ESE535: Electronic Design Automation

Day 12: February 25, 2013
Routing 2
(Pathfinder)

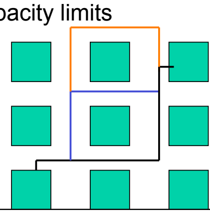
Today

- Routing
  - Pathfinder
    - graph based
    - global routing
    - simultaneous global/detail

Behavioral
(C, MATLAB, …)
↓ Arch. Select
Schedule
RTL
↓ FSM assign
Two-level,
Multilevel opt.
Covering
Retiming
Gate Netlist
↓ Placement
Routing
Layout
↓
Masks

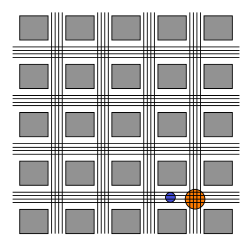
Global Routing

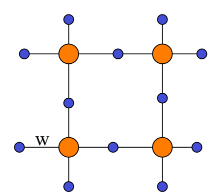
- **Problem:** Find sequence of channels for all routes
  - minimizing channel sizes
  - minimize max channel size
  - meeting channel capacity limits



Global→Graph

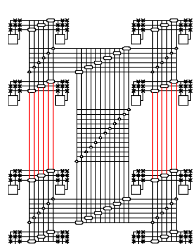
- Graph Problem on routes through regions

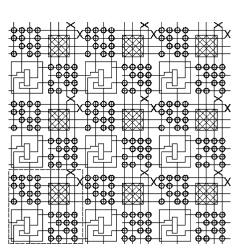


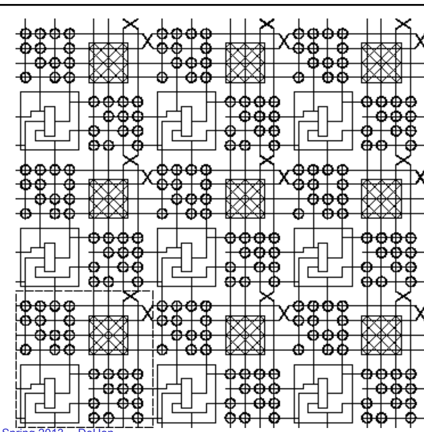


Global/Detail

- With limited switching (*e.g.* FPGA)
  - can represent routing graph exactly

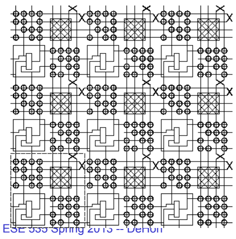






Routing in Graph

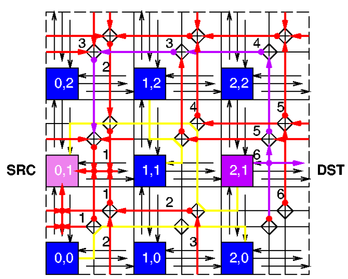
- Find {shortest,available} path between source and sink
  - search problem (e.g. BFS, A*)



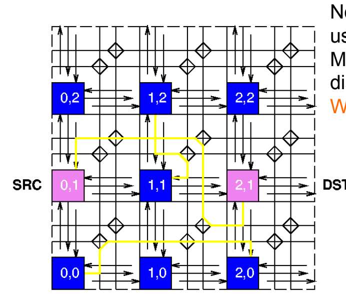
Breadth First Search (BFS)

- Start at source src
- Put src node in priority queue with cost 0
  - Priority queue orders by cost
- While (not found sink)
  - Pop least cost node from queue
    - Get: current_node, current_cost
  - Is this sink? → found
  - For each outgoing edge from current_node
    - Push destination onto queue
    - with cost current_cost+edge_cost

Search Animation

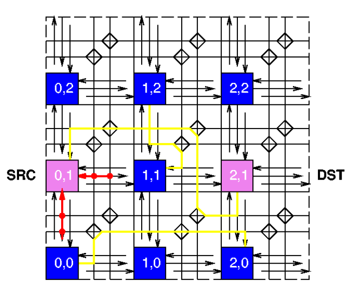


Search Animation

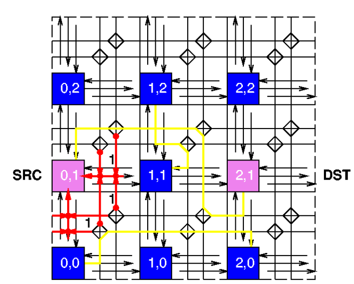


Not possible to use minimum Manhattan distance route. Why?

