Efficient Monitor Placement for Multipath Traffic Flows

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Traffic Problems

- Network flows and road traffic flows
- Multiple routes between start and destination
- Route choices based on different factors

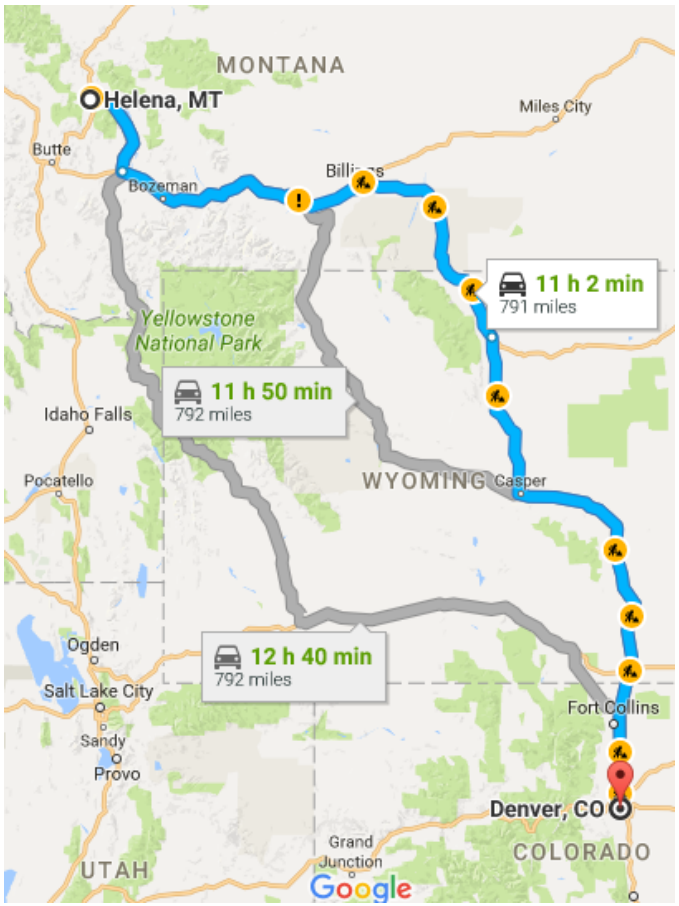


Image source: Google Maps

Road Networks

- Multiple paths make monitoring difficult
- Need to infer information about each *roadway segment*

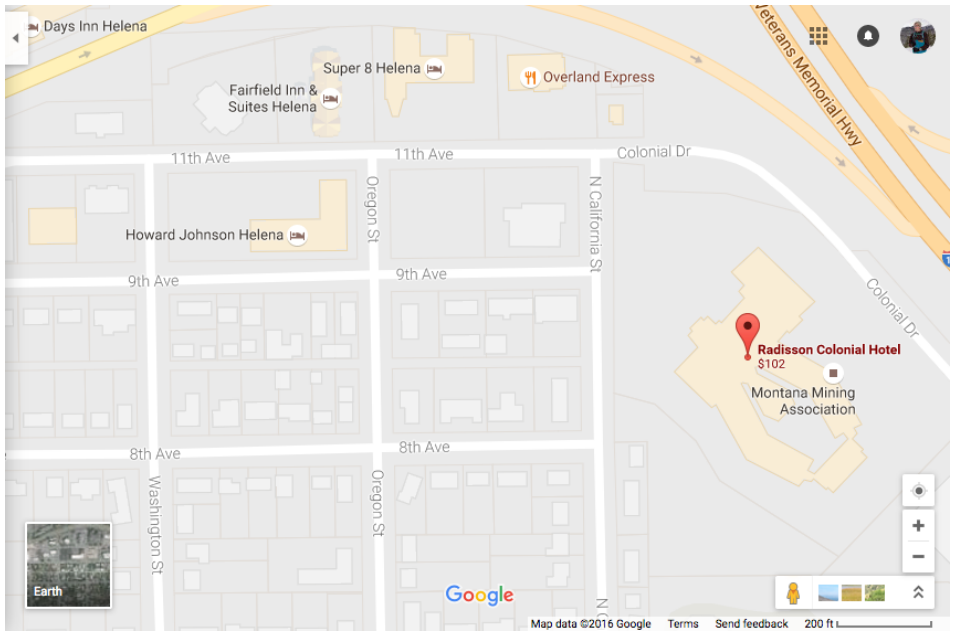


Image source: Google Maps

Road Networks as Graphs

- Sections of road networks can be represented a graph, $G = \langle V, E \rangle$.
- Each intersection becomes a vertex, $v \in V$.
- Each roadway segment becomes an edge, $e \in E$.

