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Availability Constrained Traffic Control for AMC-enabled Wireless Mobile Backhaul Networks

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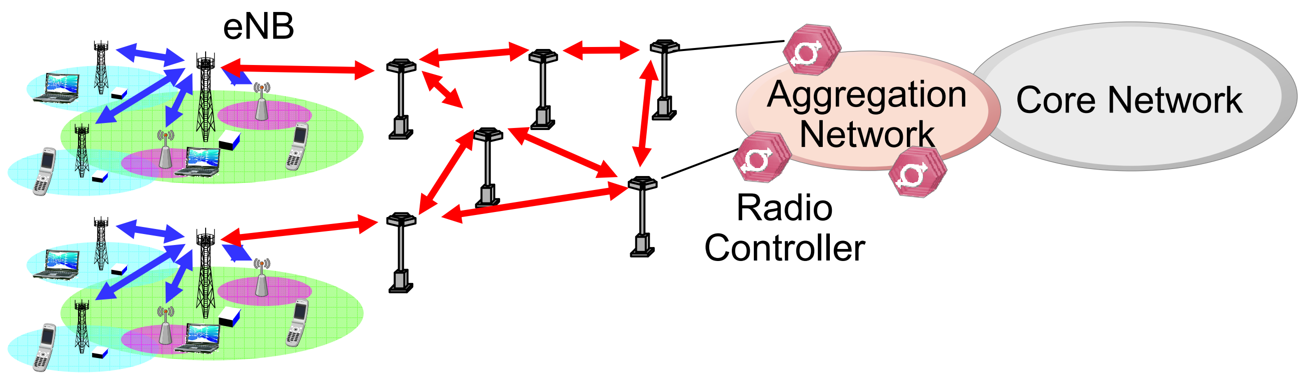
About Mobile Backhaul Network

- Microwave radio link is widely used by the operators in countries where fixed infrastructure is non-existent or difficult to install
  - Adaptive Modulation Coding (AMC) which allows links to use higher modulation under good weather condition is often used to increase spectrum efficiency
- Current concern
  - Data traffic that need to support is increasing
  - How to manage backhaul efficiently is getting difficult especially when small cells are introduced
    - Small cell could make topology more complex and difficult to manage



NEC’s involvement in Mobile Backhaul Network

- NEC is one of the leading provider for microwave equipments in Mobile Backhaul *
  - NEC's iPasolink
    - http://www.nec.com/en/global/prod/nw/pasolink/products/ipaso.html
  - Key features includes
    - Support of IP traffic
    - AMC (Adaptive Modulation and Coding)
    - XPIC (Cross Polarize Interference Canceller functions)

iPASOLINK 200

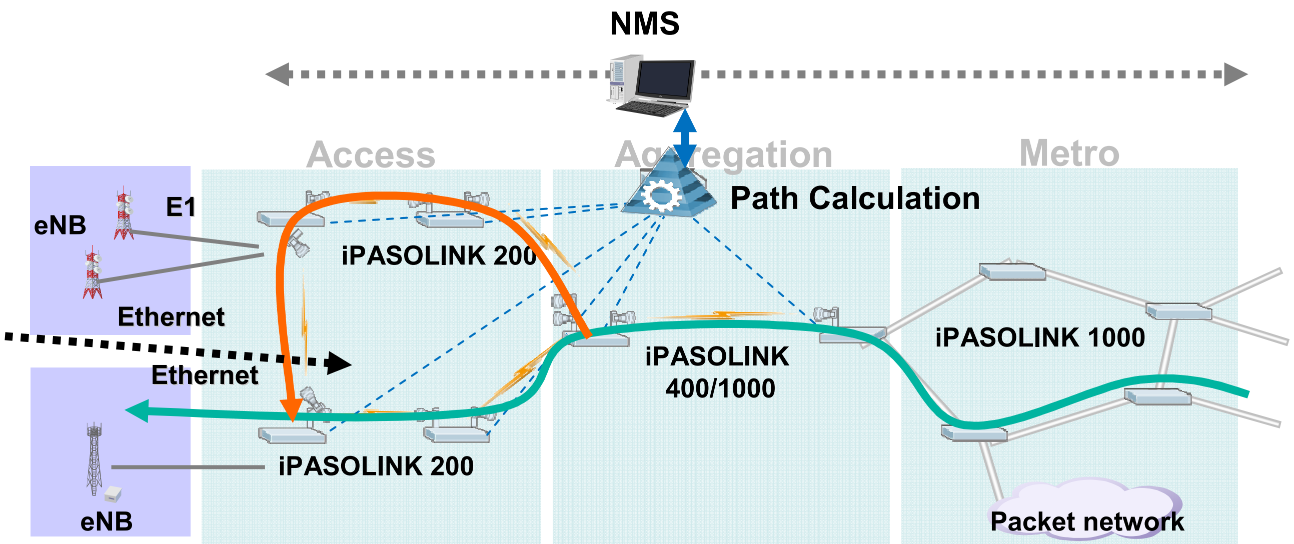
iPASOLINK AOR
(All Outdoor Radio)

