Routing and Resilience in AWG Based WDM Networks

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Arrayed Waveguide Grating based networks

- We are considering a physical star topology
  - AWG instead of a Passive Star Coupler
- Spatial wavelength reuse
  - Use the same wavelength N times in an NxN AWG
  - No sender collisions (receiver collisions possible)
- Passive wavelength router
  - AWG is robust and can be made athermal
  - Inexpensive OAM
  - Distributed control and management of the network

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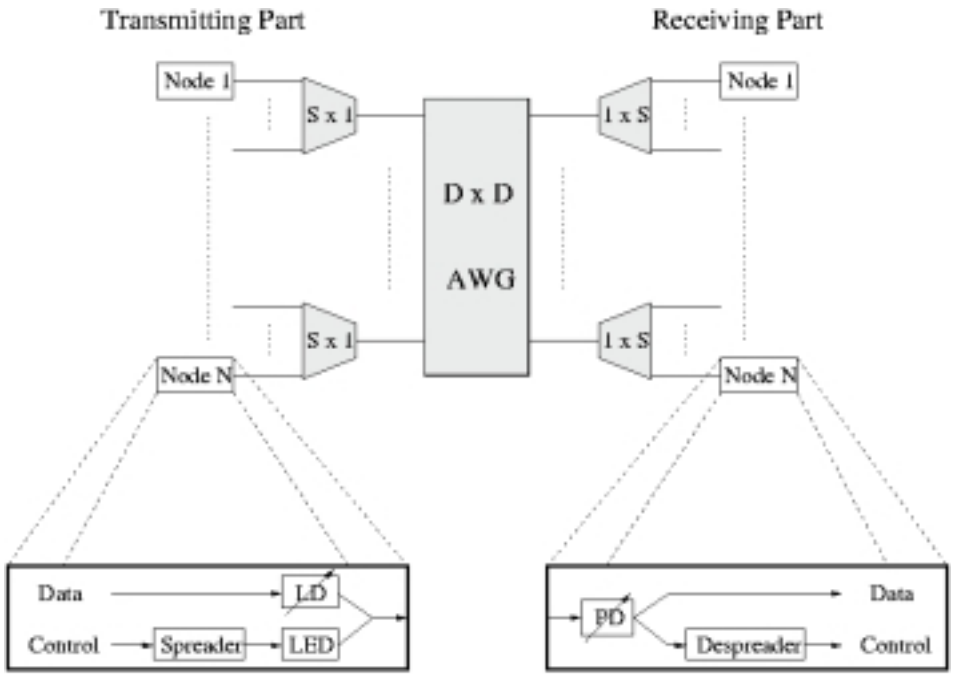
Classification of AWG Based Networks

Single-hop networks

- Route = AWG output port
- Routing is done by means of λ tuning
- Tx and Rx tunable



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Resilience: Failure Types

- Failure can be at node, fiber, and hub (AWG) level
- AWG represents a single point of failure:
  - In case of AWG failure entire connectivity is lost
  - Holds not only for single-hop networks but also for all logical multihop topologies embedded on a physical AWG based star network

  ⇒Protection needed
- Link and node failures have only local effect

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Resilience in Single-Hop Networks: Protection Types

Homogeneous protection

- Backup system is a copy of the working system
- Conventional schemes:
  - 1+1
  - 1:1
  - 1:N

Heterogeneous Protection

- Backup system differs from the working system
- AWG works in parallel to a passive star coupler (PSC)
- Combining respective strengths of both devices

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Heterogeneous Protection

- During normal operation both AWG and PSC are used for communications
- Rationale:
  - Broadcast control, multicast data, and „overflow“ unicast data is sent over PSC
  - Unicast data is sent over AWG benefitting from continuous spatial wavelength reuse
  - Mutual protection of AWG and PSC
- Each node has 2 transceivers attached to AWG and PSC via two pairs of fibers ⇒ Node and fiber protection

