Pressure Routing for Underwater Sensor Networks

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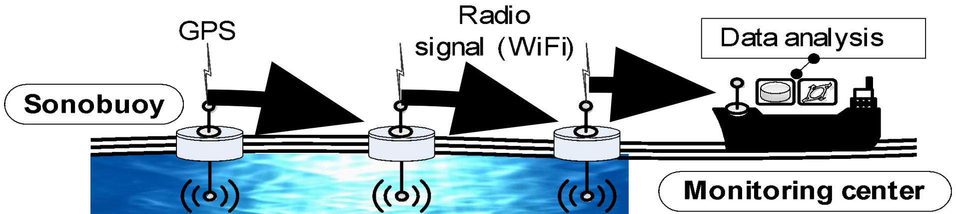
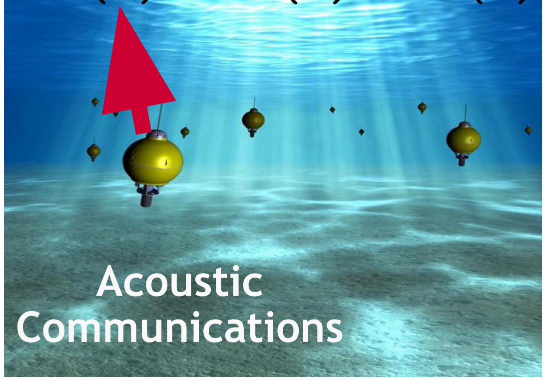
SEA-Swarm

SEA-Swarm (Sensor Equipped Aquatic Swarm)

- Monitoring center deploys a large # of mobile u/w sensors (and sonobuoys)
- Mobile sensors collect/report sensor data to a monitoring center
- Monitoring center performs data analysis including off-line localization
- Short-term "ad hoc" real-time aquatic exploration: oil/chemical spill monitoring, anti-submarine missions, surveillance etc.





Example: UCSD Drogues

Acoustic modem
Pressure (depth) sensor
Depth control device
+ Other sensors

Pictures from: http://jaffeweb.ucsd.edu/node/81

Problem Definition

SEA-Swarm challenges:

- Acoustic comms: energy hungry (~W), low bandwidth (<100kbps), long propagation delay (3x10^3 m/s)
- Node mobility due to water current (<1m/s)

Ground sensor routing protocols do not work well in underwater

- High protocol overheads, e.g., route discovery (flooding) and/or maintenance
- Not suitable for bandwidth constrained underwater mobile sensor networks (collision + energy consumption)

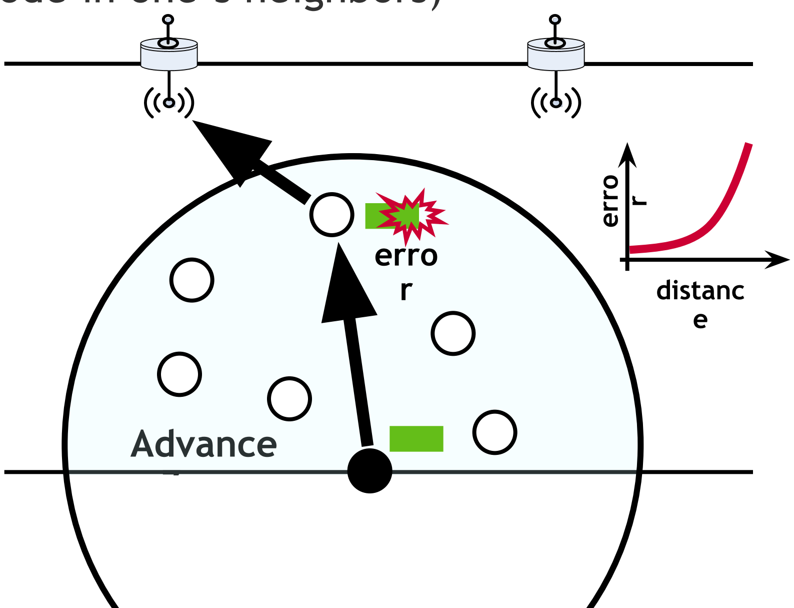
3D geographical routing (stateless, local) has the following limitations:

