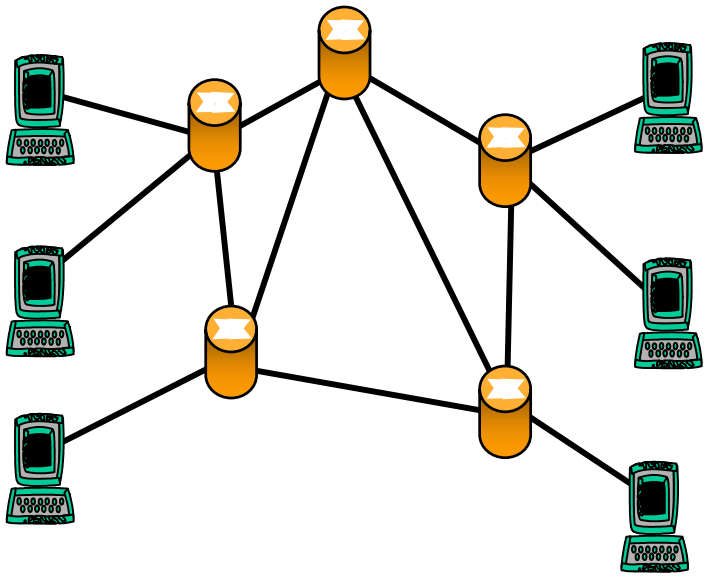
OCDMA Selective Speedup for Packet Networks

Regular packets sent one at a time with weight **w** codewords and high reliability (low BER)



Speedup packets sent **three** at a time with weight **w/3** codewords and lower reliability (higher BER)



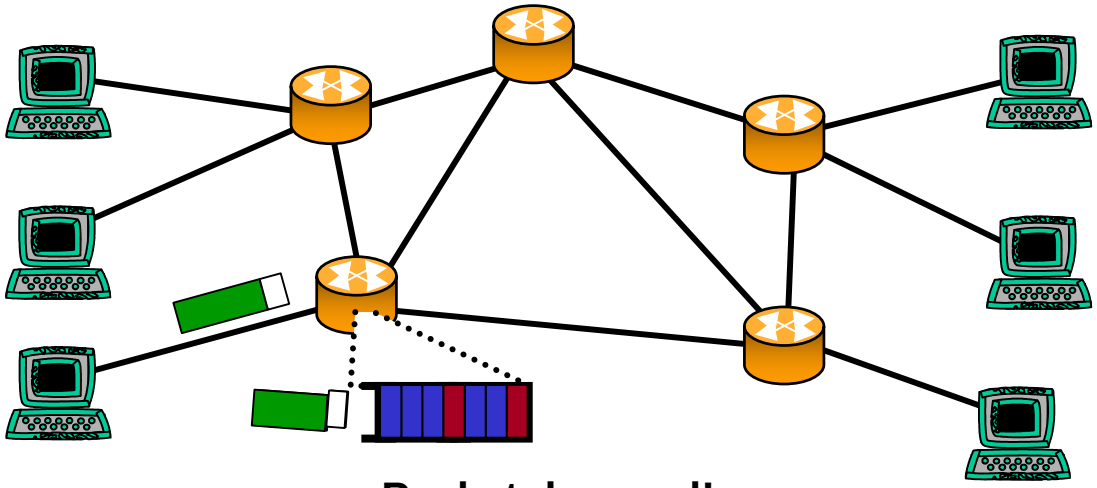


Selective speedup is a tradeoff between performance and delay:

- –Send packets at higher rate
- –Without using more network resources
- –Without affecting performance of other users on the media
- –With a performance penalty on sped-up packets – i.e. higher BER

Applications of OCDMA Selective Speedup

Active Queue Management

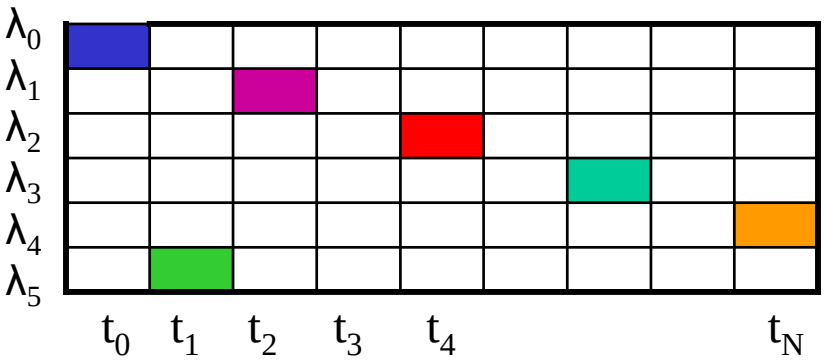


Packet dropped!

Instead of dropping packets during congestion, send some with selective speedup!

Selective speedup decreases packet dropping probability, queue length and delay.