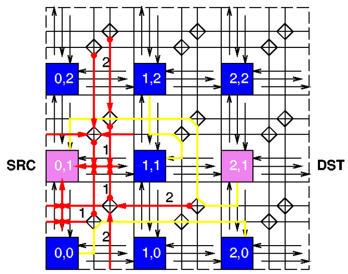
Search Animation



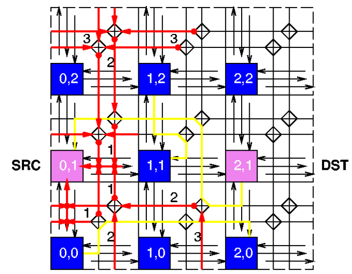
Search Animation



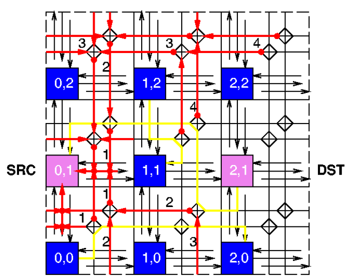
Search Animation



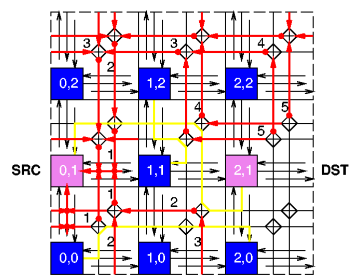
Search Animation



Search Animation



Search Animation



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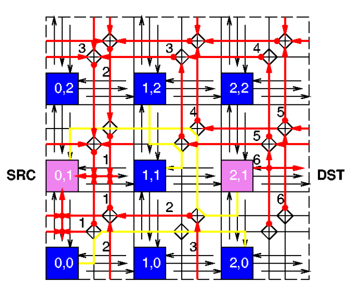

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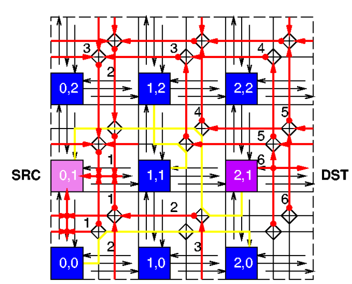

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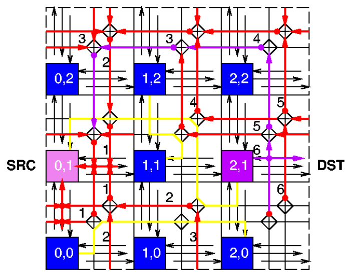
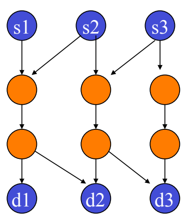


Easy?

- Finding a path is moderately easy
- What's hard?
- Can I just iterate and pick paths?
  - Does greedy selection work?

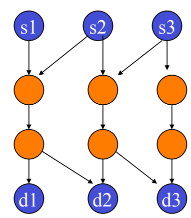
Example



All links capacity 1

$s_i \rightarrow d_i$

Challenge



- Satisfy *all* routes simultaneously
- Routes share potential resources
- Greedy/iterative
  - not know who will need which resources
    - E.g. consider routing s3->d3 then s2->d2 then s1->d1
  - *i.e.* resource/path choice looks arbitrary
  - …but earlier decisions limit flexibility for later
    - like scheduling
  - order effects result

Negotiated Congestion

- Idea:
  - try once
  - see where we run into problems
  - undo problematic/blocking allocation
    - rip-up
  - use that information to redirect/update costs on subsequent trials
    - retry

Negotiated Congestion

- Here
  - route signals
  - allow overuse
  - identify overuse and encourage signals to avoid
    - reroute signals based on overuse/past congestion

Basic Algorithm

- Route signals along minimum cost path
- If congestion/overuse
  - assign higher cost to congested resources
    - Makes problem a shortest path search
    - Allows us to adapt costs/search to problem
- Repeat until done