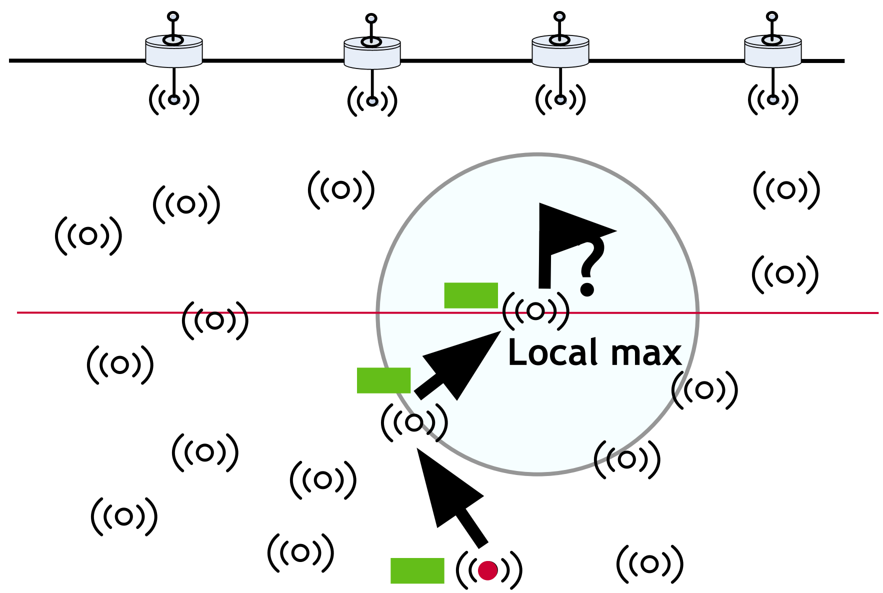
- Requires distributed underwater localization (+location service)
- Efficient recovery from a local maximum (like face routing) is not feasible (Durocher et al., ICDCN'08)

HydroCast: Underwater Pressure Routing

HydroCast: 1D geographic anycast routing (to any one of the sonobuoys)

- Using measured pressure level (or depth) from on-board pressure sensor
- A packet is forwarded to a node that is closest to the water surface (or the lowest depth node in one's neighbors)





Packet drops due to channel errors:
*requires **<u>a robust forwarding mechanism</u>***

Stuck at local maximum:
*requires **<u>a recovery mechanism</u>***

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Opportunistic Routing

Handle channel errors by opportunistic routing:

- Opportunistic packet receptions thanks to broadcast nature of wireless medium
- Any node that has received the packet correctly (called forwarding set) can forward the packet to next hop

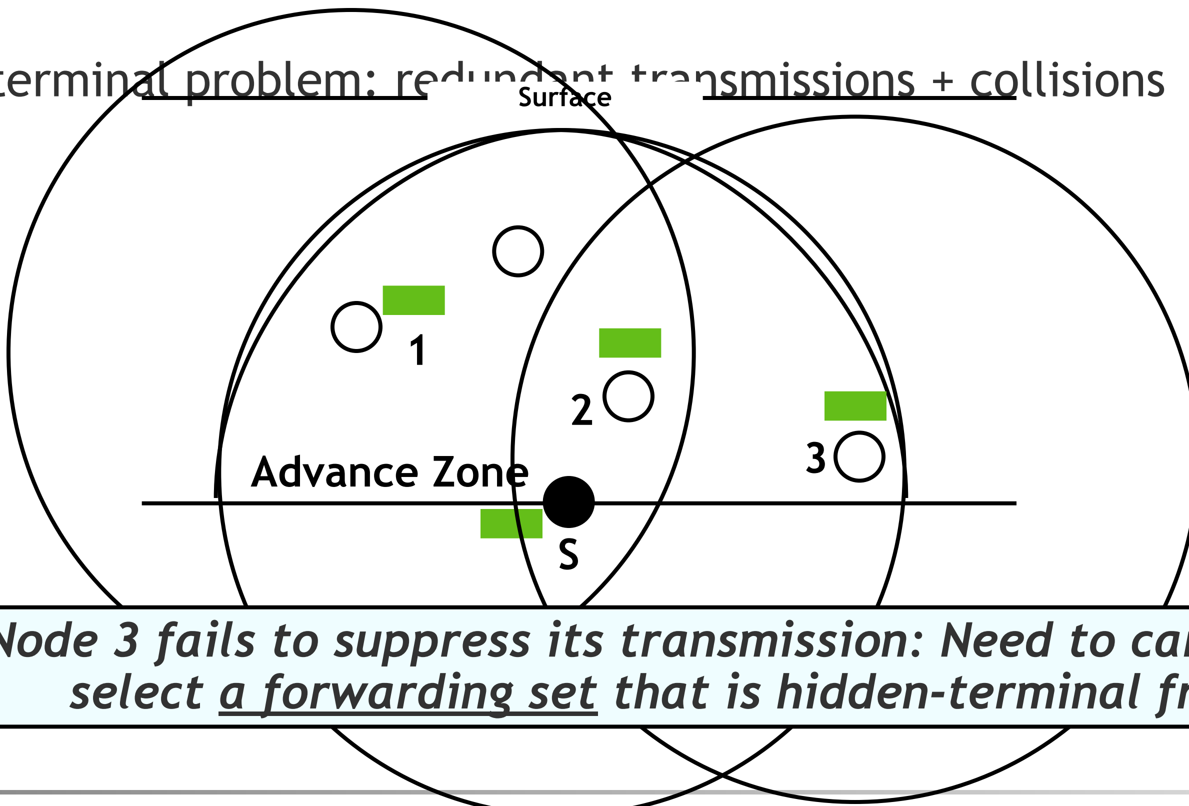
Existing opportunistic routing protocols:

- *Anypath Routing* based on extended link-state algorithms
  - ExOR, Least Cost Opportunistic Routing (LCOR)
  - Not suitable for SEA-Swarm due to overhead (network-wide link state flooding)
- *Geo-Opportunistic Routing (GOR)* based on stateless position-based algorithms
  - Geographic Random Forwarding (GeRaF), Contention Based Forwarding (CBF), Focused Beam Routing (FBR)

Geo-Opportunistic Routing (GOR)

GOR: (1) A packet is broadcast; (2) each node determines its own priority based on its distance to the surface (priority is scheduled using distance based timer); (3) high priority node's transmission suppresses low priority nodes' transmissions

Hidden terminal problem: redundant transmissions + collisions



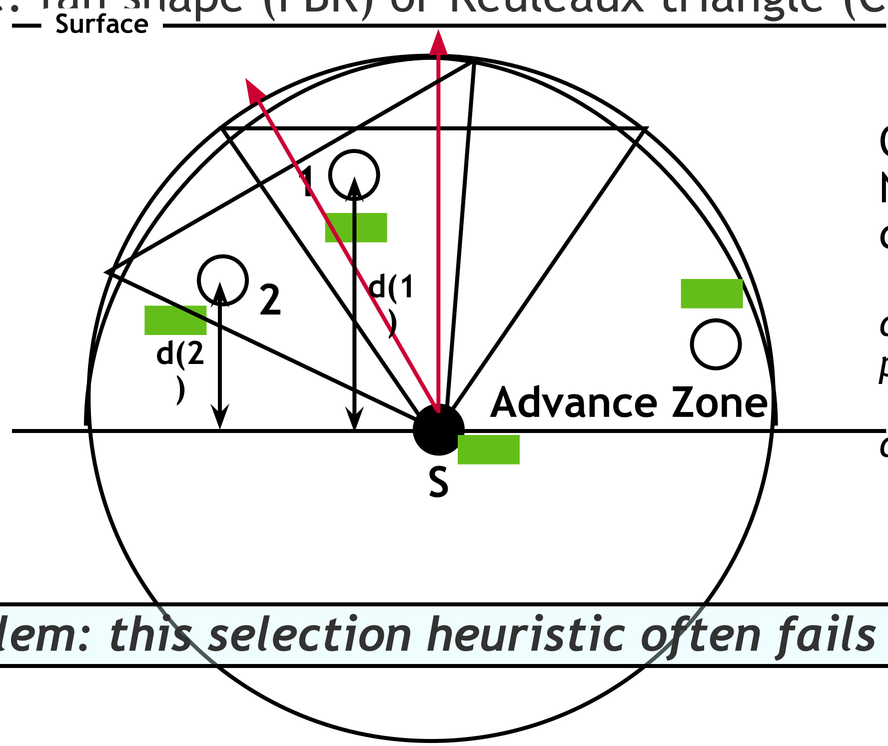
Node 3 fails to suppress its transmission: Need to carefully select <u>a forwarding set</u> that is hidden-terminal free

Geo-Opportunistic Routing (GOR)

Finding hidden terminal free forwarding set is the max clique problem (hard!)

Forwarding set selection heuristic: geometric shape facing toward the destination

- Example: fan shape (FBR) or Reuleaux triangle (CBF)



Expected progress:

Original: d(1)*p(1)
New: d(1)*p(1) +
d(2)*(1-p(1))*p(2)

d(i): node i's progress (meter)
p(i): prob. node i successfully receives a packet
*d(i)*p(i) = <u>normalized progress</u>*