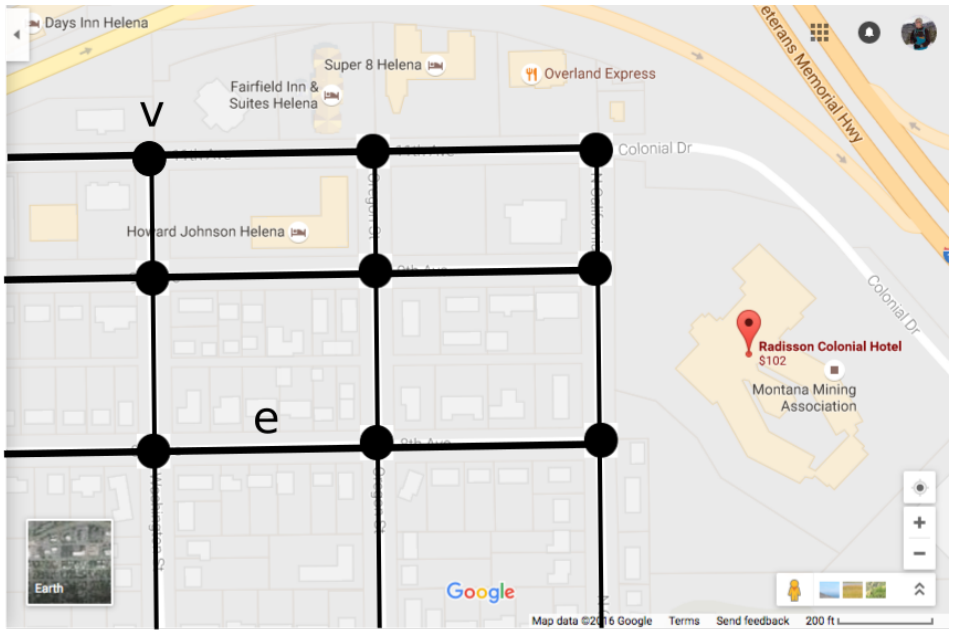
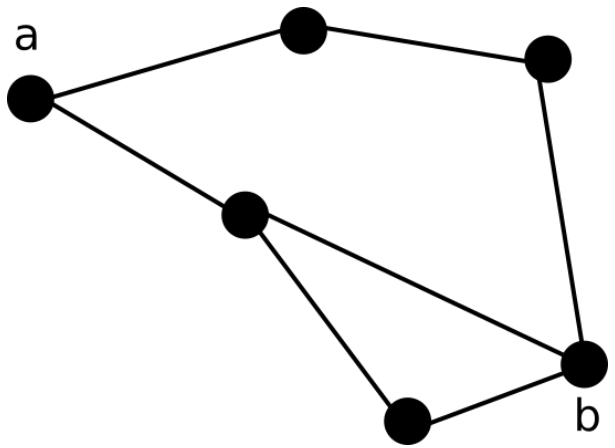