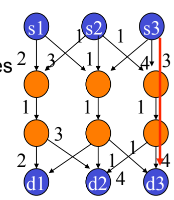
Key Idea

- Congested paths/resources become expensive
- When there is freedom
  - future routes with freedom to avoid congestion will avoid the congestion
- When there is less freedom
  - must take congested routes
- Routes that must use congested will, others will chose uncongested paths

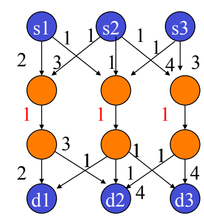
Cost Function (1)

- PathCost=Σ (link costs)
- LinkCost = base × f(#routes using, time)
- Base cost of resource
  - *E.g.* delay of resource
  - Encourage minimum resource usage
    - (minimum length path, if possible)
  - minimizing delay = minimizing resources
- Congestion
  - penalizes (over) sharing
  - increase sharing penalty over time

3+1+4=8



Example (first order congestion)

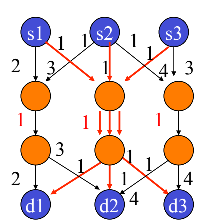


Capacity

Base costs (delays)

What is preferred path for s1→d1, s2→d2, s3→d3?

Example (first order congestion)

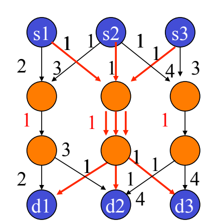


Capacity

Base costs (delays)

All, individual routes prefer middle; create congestion.

Example (first order congestion)



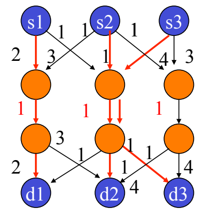
Capacity

Base costs (delays)

If make congestion expensive:
e.g. cost(congest)=2^{users}

What happens when reroute s1→d1?

Example (first order congestion)

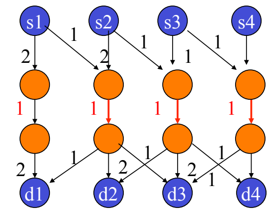


Capacity

Base costs (delays)

Reroute, avoid congestion.

Example (need for history)

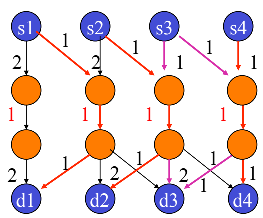


Capacity

Base costs (delays)

Need to redirect uncongested paths.

Example (need for history)

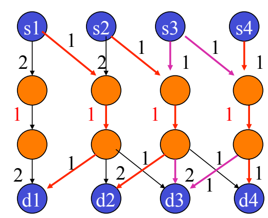


Imagine partially routed.

Where do we route s3→d3?

What happens when we reroute?

Example (need for history)



Local congestion alone won't drive in right directions.

Both paths equal cost …neither resolves problem.

May ping-pong back and forth.

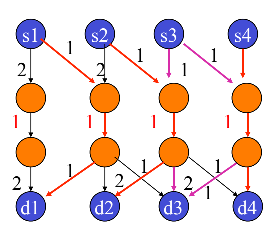
Cannot route s3→d3

(can imagine longer chain like this)

Cost Function (2)

- Cost = (base + history)*f(#resources,time)
- History
  - avoid resources with history of congestion
  - E.g. add 1 to history every time resource is congested

Example (need for history)



S3→d3 and s4→d4 initially ping-pong

How does history help?

Builds up congestion history on path 3 and 4

Eventually makes path 3 and 4 more expensive than path 1; …resolves conflict…

➔ Adaptive cost scheme.

Delay

What about delay?

- Existing formulation uses delay to reduces resources, but doesn't directly treat
- How do we want to optimize delay?
- Want:
  - prioritize critical path elements for shorter delay
  - allow nodes with slack to take longer paths

Integrate Delay into Cost Function

- Cost=
  - (1-W(edge))*delay + W(edge) *congest
  - congest as before
    - (base+history)*f(#signals,time)
- W(edge) = Slack(edge)/D_{max}
  0 for edge on critical path
  >0 for paths with slack
- Use W(edge) to order routes
- Update critical path and W each round

Cost Function (Delay)

- Cost=
  - (1-W(edge))*delay + W(edge) *congest
  - congest as before
    - (base+history)*f(#signals,time)
- W(edge) = Slack(edge)/D_{max}
- What happens if multiple slack 0 nets contend for edge?
- W(edge)=Max(minW,Slack(edge)/D_{max})
  - minW > 0

Problem

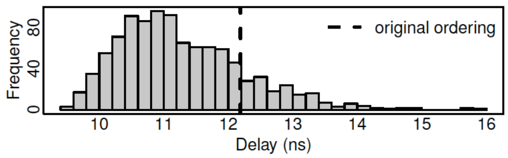
- Are nanoseconds and congestion comparable?
- How normalize/weight so can add together?