* http://www.infonetics.com/pr/2011/2Q11-Microwave-Equipment-Market-Highlights.asp

Resource management for Mobile Backhaul Network

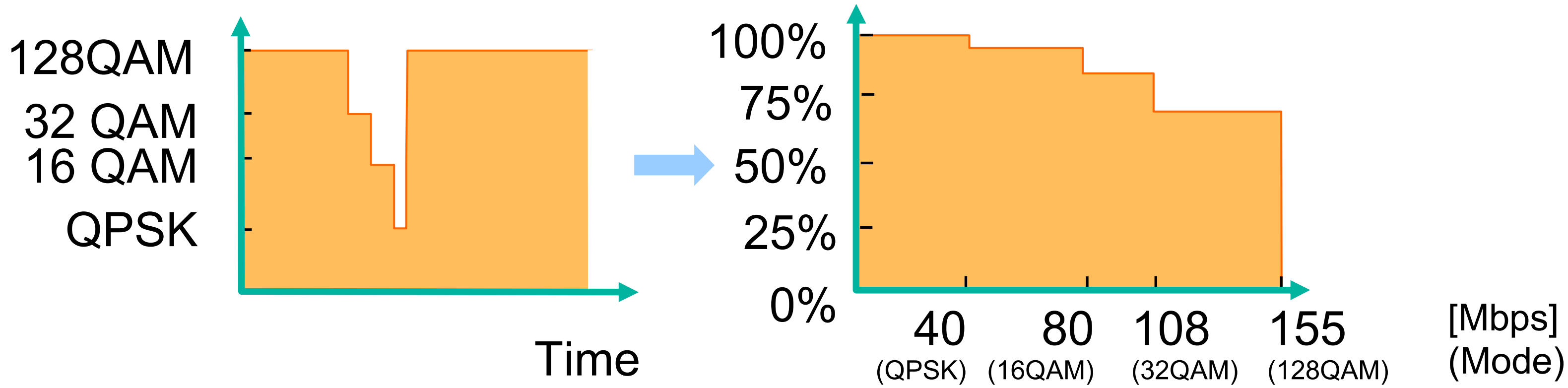
- Adaptive network control from NMS (with Path Calculation Engine)
  - Increase effective capacity of wireless links to maximize the available infrastructure by dynamically sets path based on the network condition
    - Biggest difference of microwave radio links is that data rate could change
- Benefit of adaptive network control
  - Less hassle for network operator
    - Can find most efficient path under current network condition
      - Only specifying src/dst pair and requirements
    - Change route of paths upon detecting network status change
      - Data rate change of links, traffic imbalance

Upon detecting modulation change from switches, NMS calculate alternate paths which is less vulnerable from AMC



Availability of bandwidth with microwave radio links

- With AMC, microwave radio links change its modes (modulation coding scheme) to adapt to channel condition
  - Although link connection is maintained, data rate at which microwave radio links can communicate decreases
  - This in effect makes microwave radio links to have bandwidth with different availability
    - e.g.) at least 40 Mbps of bandwidth is usable regardless of mode but additional 40 Mbps can only be used when link use 16QPSK or higher

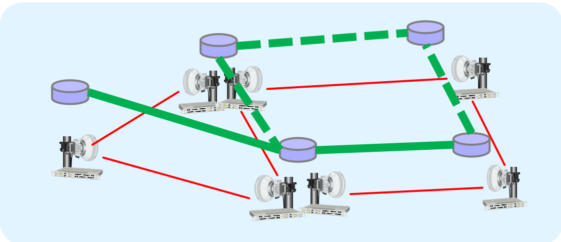


How can we admit flows efficiently while satisfying QoS requirement ?

