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Node Architecture Design and Network Engineering Impact on Optical Multicasting Based on Physical Layer Constraints

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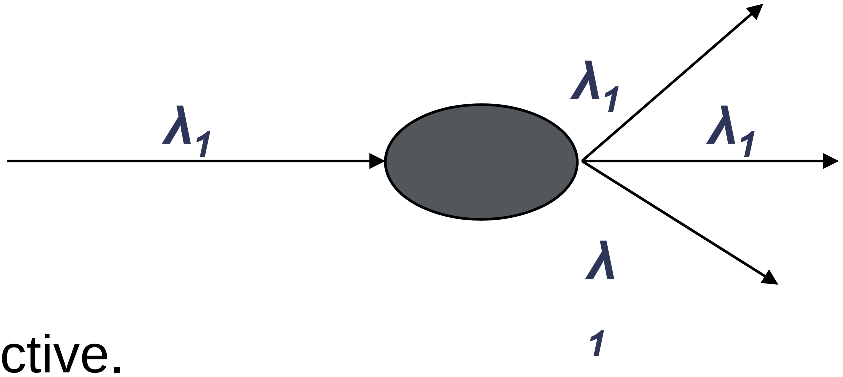
Outline

- Introduction
- Physical Layer System Modeling
- Node Architectures and Node Engineering Designs
- Multicast Algorithms
- Simulation Results
- Conclusions and Future Work

Introduction

- Multicasting refers to point to multipoint connection. Light from one source must reach many destinations.

- In transparent optical networks, optical splitters can be used to split the incoming signal to multiple output ports.



- Optical Splitters: Passive, Active.

- Bandwidth-intensive, real-time multicasting applications such as video-conferencing, real time on-line games, e-learning, etc are becoming very popular in today’s networks.

Introduction

- **Multicast RWA in dynamic optical networks:**
  - A light-tree that spans the source and the destination set must be found.
  - A wavelength must be assigned to the light-tree.
  - Multicast requests are blocked if there are no available resources.

- Recent work on the RWA problem for provisioning multicast connections in transparent optical networks has taken into account physical layer impairments

- A Q-budgeting approach is used in this work as a metric of the physical performance of the system .

Physical Layer System Modeling

- Modeling of the physical layer is based on the physical path Q factor that is used to calculate the BER of the system.

$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0}, \textbf{\textit{where}}$$

$$\sigma_i^2 = \sigma_{th}^2 + \sigma_{shot-i}^2 + \sigma_{ASE-ASE}^2 + \sigma_{s-ASE-i}^2 + \sigma_{RIN-i}^2 + \sigma_{ASE-shot}^2$$

- This approach assumes a baseline system with various receiver noise terms as well as ASE noise.

- A Q-budgeting approach is used to include:
  - Incoherent crosstalk channel penalty budgeted at 0.8dBQ.
  - Fiber nonlinearities factored at 1 dBQ.
  - PMD budgeted at 0.2 dBQ.
  - Optical filter narrowing penalty budgeted at 0.4 dBQ.
  - Safety margin of 1dBQ included for component aging.
  - No polarization-dependent gain/loss (PDG/PDL) are present.

Physical Layer System Modeling

- This approach enables a network designer to calculate the impact of physical layer effects, in the design of an optical network without the computationally complex time-domain approach.

- A Q threshold is set for a specified BER and the decision to provision a given multicast connection relies on whether we are above or below the threshold.

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}} \right) \approx \frac{e^{\frac{-Q}{2}}}{Q\sqrt{2\pi}}$$