VPR

- If doesn't uncongest,
  weight congestion more
- Cost=
  (1-W(e))×delay + W(e)×$PF^{(iter)}$×congest
  PF=Pressure Factor Multiplier
- Eventually congest dominates delay
- What might go wrong?

VPR Pressure Factor

- Converges quickly
- But may “freeze” with higher delay than necessary
- Netlist Shuffle experiment



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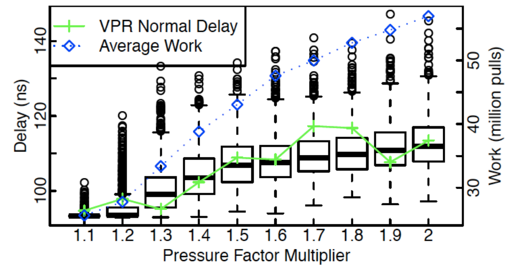
VPR Pressure Factor Tuning



(1-W(e))×delay + W(e)×PF$^{(iter)}$×congest

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Alternate Delay Approach

- Believe Pathfinder can resolve congestion
- Pathfinder has trouble mixing delay and congestion
- **Idea:** Turn delay problem into congestion problem
  - Reject paths that are too long
  - All signals compete only for resources that will allow them to meet their timing goals

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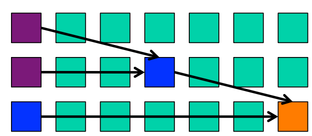
Outlaw Long Paths

- **Issue:** Critical path may go through multiple gates
  - Contain more than one gate→gate path
  - How allocate slack among paths?



Target 12
Gate 1
Manhattan hop 1

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Outlaw Long Paths

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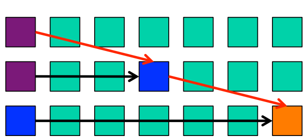

Target 12
Gate 1
Manhattan hop 1

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Outlaw Long Paths

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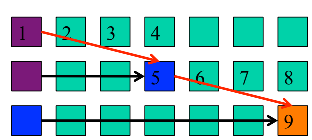

Target 12
Gate 1
Manhattan hop 1

Total Slack?

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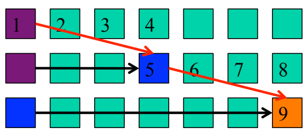
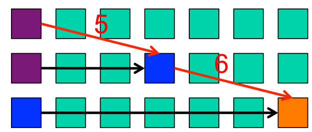
Slack Budgeting

- Divide slack among the paths
  - Slack of 3
  - Example: give slack 1 to first link
    2 to second



Slack Budgeting

- Divide slack among the paths
- Each net now has delay target
- Reject any path exceeding delay target
- Reduce to congestion negotiation



Slack Budgeting

- Can often find lower delay routes that VPR
- Takes 10x as long
  - Mostly in slack budgeting
- Solution depends on slack budget
  - Not exploiting full freedom to re-allocate slack among links

Delay Target Routing

- Similar high-level idea
- Just set target for Pathfinder cost
  - Rather than allowing to float

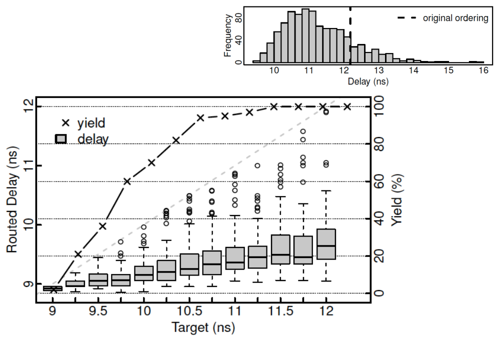
Delay Target

- Cost=
  (1-W(edge))*delay + W(edge) *congest
- W(edge) = Slack(edge)/D_{target}
  - Previously: denominate was D_{max}
- Compute Slack based on D_{target}
  - can be negative
- W(edge)=Max(minW,Slack(edge)/D_{target})
  - minW > 0