Brief summary

Main Contribution

- Presents methods to find paths more efficiently when network is constructed with AMC-enabled wireless links
  - Availability Constrained Shortest Path
  - Partial Disjoint Protection
  - Bandwidth reallocation
- Investigated how these methods contribute to improve network efficiency under various link conditions through simulation
  - Favorable, decent, and, sever link condition



Example of availability of wireless link under different modulation

Wireless link (4.3 km, 23 GHz, 58 MHz, 1 ft ant.)	QPSK	16QAM	32QAM	128QAM
	99.999%	99.997%	99.996%	99.992%

Ceragon, "LTE Ready Mobile Backhaul," jan, 2009
http://www.ceragon.com/files/Ceragon_%20LTE%20backhaul_White%20Paper.pdf.pdf

Finding path for flows with end-to-end availability requirement

Conservative approach: Baseline

- Set availability requirement for bandwidth that can be used for the path at each link
  - e.g., Anything below 99.995% is deemed to be unusable
- Find shortest-hop path based on above assessment

Other approaches: Enhancements

- Find highest end-to-end availability path among available bandwidth which satisfy flow's requirement
  - Single path
  - Add protection path to improve end-to-end availability
- Reallocate bandwidth of a flow to lower availability bandwidth of the same link if the flow can maintain required end-to-end availability
  - This can help optimize the bandwidth usage

We investigate how these methods are effective through simulation

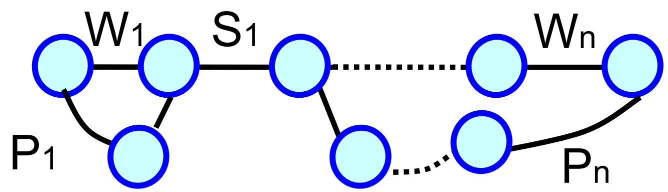
A-CSPF and Partial Disjoint Protection

Availability-Constrained Shortest Path First (A-CSPF)

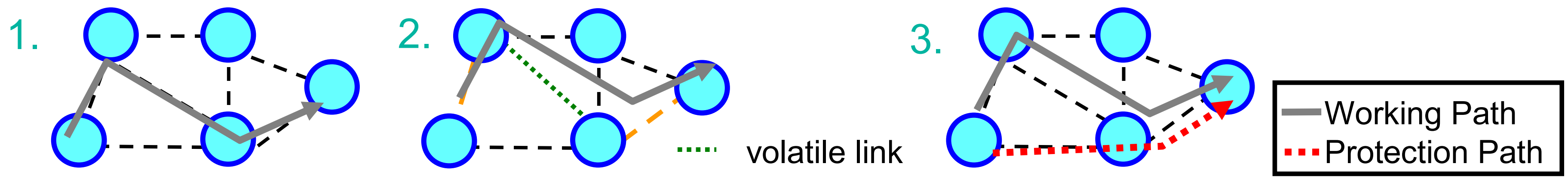
- Modifies Dijkstra's algorithm to considering availability
  - Searches the highest end-to-end availability path
    - Consider availability of usable bandwidth as the availability the link

Partial Disjoint Protection

- Allow sharing of high availability links by working and protection path to use resource efficiently
- Protection path is searched based on the equation below
  - $\Pi S_n (1 - (1 - \Pi W_n)(1 - \Pi P_n))$
    - Sn: Set of shared links
    - Wn: Set of links used only in working path
    - Pn: Set of links used only for protection path