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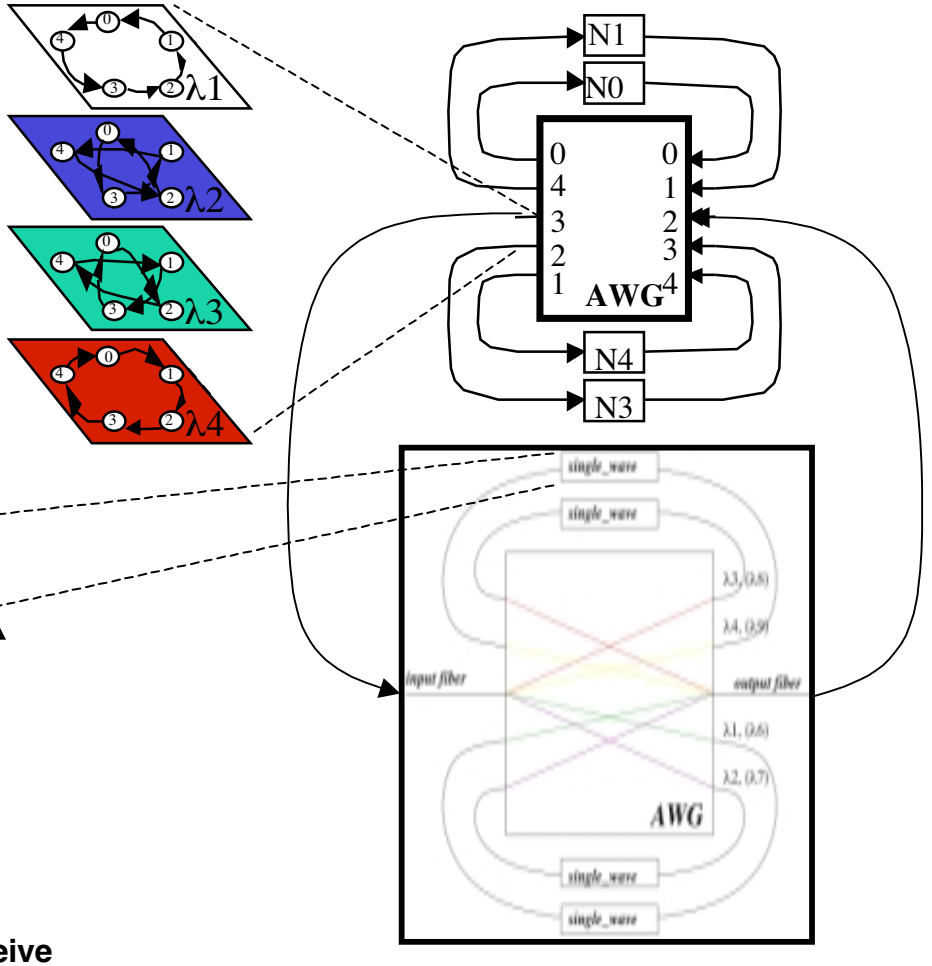
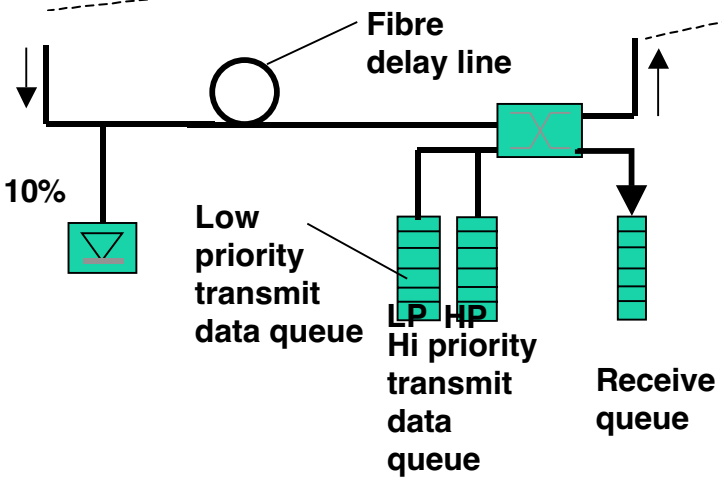
Classification of AWG Based Networks (cont.)

Multihop networks

- Route = multiple passing the AWG
- Each node equipped with a 2 x 2 space switch per wavelength





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Classification of AWG Based Networks (cont.)

- PrimeNet - A special kind of multihopping
  - Number of input ports of the AWG has to be prime
  - Number of rings between 1 and (N-1)
  - All nodes connected to all rings
  - No wavelength conversion in the nodes
    - A packet stays on the ring until it reaches its destination
- Other multihop architectures are possible
  - Spatial wavelength reuse reduces total number of wavelengths
    - E.g. (2,2) ShuffleNet uses 5 wavelengths instead of 16 in a PSC
    - Band limited amplifiers support a larger number of nodes

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Protection in Multihop Networks