- Q threshold set at 8.5 dBQ which corresponds to a BER of 10^{-12}

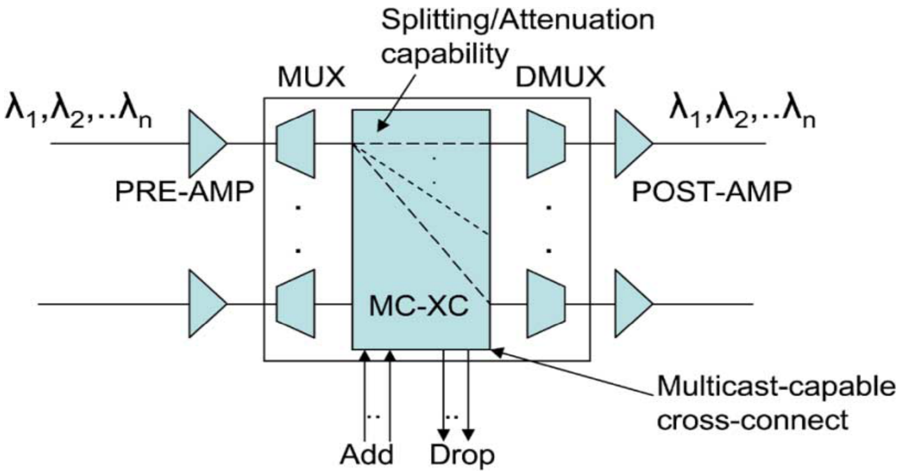
Node Architectures and
Node Engineering Designs

- **Motivation:**

  Different engineering of the physical layer produces different multicast group blocking - a strong indicator that a more refined interaction between physical and logical layer is needed for multicast connection provisioning

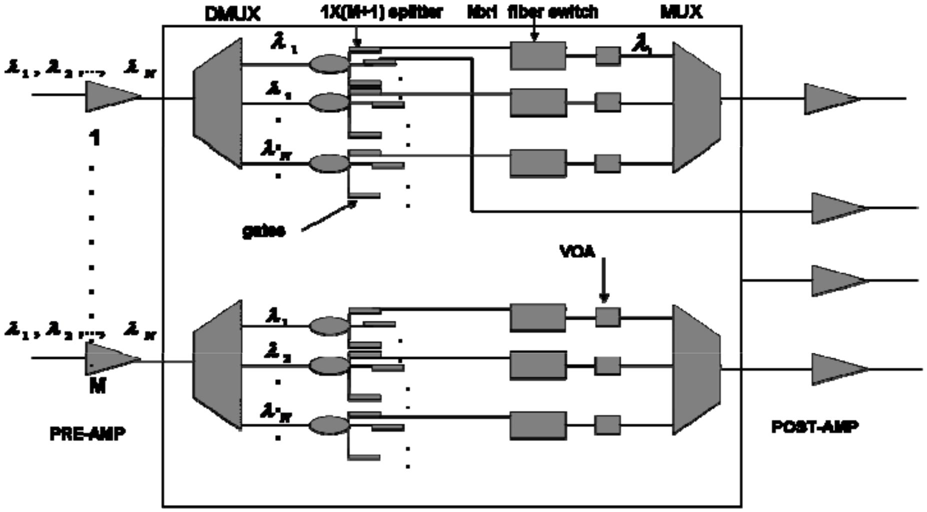
- We investigate the node design/engineering, initially looking at:

  1. active vs. passive splitters.
  2. various transmitter/receiver designs.



1. Active vs. Passive Splitters

- ❑Generic node architecture for passive splitters for a node with degree *M* and *n* wavelengths. Transmitter/receiver design is initially ignored.



- ❑Component Insertion Loss:

Component	Mux/Dmux	VOA	Splitter	SOA	Switch
Losses in dB	3	0.5	10*log(fanout)	0.6	1

1. Active vs. Passive Splitters

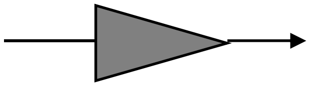
❑Worst case scenario :

Calculated based on the maximum insertion loss a signal will encounter passing through the maximum degree node in both active and passive cases.

❑Components:

Gain in dB	NF
G<13	7
13<G<15	6.7
15<G<17	6.5
17<G<20	6
G>20	5.5

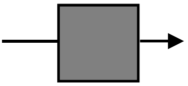
➢Amplifiers:



- Noise Figures are based on realistic device specifications.
- Post-Amplifiers: Compensate for the node losses and the gain is set for the worst case scenario with an output power of +3dBm.
- Pre-Amplifiers: Preceding the fiber span to compensate for the fiber losses that are set at 0.3dB/Km. Output power is +6dBm.