* S_n : Shared Link



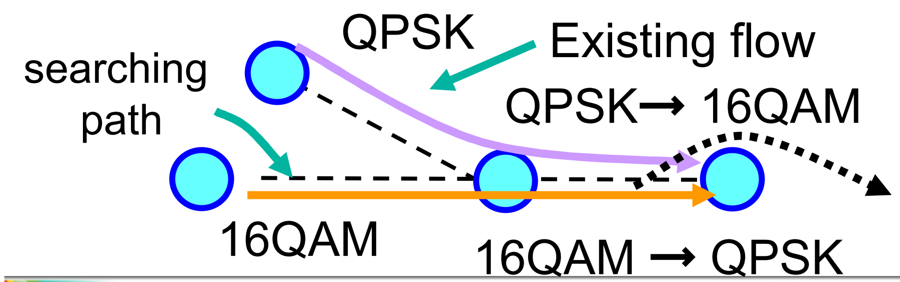
Bandwidth reallocation

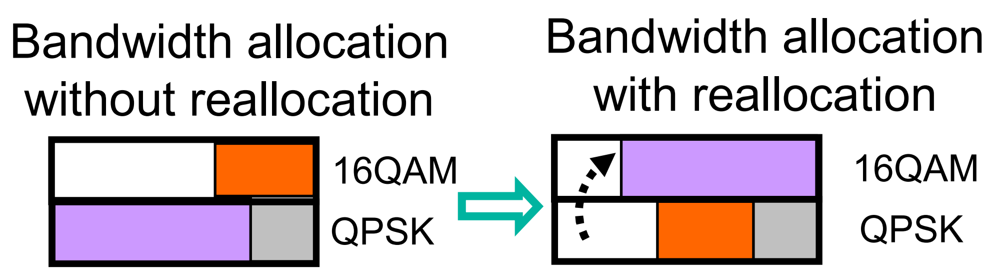
Problem with availability aware routing

– When path is determined in first-come-first-served basis, bandwidth allocation can be inefficient
  - Some earlier flows gets higher end-to-end availability than necessary while future flows can not find path that satisfy end-to-end availability
– Why not reallocate bandwidth used by those earlier flows to a lower availability bandwidth and free up high availability bandwidth

Bandwidth reallocation

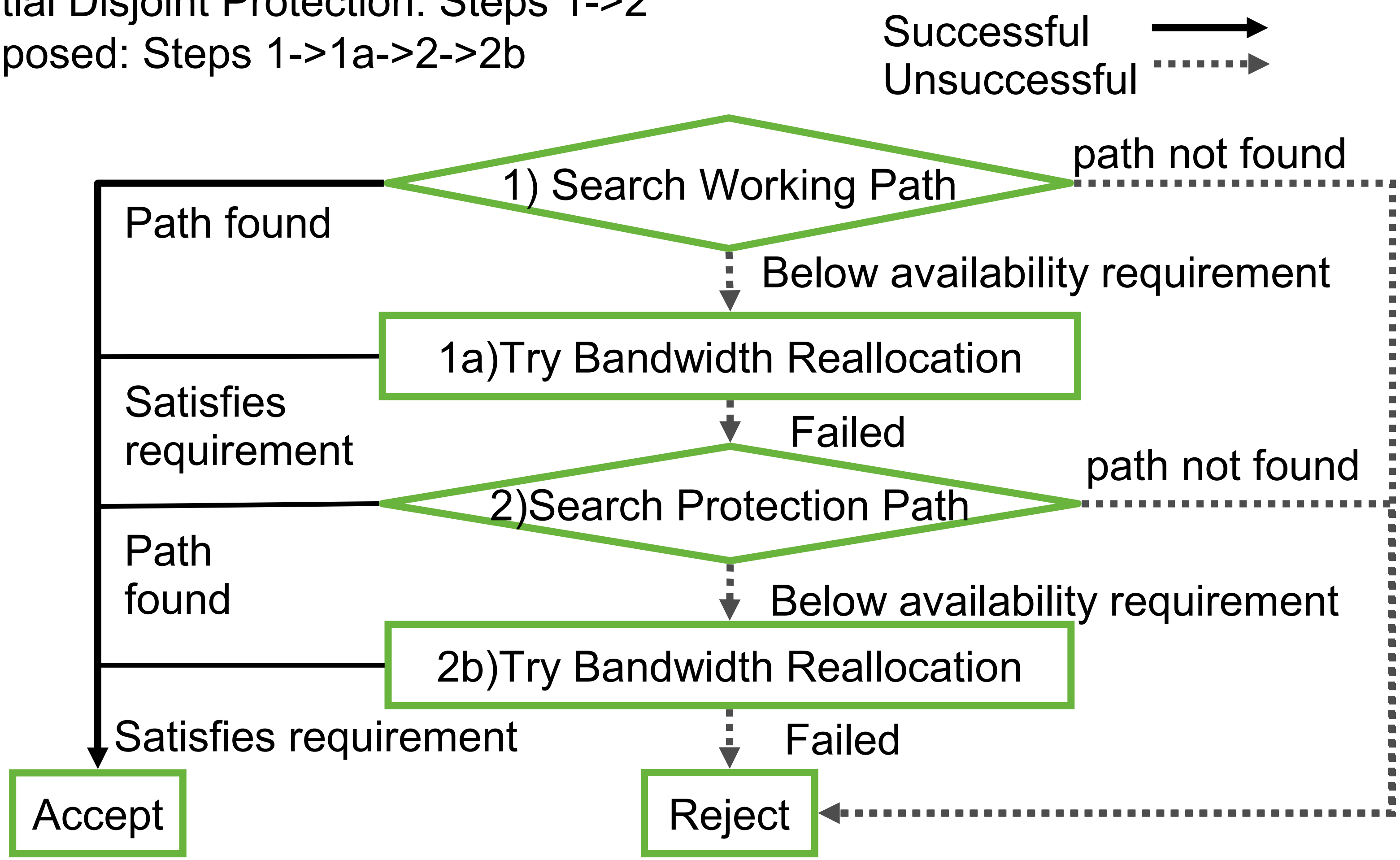
1. Find out any flows that can be reallocated to lower availability bandwidth while meeting required end-to-end availability requirement
2. Use freed bandwidth to increase end-to-end availability of searched path