- AWG protection could be 1+1 or 1:1
  - Homogeneous protection
  - Heterogeneous protection using Cayley graphs follows
- Node or link failure
  - All rings affected, but the position of the failed node is different in each ring
  - Different mechanisms
- Unidirectional ring
  - “Bridge” the failed node
    - Outband signalling required!
    - Neighboring working nodes tune to the wavelength $(2*\lambda) \bmod N$
      - Relatively slow tunable devices can be used (tuning time < 50 ms)

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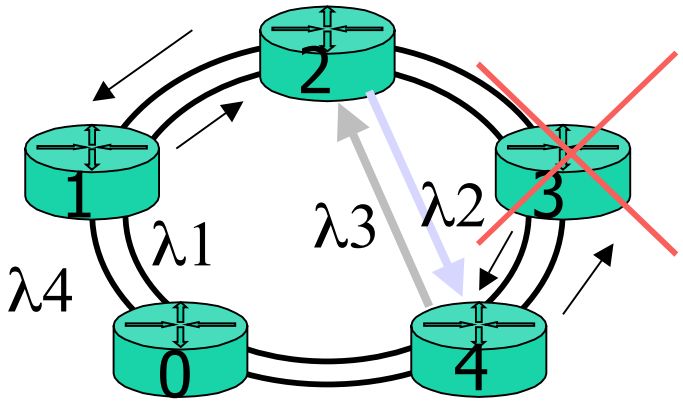
Protection in Multihop Networks (cont.)

- **Bidirectional ring**
  - **No LOS alarm possible (because there is no continous signal in optical packet switching)**
    - **Timeout for SRP usage packets**
  - **Either re-routing similar to RPR**
  - **Or re-tuning when Rx/Tx are (slowly) tunable**
    - **If the next wavelength is not already in use**



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Routing in Multihop Networks (here: PrimeNet)

- **Routing depends on the capability of the nodes**
  - **Nodes w/ or w/o wavelength conversion**
    - **Wavelength conversion means to receive and reroute**
  - **Example: 2 rings (=wavelengths), Diameter Δ**
    - **Without wavelength conversion: (bi-directional)**
      - **N/2**
    - **With wavelength conversion: (FLBH rings)**
      - **Forward loop (+1 node), backward hop (-a nodes)**
      - **$\Delta = \lfloor N/(a+1) \rfloor + (a-1)$ for $1 <= a <= \sqrt{N}$**
      - **Which is smaller for all a>1**

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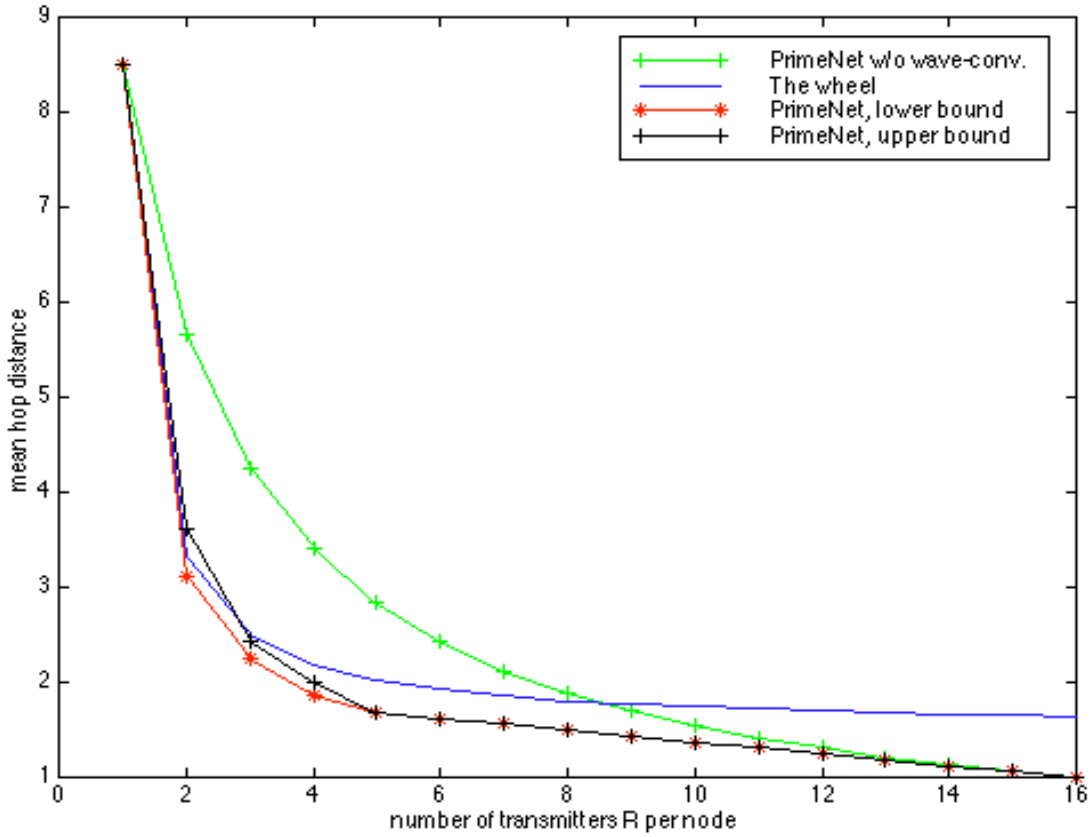
Routing in Multihop Networks (here: PrimeNet)