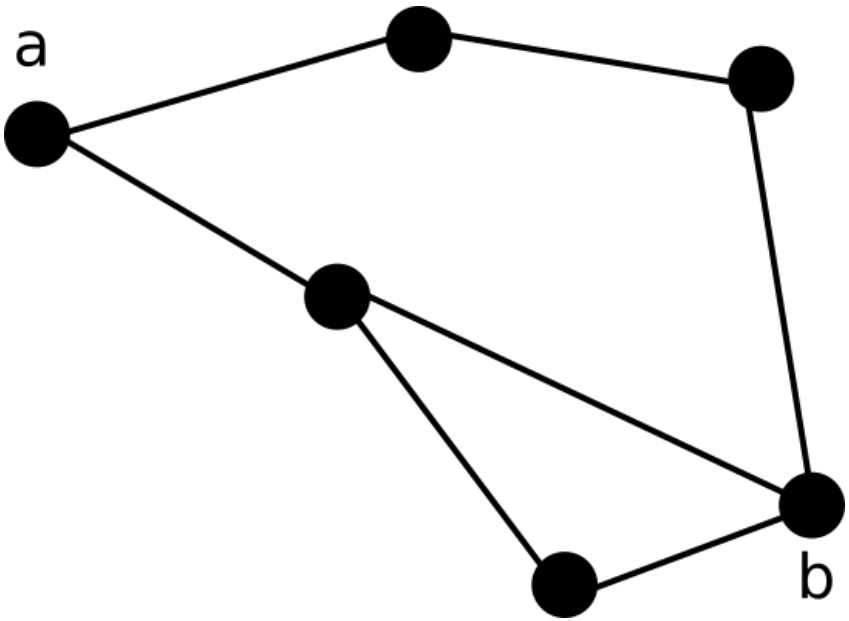
Image source: Google Maps

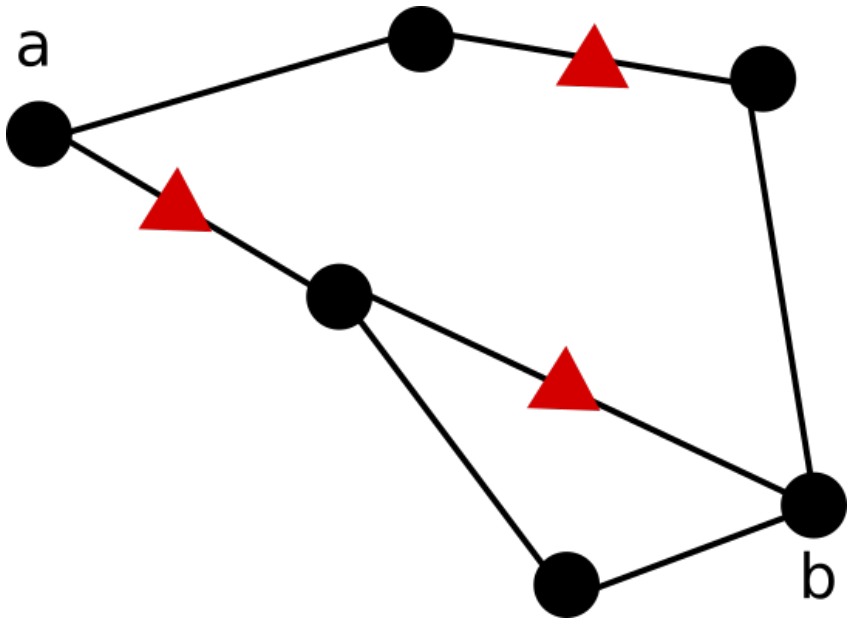
Monitoring Different Paths

- Placing the fewest monitors on a graph is not trivial.
- How do we observe all traffic traveling from point a to b?
- How do we do it with the fewest number of monitoring devices?