Overall routing decision

- Routing decision done by A-CSPF, Partial Disjoint Protection and Proposed (Partial Disjoint Protection w bandwidth reallocation)
  - A-CSPF: Step 1
  - Partial Disjoint Protection: Steps 1->2
  - Proposed: Steps 1->1a->2->2b



Simulation evaluation

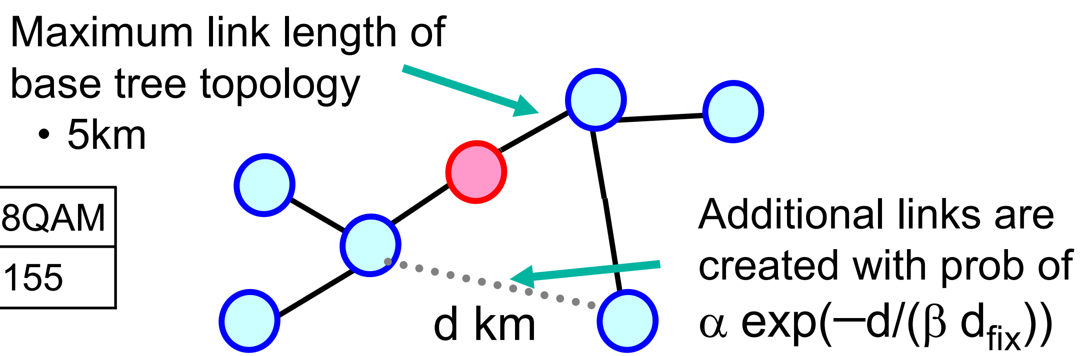
- Simulation study
  - Evaluation
    - Generate flows and evaluate how many flows can be admitted to the network
      - Topology with different link density and link conditions
  - Compared routing algorithms
    - Shortest-path, A-CSPF, Partial Disjoint Protection, and Proposed
- Assumptions
  - Links
    - Availability of each links are independent to each other
    - Consider links to disjoint if they are not used for the same pair of nodes
    - Availability of mode is affected solely by the distance
      - Location of links are not considered
  - Traffic
    - Flows are generated randomly
    - Flows concentrates to one root node
      - 1Mbps flows are generated from randomly picked nodes
      - Requires 99.99% end-to-end availabilty

Topology used in the simulation

- Tree Topology with additional links is used for the simulation study
  - Tree topology
    - Maximum link length = 5 km
    - Number of nodes: 50
      - Scattered around: 30 × 30 km region
  - Additional links
    - Created with probability of $p = \alpha \exp(-d/(\beta\, d_{fix}))$
      - $\alpha = 0.2$, $\beta = 0, 0.05, 0.1, 0.2, 0.4$
      - d = distance between two nodes, d_{fix} = 15 km
  - Link density:
    - e / (N (N-1) /2)
      - e = Number of links, N = Number of nodes