Delay Target Routing

- Does allow slack to be used on any of the gate→gate connections on path
  - …but not being that deliberate/efficient about the allocation
- Doesn't require time for slack allocation

Delay Target Routing



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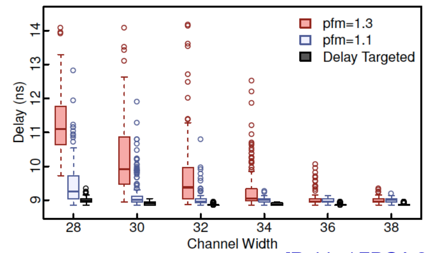
Delay Target Routing

- Less sensitive to initial conditions



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Run Time?

- Route |E| edges
- Each path search $O(|E_{graph}|)$ worst case
  - …generally less
- Iterations?

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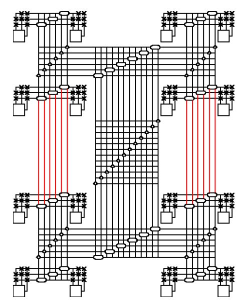
Quality and Runtime Experiment

- For Synthetic netlists on HSRA
  - Expect to be worst-case problems
- Congestion only
  - Quality = # channels
- Number of individual route trials limited (measured) as multiple of nets in design
  - (not measuring work per route trial)



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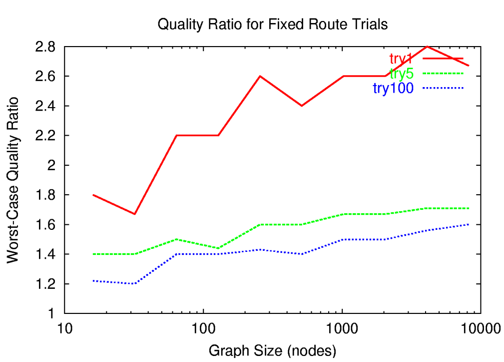
Quality: fixed runtime



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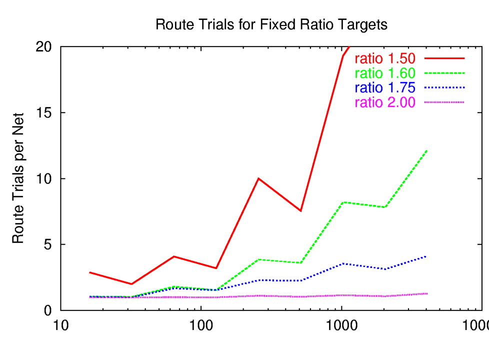
Quality Target



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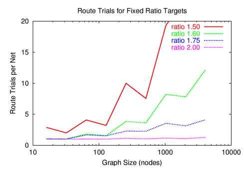
Conclusions?

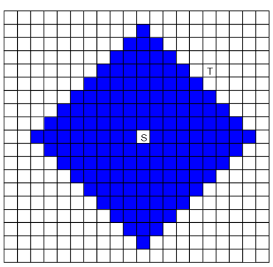
- Iterations increases with N
- Quality degrade as we scale?



Techniques to Accelerate

(already in use in data just shown)

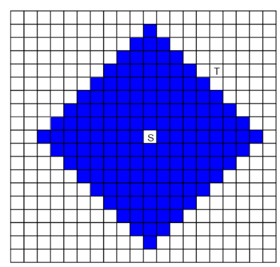
Inefficient?



What is inefficient about this search?

How might we do better?

Inefficient?

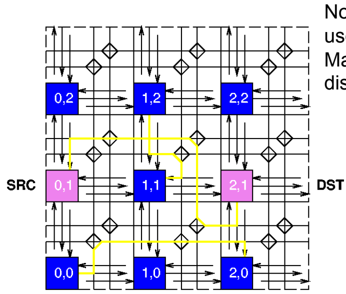


What if we only searched for minimum length paths?

How would we do that?

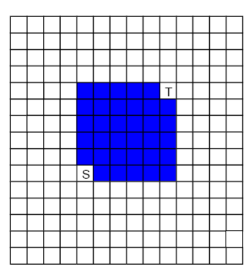
Downside?