- **Mean hop distance w/ and w/o wavelength conversion**



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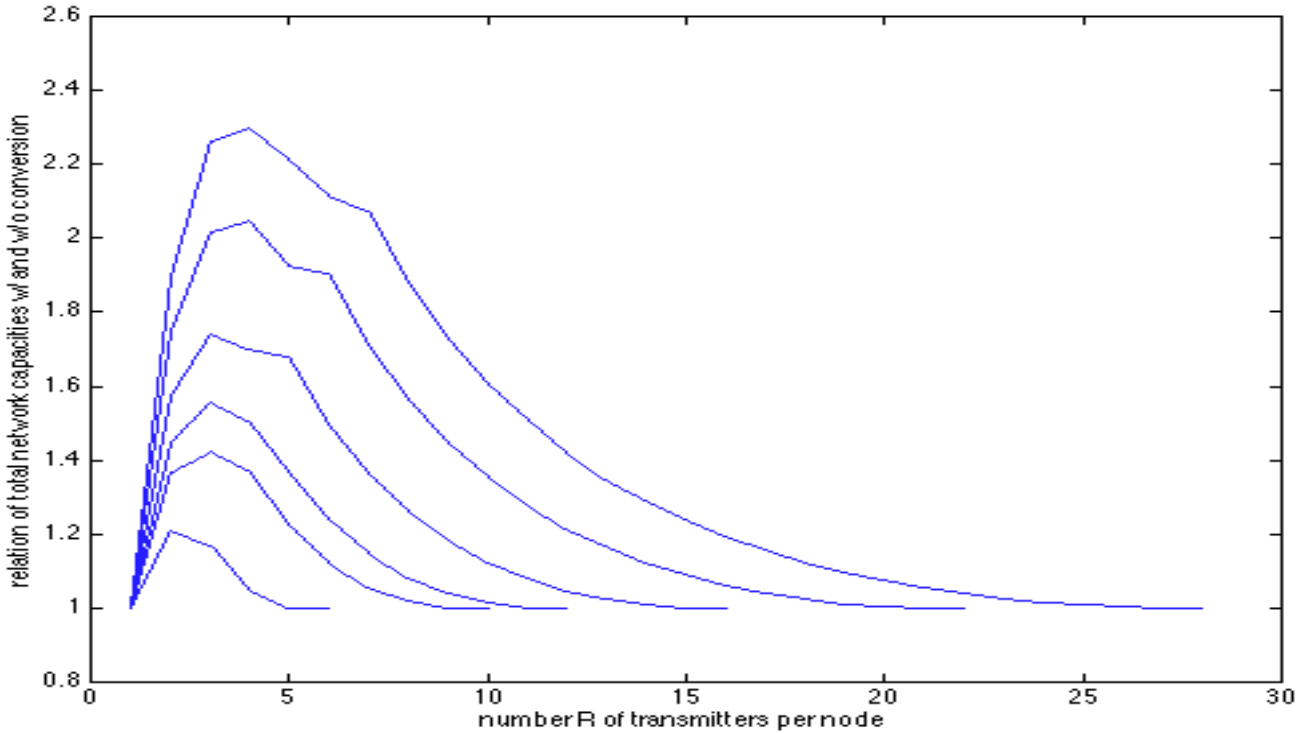
Routing in Multihop Networks (here: PrimeNet)

- **Does it pay off?**
  - **Quotient of total network capacities w/ and w/o conv.**
  - **Assuming a uniform load distribution**