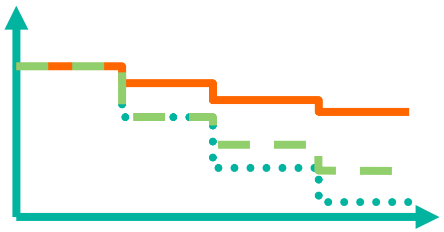
Data rate of each mode

Mode	QPSK	16QAM	32QAM	128QAM
Data rate [Mbps]	40	80	108	155



Link conditions used for the simulation

- Three different link conditions are used
  - Favorable, decent, severe
- Availability of modes
  - Availability of higher mode is less than those of lower modes
  - Availability decreases as link length increases
    - Assuming antenna size does not change



Favorable Condition

Length d [km]	QPSK	16QAM	32QAM	128QAM
0 < d < 5	99.999%	99.993%	99.987%	99.973%
5 ≤ d < 10	99.996%	99.987%	99.98%	99.967%
10 ≤ d < 15	99.993%	99.984%	99.96%	99.9%
15 ≤ d	99.99%	99.97%	99.92%	99.85%

Decent Condition

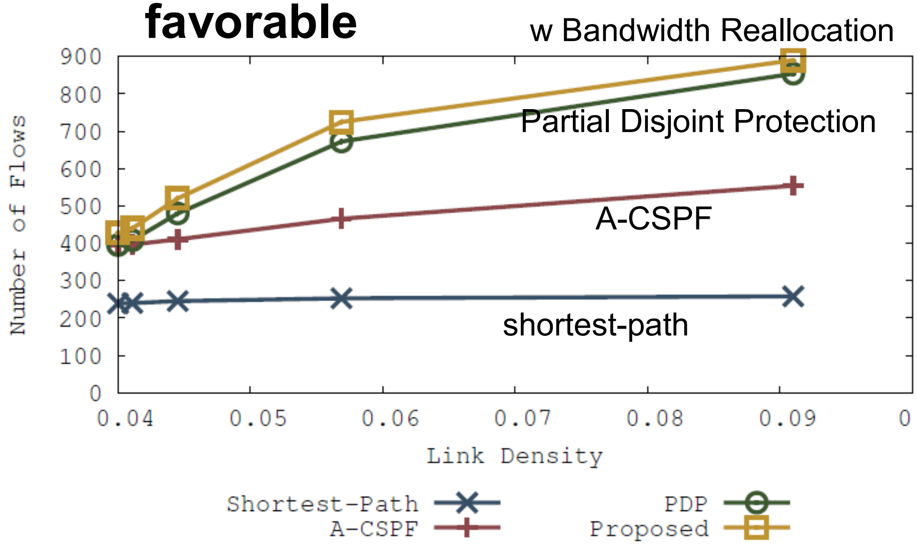
Length d [km]	QPSK	16QAM	32QAM	128QAM
0 < d < 5	99.999%	99.99%	99.95%	99.9%
5 ≤ d < 10	99.99%	99.95%	99.9%	99.5%
10 ≤ d < 15	99.95%	99.9%	99.5%	99%
15 ≤ d	99.9%	99.5%	99%	95%

Severe Condition

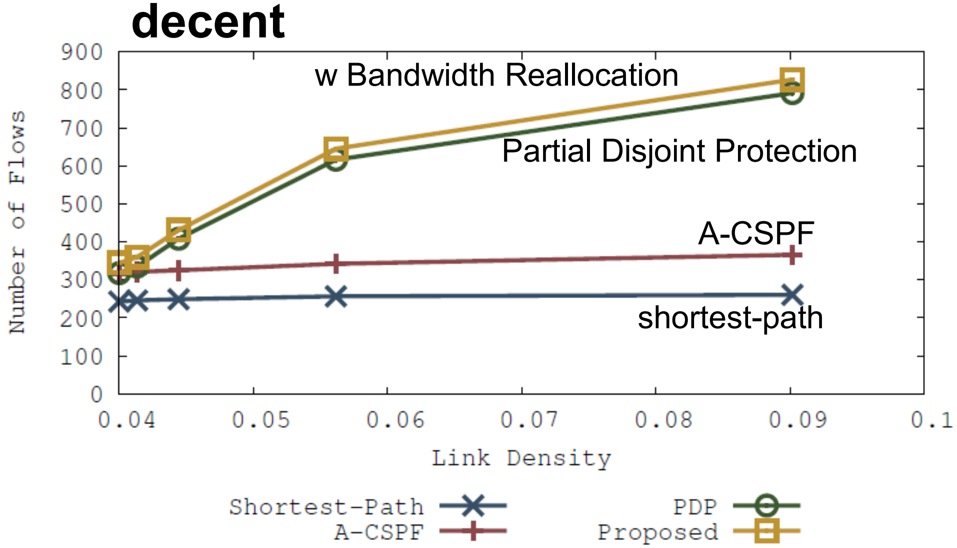
Length d [km]	QPSK	16QAM	32QAM	128QAM
0 < d < 5	99.999%	99.99%	99.9%	99.9%
5 ≤ d < 10	99.99%	99.9%	99%	95%
10 ≤ d < 15	99.9%	99%	95%	90%
15 ≤ d	99%	95%	90%	80%