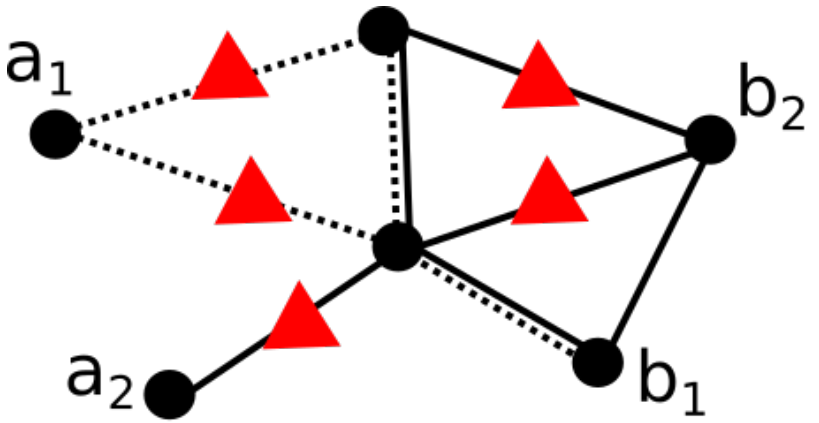
Monitoring Different Paths

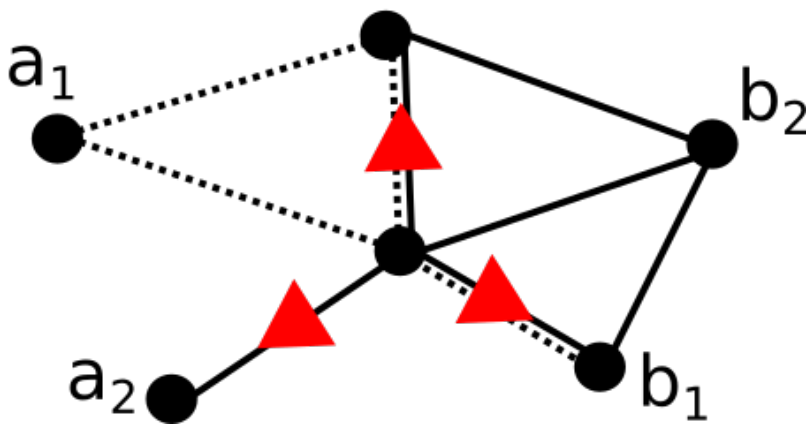




Multiple Paths and Multiple Flows

- Two traffic flows with two start/end points
- Flow 1 requires two monitors and Flow 2 requires three
- Solving for both reduces the number of monitors overall





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Contributions

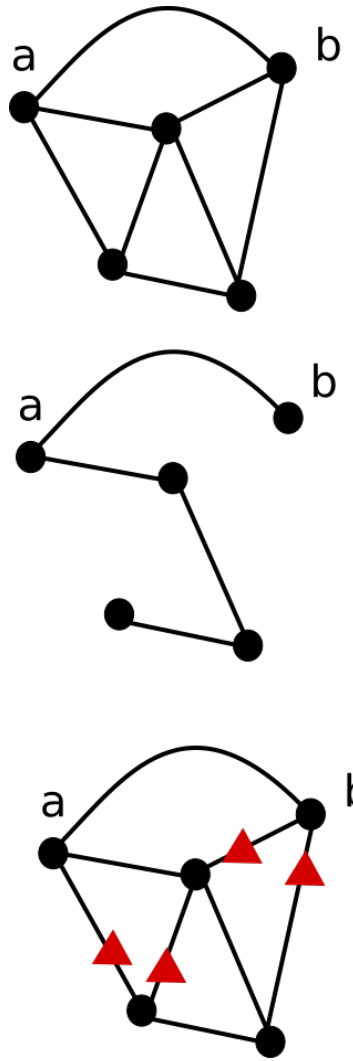
Solving the monitoring problem optimally is not practical for large sets of data. To address this problem we:

- NP-Hardness reduction from Minimum Set Cover problem
- introduce two heuristics
- describe an approximation algorithm
- evaluate the effectiveness of the solutions on different networks

Heuristics

We introduce two heuristics

- based on relationship to cycle-transversal problem
- add back edge from $b \to a$ with no capacity
- we can solve the monitoring problem for a single flow by finding a *minimum cost spanning tree* (MST)



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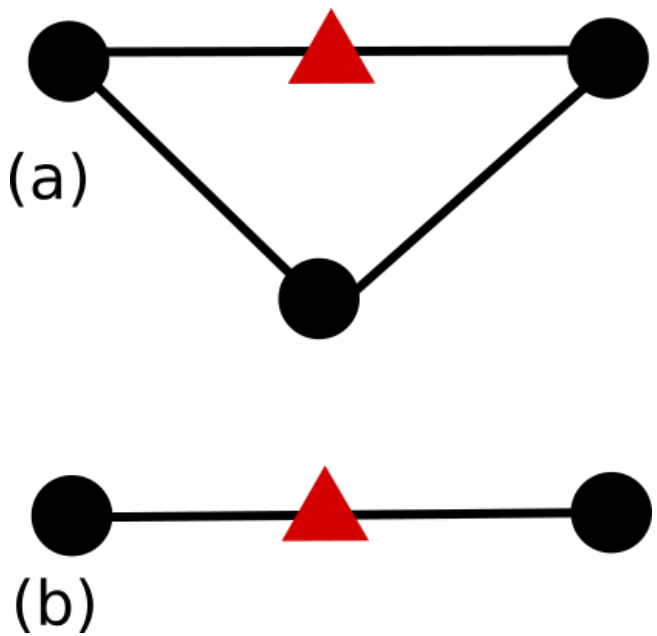
Heuristics