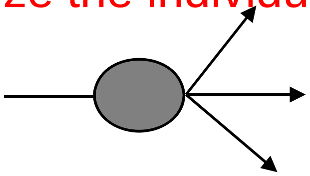
1. Active vs. Passive Splitters

- Variable Optical Attenuators (VOAs):



  - Required to attenuate the total input power to the post-amplifiers (equalize the individual input powers).

- Optical Splitters:



  - Active: Split the power only as many times as needed for the signal to be forwarded to the destined outputs.
  - Passive: Split the power as many times as the degree of the node plus one to account for the drop operations. Gates are required to block the power at outputs where the signal is not destined for.

- PIN photodiodes:
  - Used at the destination nodes. Their pre-amplifier gain is assumed to depend on the degree of the node, with a maximum output power of -4dBm and a noise figure of 4.5dB.

1. Active vs. Passive Splitters

❑To determine the Q-value for each multicast call, a baseline system Q-value is first calculated based on the signal and noise terms, assuming:

- 10 Gbps bit rate
- A pre-amplified photodiode
- 32 wavelengths in each fiber spaced at 100 GHz.
- +3dBm power launched into the system .

2.Transmitter/Receiver Designs

- **Different types of transmitter/receiver designs:**
  - Fixed Txs/Rxs ✓
  - Tunable Txs/Rxs ✓
  - Tunable Txs/ Fixed Rxs
  - Fixed Txs/Tunable Rxs

- **Assumptions:**
  - Passive splitting.
  - Component losses are as described for the case of passive splitters.
  - Noise Figures of the amplifiers used are as previously described.
  - Worst case scenario is the maximum insertion loss a signal encounters passing through the maximum degree node of the network.
  - Q-value is calculated based on the signal and noise terms, assuming 10 Gbps bit rate, a pre-amplified photodiode, and 32 wavelengths spaced at 100 GHz.