Regular packets sent one at a time with weight **w** codewords and high reliability (low BER)



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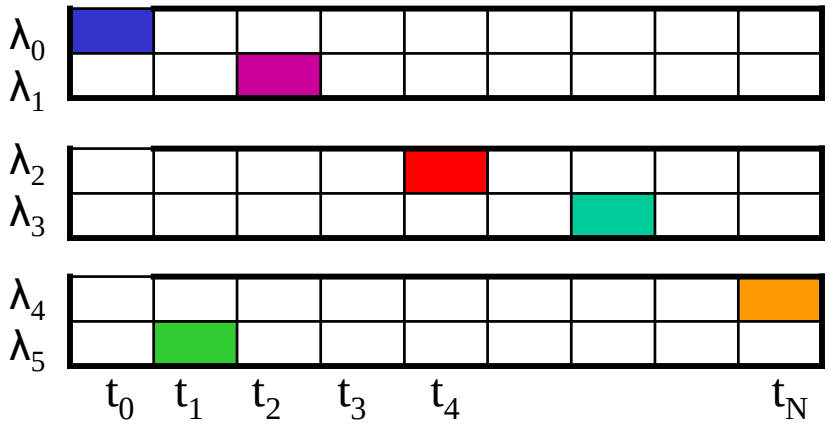

Applications of OCDMA Selective Speedup

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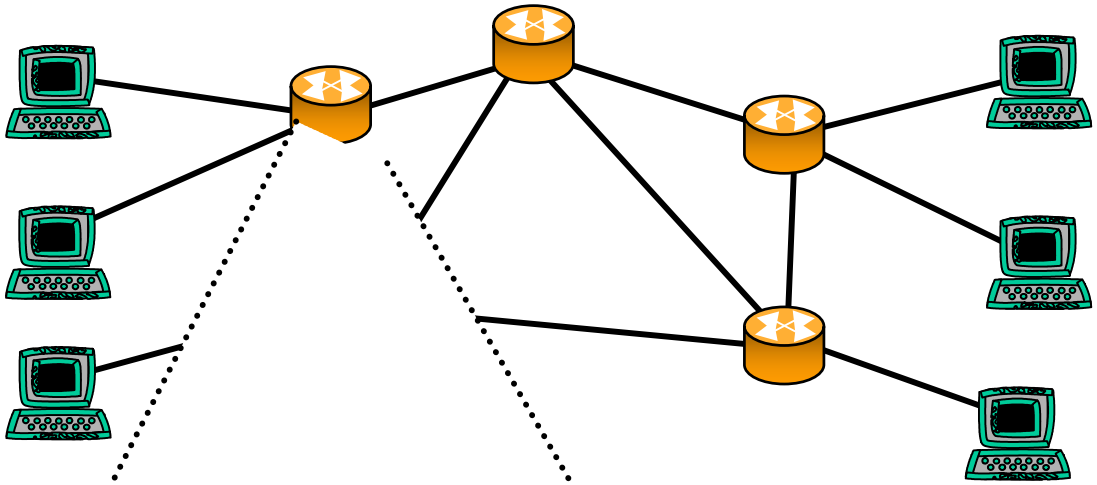

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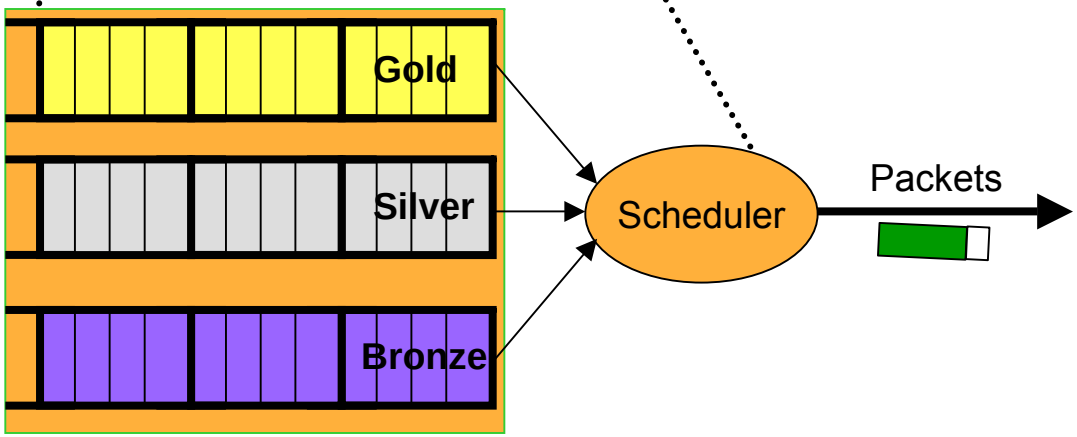
Class Based Queuing (CBQ)



Traditionally, CBQ schedules packets according to packet latency and link utilization priority level.

Selective speed-up adds a new degree of freedom – reliability (BER) vs latency

Leverage the Tradeoffs with Optical CDMA

- Bandwidth on demand
  Tradeoff: BER vs Capacity
  – No hard limit on the number of active users

- Differentiated services
  Tradeoff: BER vs Capacity
  – Variable QoS - enabled by variable weight codes
  – Variable rate - enabled by variable length codes

- Reduced congestion in packet-switched networks
  Tradeoff: BER vs Delay
  – The selective speedup
  – Applications to:
    - Active Queue Management
    - Class Based Queuing