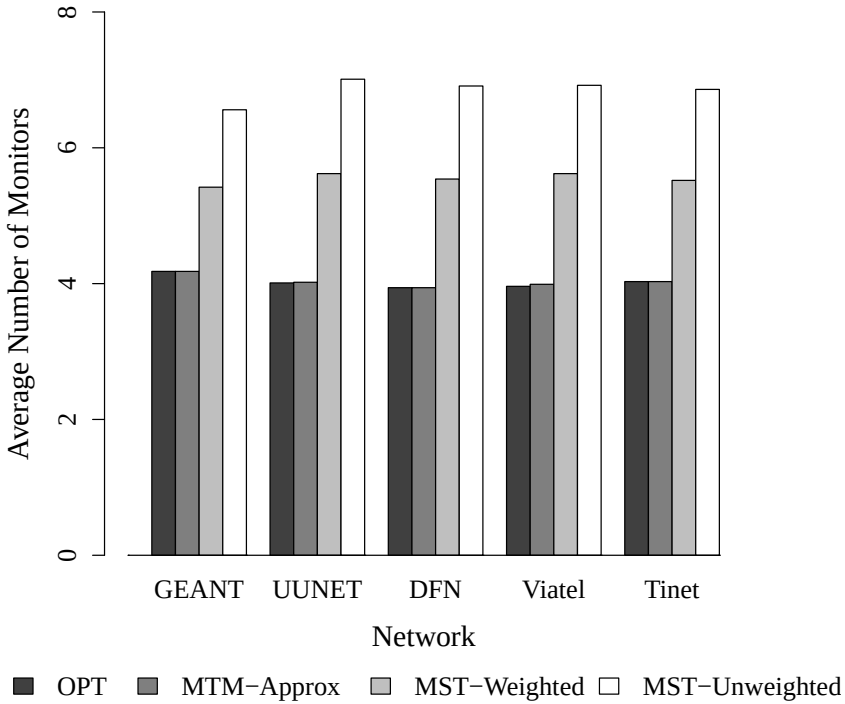
- Heuristic 1 (MST-Unweighted):
  - For each flow, find a random MST
  - Place monitors on edges not in the MST solutions
- Heuristic 2 (MST-Weighted):
  - For each edge, weight the edge with the number of flows on it
  - For each flow, find the minimum cost MST
  - Place monitors on edges not in the MST solutions

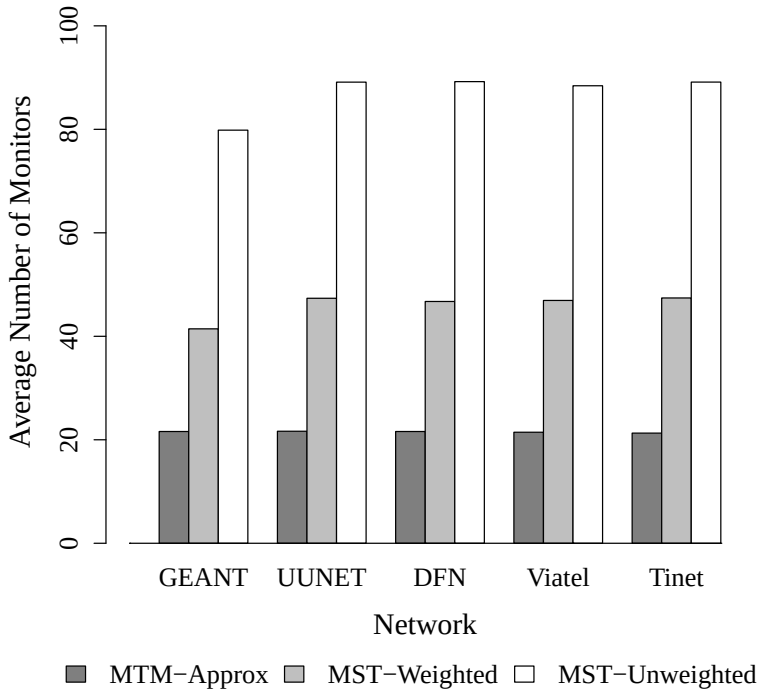
Approximation Algorithm

- greedily choose monitor placements that "help" the most flows until all cycles are covered
  - monitor placement in (a) covers a cycle and helps the flow whereas (b) does not
- $(\ln m + 1)(\ln k + 1)$-approximation, for m edges and k flows