2.Transmitter/Receiver Designs

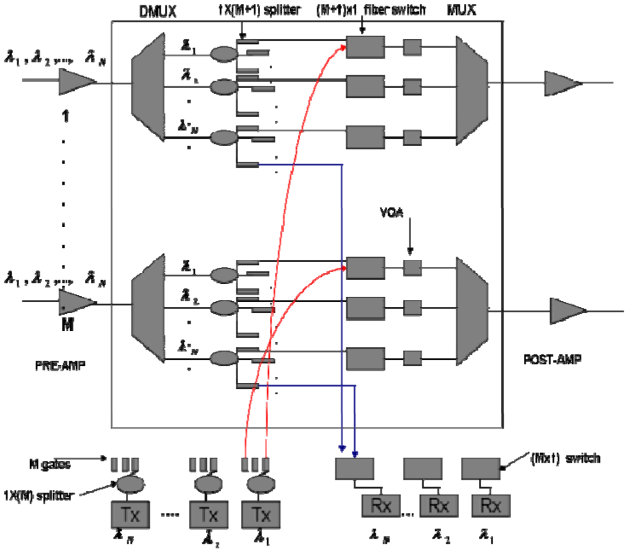
- ❑ **Node Architectures:**

a) Fixed Tx/Rx

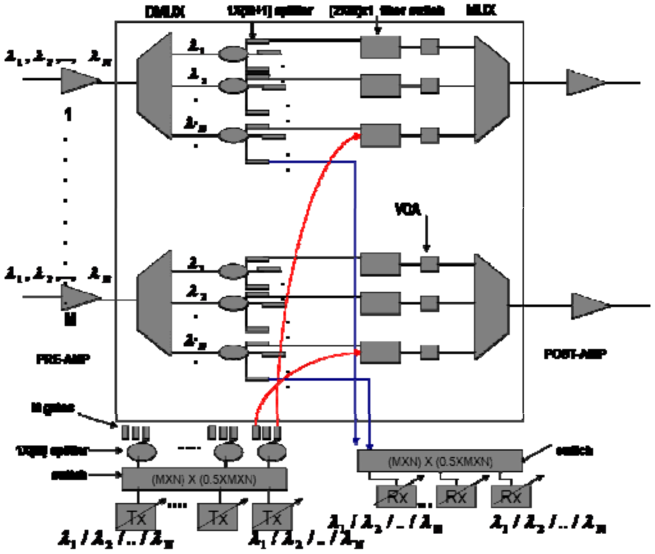
b) Tunable Tx/Rx

Where the number of transmitters/receivers for each source/destination node is equal to the number of wavelengths.

a)



b)



2.Transmitter/Receiver Designs

- Tunable Tx/Rx case:
  - Switches added at the Tx/Rx can add/drop 50% of the total number of wavelengths in the network.
  - The size of the switches is proportional to the number of wavelengths and the fan-out of the node.
  - Insertion loss of switches depends on their size

- Node engineering is modified to account for the various new architectures

- Output power of pre and post amplifiers is now set to +3dBm.

- Signal launched power into the fiber is now set to +5dBm.

Size	**Losses in dB**
X<25	1
25<X<36	1.5
36<X<56	2.2
56<X<68	3
68<X<80	3.7
80<X<100	4.5
X>100	5

Multicast Routing Algorithms

- ☐ Five multicast routing algorithms are used in this work:

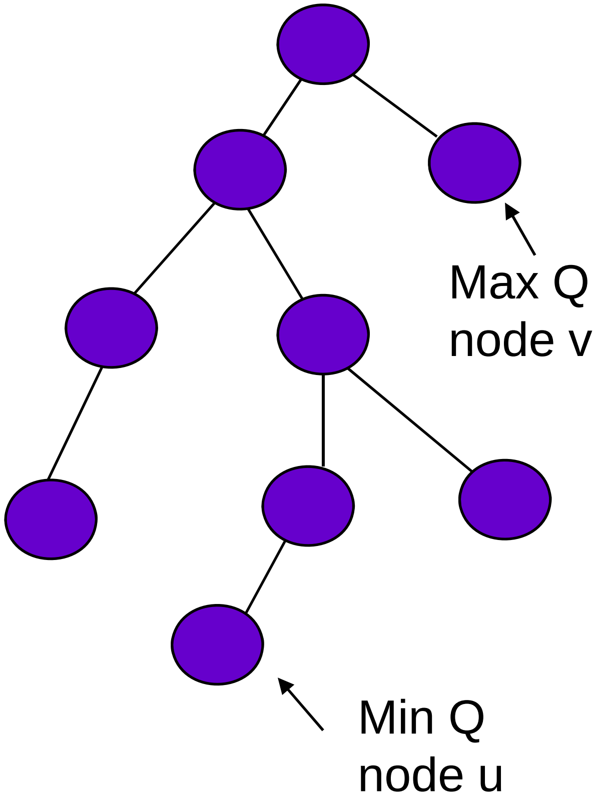
1. **Steiner tree heuristic (ST):**
    - Finds the minimum cost tree
    - NP-complete when the multicast group has more than two members.
    - Several heuristics have been developed for the Steiner tree problem.