Recall Search Example

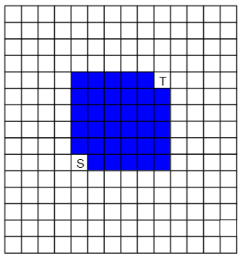


Not possible to use minimum Manhattan distance route.

Only Search Minimum Length



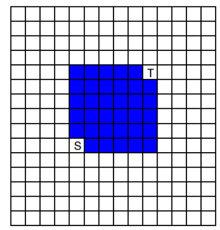
Minimum Search

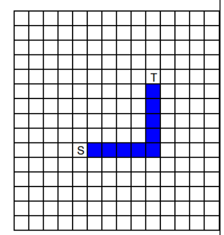


What is the minimum we need to search (if uncongested)?

What would that search look like?

BFS vs. DFS





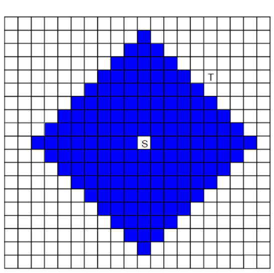
Search Ordering

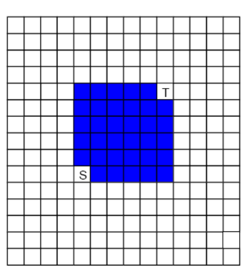
- Default: breadth first search for shortest
  - O(total-paths)
- Alternately: use A*:
  - estimated costs/path length, prune candidates earlier
  - can be more depth first
    - (search promising paths as long as know can't be worse)

BFS → A*

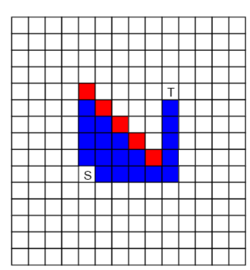
- Start at source
- Put src node in priority queue with cost 0
  - Priority queue orders by cost
  - Cost = Σ (path so far) + min path to dest
- While (not found sink)
  - Pop least cost node from queue
    - Get: current_node, current_cost
  - Is this sink? → found
  - For each outgoing edge
    - Push destination onto queue
    - with cost current_cost+edge_cost

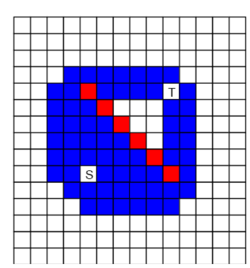
BFS vs. A*





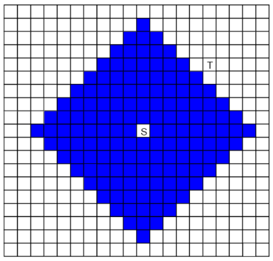
Single-side, Directed (A*)

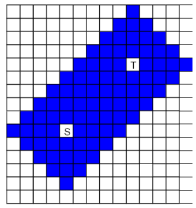




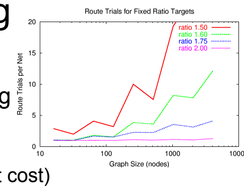
Only expand search windows as prove necessary to have longer route.

Search: one-side vs. two-sides





Searching



- In general:
  - greedy/depth first searching
    - find a path faster
    - may be more expensive
      - (not least delay, congest cost)
  - tradeoff by weighting
    - estimated delay on remaining path vs. cost to this point
    - control greediness of router
  - More greedy is faster at cost of less optimal paths (wider channels)
    - 40% W → 10x time reduction [Tessier/thesis'98]

Searching

- Use A* like search
  - Always expanded (deepen) along shortest …as long as can prove no other path will dominate
  - Uncongested: takes O(path-length) time
  - Worst-case reduces to breadth-first
    - O(total-paths)

Summary

- Finding short path easy/well known
- **Complication:** need to route set of signals
  - who gets which path?
  - Arbitrary decisions earlier limit options later
- **Idea:** iterate/relax using congestion history
  - update path costs based on congestion
    - Cost adaptive to route
  - reroute with new costs
- Accommodate delay and congestion

Big Ideas

- Exploit freedom
- Technique:
  - Graph algorithms (BFS, DFS)
  - Search techniques: A*
  - Iterative improvement/relaxation
  - Adaptive cost refinement

Admin

- Assignment 4 due Wednesday
- Reading for Wednesday on web
- Spring Break next week
- Reading for Monday after break
  - On Blackboard