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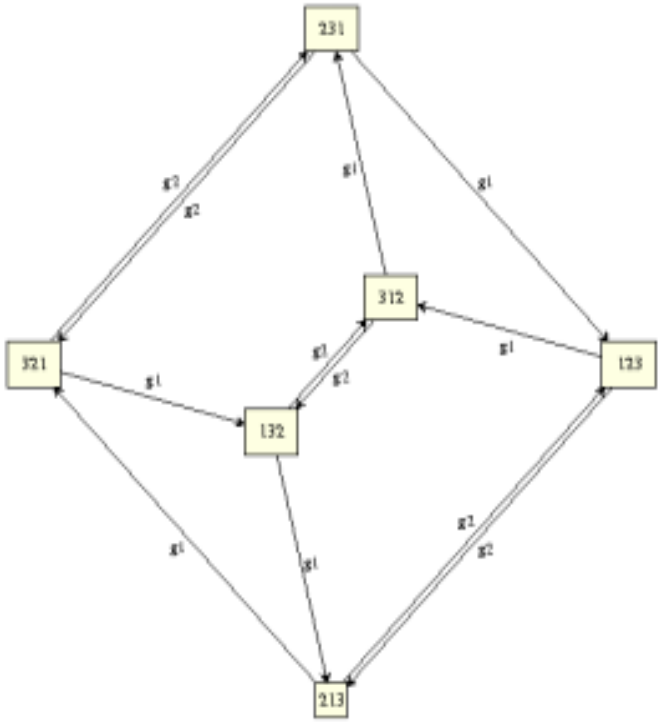
Routing in Multihop Networks (here: PrimeNet)

- **What happens if the AWG breaks (or my fibre)?**
  - **Or: interconnecting PrimeNets**
- **Cayley graphs**
  - **Highly regular structures based on permutation groups, introduced 1986**
  - **A Cayley graph G=(V,G) with vertex set V and generator set G**
  - **Two vertices (nodes) v1 and v2 are adjacent if v2=v1*g**
  - **Example:**
    - **g1=312**
    - **g2=213**



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Why Cayley Graphs?

- The AWG itself makes up a Cayley graph
  - Example: A 5x5 AWG can be represented as a cyclic permutation generator for each wavelength:
    - g1=51234
    - g2=45123
    - g3=34512
    - g4=23451
    - g5=12345 (this one maps the same wavelength from input to output)
- Hierarchical Cayley graphs show maximum fault tolerance (d-1)
- Every Cayley graph is vertex-symmetric (balanced load over all links, unlike other multihop networks like deBruijn, Kautz)

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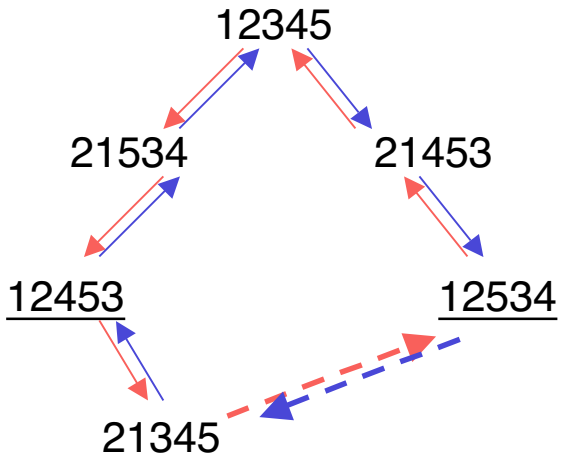
Routing in Cayley Graphs

- Routing has to be done once for all packets.
  - Set of generators has to be closed under inverses (g1 and $g1^{-1}$ have to be in the generator set)
- Packet from n1 to n2 takes the same route through the graph as a packet from $(n2)^{-1}*n1$ to e (identity).
- Routing steps:
- Transform myself using the inverse of the destination node
- Either sort the permutation using the available generators or
- build routing tree with the identity element as root of the tree and find myself in there



g1=21534
g2=21453
n1=12453
n2=12534
$n2^{-1}*n1=12453*12453=12534$

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Conclusions

- Networks based on AWG offer increased capacity due to spatial wavelength reuse
- However, AWG is single point of failure
  - Protection can be done in single hop networks
    - Homogeneous
      - Copy of the working system
    - Heterogeneous
      - Use PSC to protect AWG and vice versa
      - Separate unicast/multicast traffic in normal operation
  - Protection in multihop systems by re-routing or re- tuning
- Routing in multihop networks depends on node structure
  - Wavelength continuity constraint costs most capacity for low number of rings and large number of nodes
- Using Cayley graphs for network construction guarantees maximum fault tolerance and fast routing

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