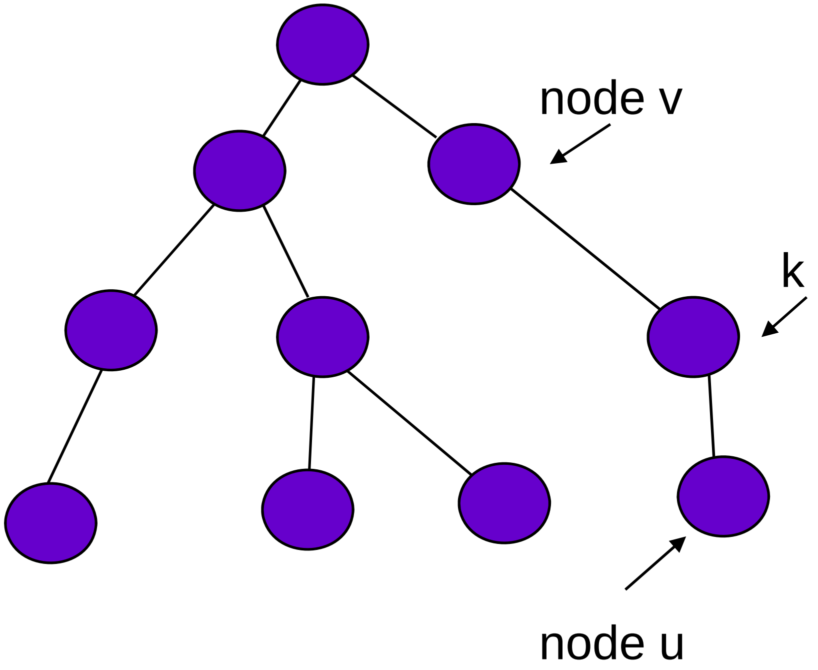
2. **Shortest Paths Tree (SPT):**
    - Finds the multicast tree by merging all unicast shortest path connections from source to all destinations.

3. **Balanced light-tree (BLT):**
    - Takes only power budget constraints into consideration during a balancing procedure.
    - Starts with an initial light tree T. Finds the maximum splitting node u and the minimum splitting node v. Removes node u from the tree and adds it back to the tree by connecting it to the path from the source to node v.
    - Terminates when two successive iterations fail to reduce the maximum split ratio.

Multicast Algorithms

4. **Balanced Light Tree_Q (BLT_Q) :** Takes the Q-factor into consideration during the balancing procedure.





Multicast Algorithms

- As a result, the difference between the minimum and maximum Q-factor values decreases with each iteration.
- The balancing part of the algorithm terminates when two successive iterations fail to increase the minimum Q-factor

5. **Balanced Light tree_$\mathbf{Q_{tolerance}}$ (BLT_$\mathbf{Q_{tolerance}}$):**

- Modification of BLT Q algorithm. BLT_Q tends to create trees that have more breadth than depth. BLT_$Q_{tolerance}$ decreases the total number of links in the tree.
- Considering that the minimum acceptable Q-factor for each path is q, this algorithm tries to maximize the Q-factor only at those destination nodes where the Q-factor is lower than q.
- Terminates after a number of iterations if the minimum Q-value for all destination nodes is higher than q, or if two successive iterations fail to increase the minimum Q-factor.

Simulation Results

- **RWA for multicast requests:**

For each multicast connection request, the algorithm first solves the multicast routing problem and then assigns a wavelength for that tree (first-fit algorithm).

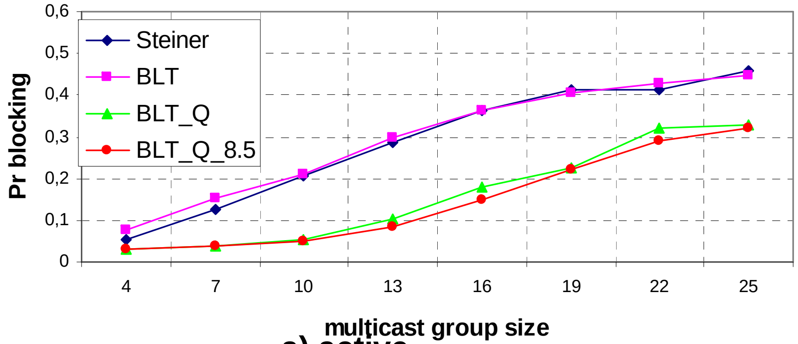
- Blocked: There is no available wavelength for the entire tree.
- Accepted:
  a. A route and wavelength assignment can be found.
  b. The Q-factor for each path on the tree is above the predetermined Q threshold.
  c. There are available Txs and Rxs for that connection

If the physical impairments constraints are not met, a new wavelength assignment is implemented and the heuristic is repeated until no new wavelength assignments are possible.