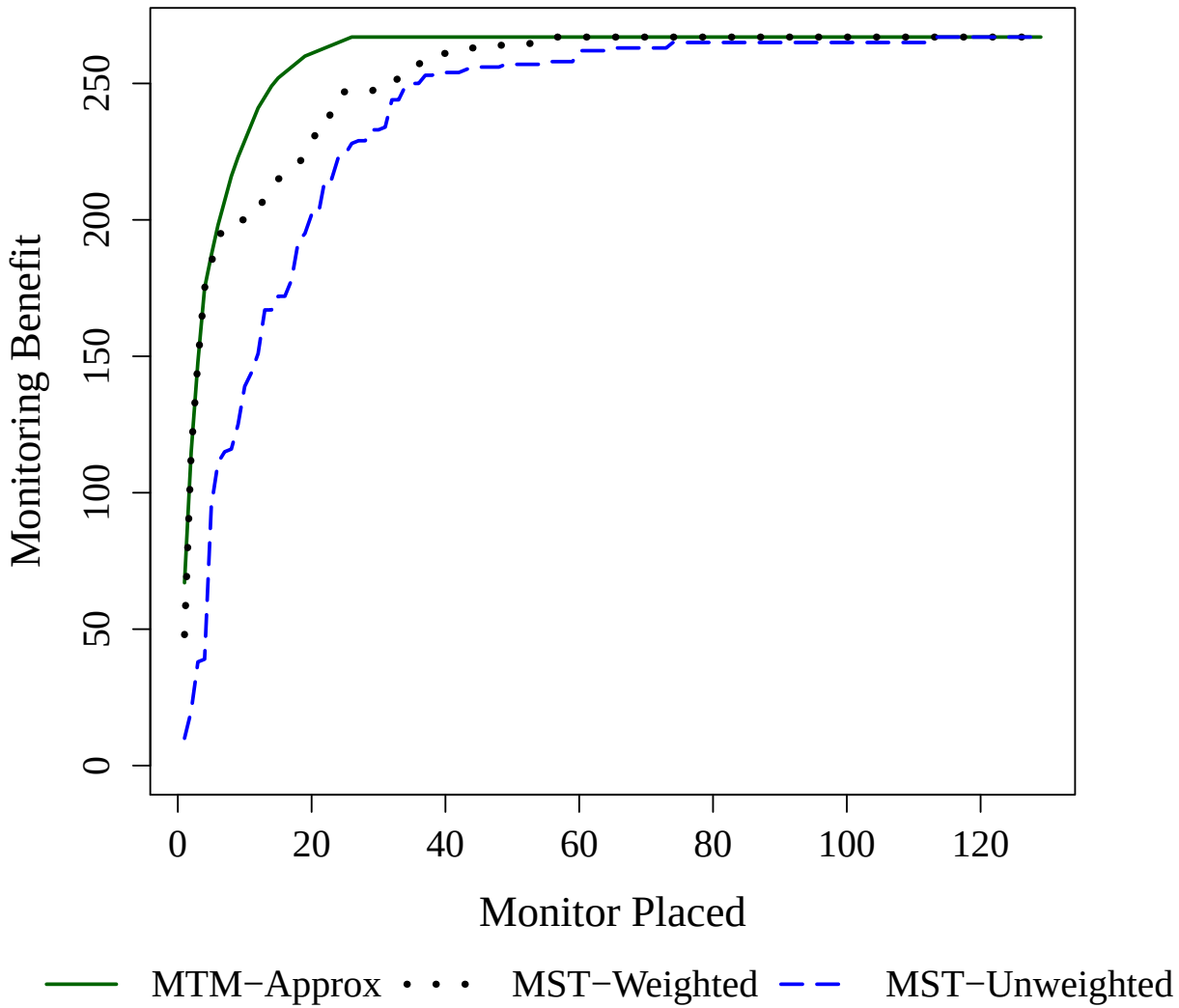


Results


Average Number of Monitors
0
2
4
6
8
GEANT
UUNET
DFN
Viatel
Tinet
Network
OPT
MTM−Approx
MST−Weighted
MST−Unweighted


Average Number of Monitors
0
20
40
60
80
100
GEANT
UUNET
DFN
Viatel
Tinet
Network
MTM−Approx
MST−Weighted
MST−Unweighted

Results


Monitoring Benefit
0
50
100
150
200
250
0
20
40
60
80
100
120
Monitor Placed
MTM−Approx
MST−Weighted
MST−Unweighted

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Conclusions

- Monitoring multi-path flows is a difficult problem
- Proposed approximation algorithm is a very effective alternative
- Monitoring traffic flows can help disambiguate paths taken by vehicles
- This information can be used to help plan for maintenance and vehicle routing

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Future Work

- Find new applications of research in the field of traffic management
- Create realistic simulations on road networks

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- Thank you!