Admitted flows under different link conditions

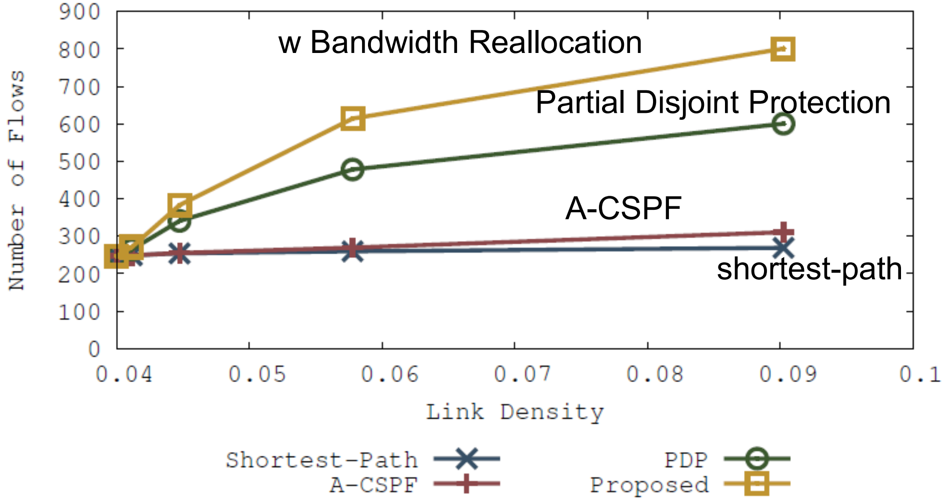
favorable



decent



severe

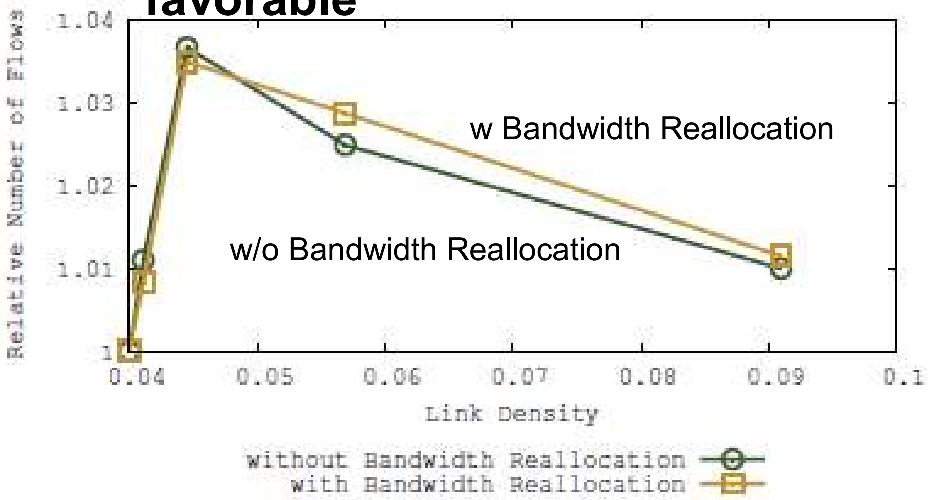


Comparison: from favorable to severe link condition

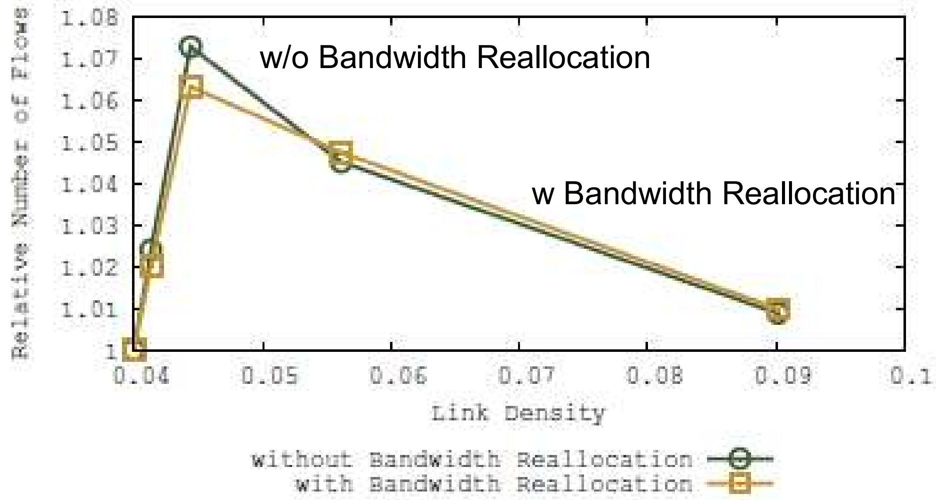
- A-CSPF v Shortest Path
  - 200% -> 45% -> 15%
- Path Protection v A-CSPF
  - 54% -> 200+% -> 200+%
- improvement with Bandwidth reallocation
  - 4% -> 4% -> 33%

Partial Disjoint Protection v 1+1 protection

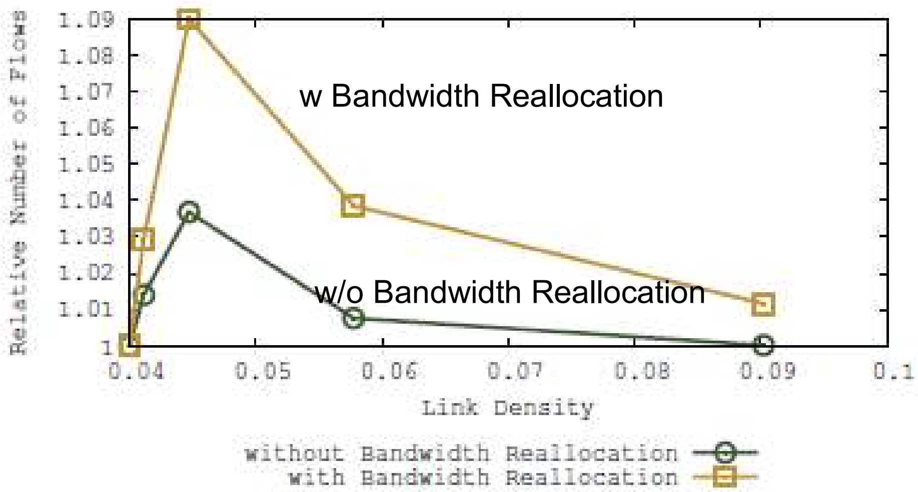
favorable



decent



severe



- Partial Disjoint Protection is slightly more efficient when topology is somewhat skewed
  - Benefit decreases as topology becomes more mesh
- Improvement is more visible under sever link condition

Summary of simulation results

- To increase network efficiency when admitting flows with end-to-end availability requirement:
  - It is better to find path that meets end-to-end availability requirement rather than shortest-path routing
  - Having protection path can improve network efficiency
    - Low availability bandwidth which are not usable for single path can be used because of protection path
  - Bandwidth reallocation is effective when difference of availability of bandwidth within a same link is large
    - There is little flexibility when difference is small
- Effectiveness of each method varies with topology and link conditions
  - Partial Disjoint Protection is more effective compared to 1+1 protection when topology is not fully meshed
  - Bandwidth reallocation is effective under severe link condition

Conclusion

- Studied methods for improving network efficiency for the network with AMC-enabled wireless links
  - A-CSPF, Partial Disjoint Protection, and Bandwidth reallocation
- By exploiting various methods it is be possible to improve network efficiency
  - Having protection path allows more flows with end-to-end availability requirement to be admitted to the network
  - Topology and link conditions affect effectiveness of each method
    - There is scope for further improvements depending on link conditions
- Network wide traffic control will be important feature for future Mobile Backhaul Networks

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