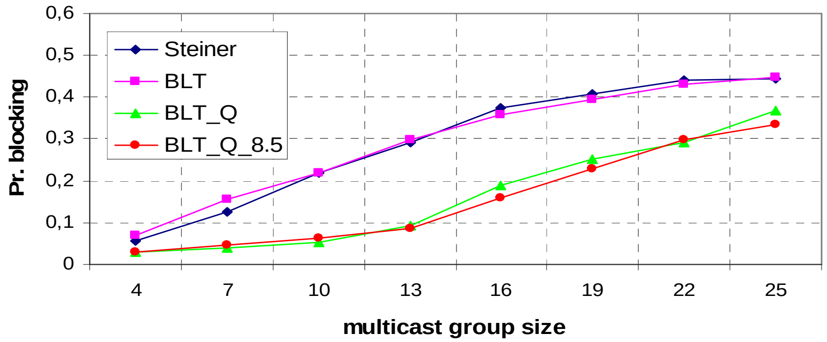
Simulation Results

- ❑ Network :
  - 50 nodes,
  - 196 bidirectional links,
  - average node degree of 3.92,
  - maximum node degree of 6,
  - an average distance between the links of 60 Km.
- ❑ Dynamic System:
  - Poisson arrivals
  - Exponentially distributed holding times with a unit mean.
  - 100 Erlangs load.
  - 5.000 requests were generated for each multicast group size.
  - The results for each simulation point are obtained as the average of 5 runs (5000 simulations for each run)

Simulation Results



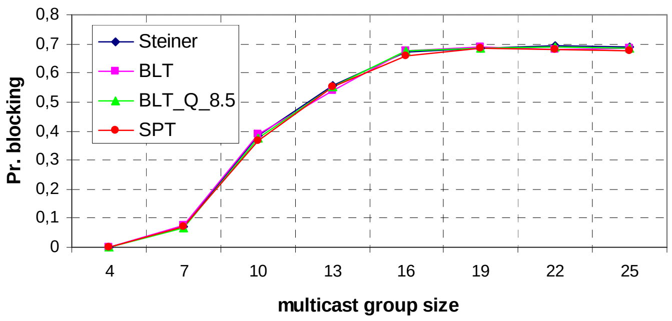
a) active



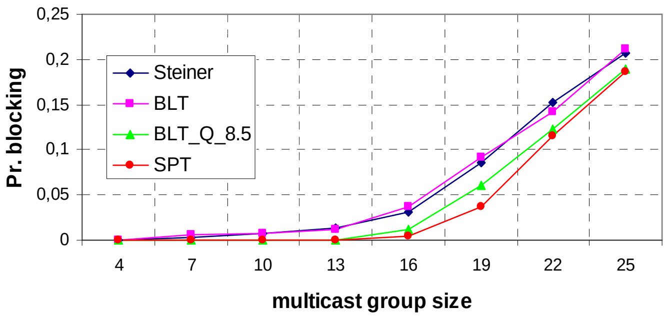
b) passive

- ❑ BLT$_{Qthreshold}$ and SPT heuristics perform the best for both passive and active splitting cases.
- ❑ No particular advantage of using active instead of passive splitters.
  - This is due to the fact that VOAs are used to attenuate the total power to a predetermined value that is calculated based on the worst case scenario.
  - Results were slightly better for active splitters because at the destination nodes the signal is dropped to the Rx before facing VOA attenuation, thus resulting in an improvement on the Q-factor.

Simulation Results



a) Fixed Tx/Rx



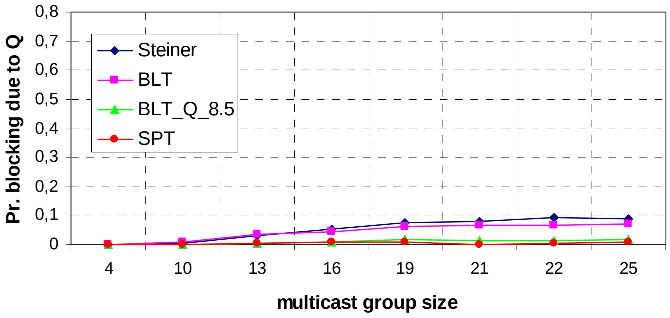
a) Tunable Tx/Rx

- Blocking probability is greatly reduced in the case of tunable Txs/Rxs, since in this case there is more flexibility in the network to assign wavelengths to the multicast connections.

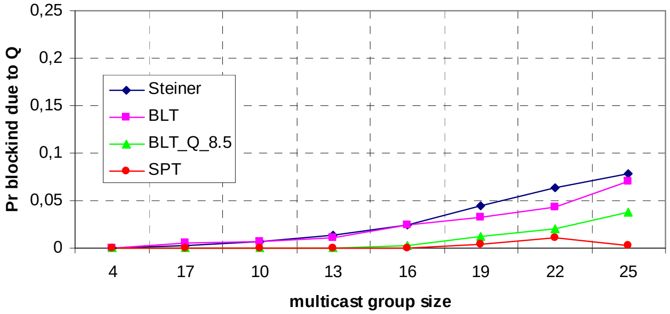
- $\text{BLT}_{\text{Qthreshold}}$ and SPT heuristics perform the best for both cases as the blocking due to Q is limited compared to the other routing algorithms.

Simulation Results

a) Fixed Tx/Rx



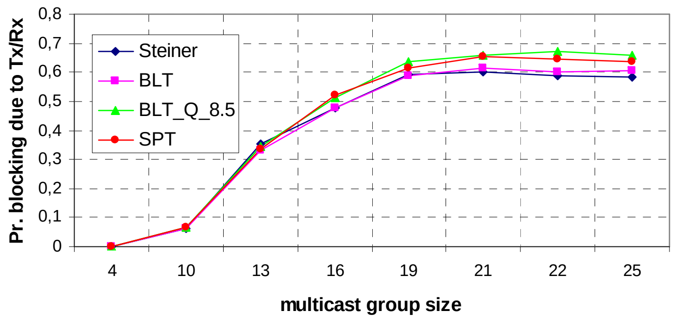
b) Tunable Tx/Rx



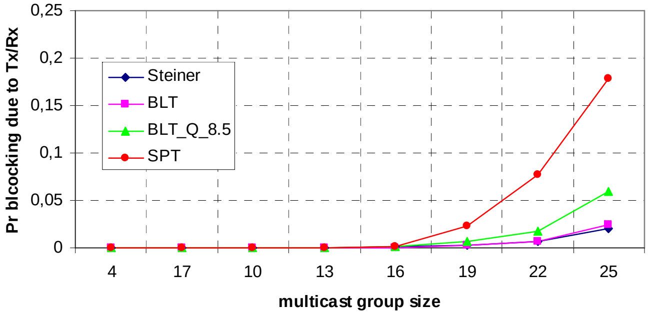
- Figures show the blocking probability due to Q versus the multicast group size
- Blocking probability due to Q for the tunable case is slightly higher than blocking probability due to Q for the fixed case.
- However the overall blocking probability in the tunable case is greatly reduced compared to the fixed case.

Simulation Results

a) Fixed Tx/Rx



b) Tunable Tx/Rx



- Figures show the blocking probability due to Tx/Rx constraint versus the multicast group size

- Blocking probability due to Tx/Rx for the fixed case is greatly increased compared to the Tunable case.

- Therefore Tunable Tx/Rx designs perform better than Fixed Tx/Rx, with SPT and BLT_Q$_{tolerance}$ performing the best amongst the multicast routing algorithms.

Conclusions and Future Work

- **Conclusions:**
  - It is clear from this work that different node architectures and engineering designs produce different multicast group blocking, a strong indicator that a better interaction between physical and logical layers is needed for multicast connection provisioning.

- **Future Work:**
  - Our current work focuses on further accounting and determining the impact of PDG and PDL on the algorithms and the system performance.
  - Examining different protection and traffic grooming schemes when physical layer impairments are taken into account for the provisioning of multicast requests. This work is currently underway.
  - Examining the provisioning and protection of groupcast requests when physical layer impairments are taken into consideration.