Problem: this selection heuristic often fails to maximize progress

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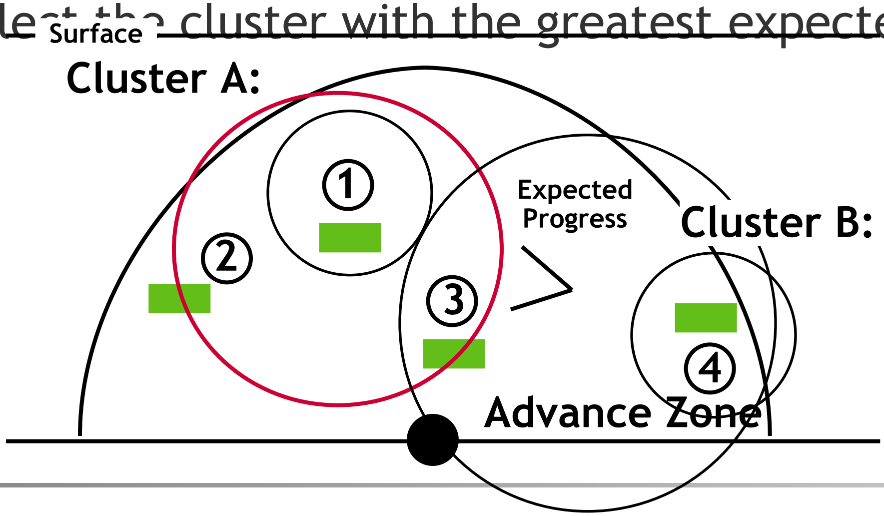
HydroCast: Forwarding Set Selection (Clustering)

- 1. find *node i* that has the greatest normalized progress: ***d(i)*p(i)***
- 2. include all nodes whose distance from *node i* is in ßR (R tx range, ß=0.5)
- 3. if other neighbors are left, clustering proceeds starting from the remaining node with the highest normalized progress (i.e., repeat step 1 and 2).
- 4. each cluster is then expanded by including nodes whose distance to any node in the cluster is smaller than R (node can hear one another)
- 5. select the cluster with the greatest expected progress as a forwarding set



Expected Progress:
Cluster A: d(1)*p(1) + d(2)*(1-p(1))*p(2) + d(3)*(1-p(1))(1-p(2))*p(3)
Cluster B: d(3)*p(3) + d(4)*(1-p(3))*p(4)

d(i): node i's progress (meter)
p(i): prob. node i successfully receives a packet
*d(i)*p(i) = normalized progress*

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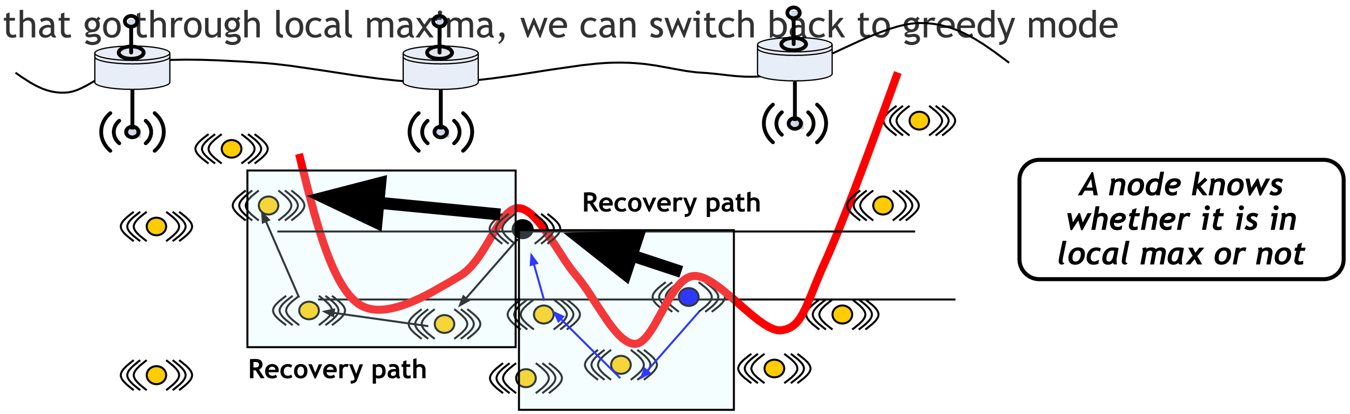
HydroCast: Recovery Mode

- No efficient recovery method in 3D geographic routing (Durocher et al., ICDCN'08)
  - State-of-the-art "stateless" recovery method: random walk (Flury et al., INFOCOM'08)
- Limitation of random walks in SEA-Swarm
  - Due to vertical routing, any nodes below the local max need to repeatedly perform random walks
- HydroCast: local lower-depth-first recovery (stateful approach)
  - Each local max builds an escape path to a node whose depth is lower; after one or several path segments that go through local maxima, we can switch back to greedy mode



Path discovery is still expensive: hop-limited 3D flooding

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HydroCast: Recovery Mode

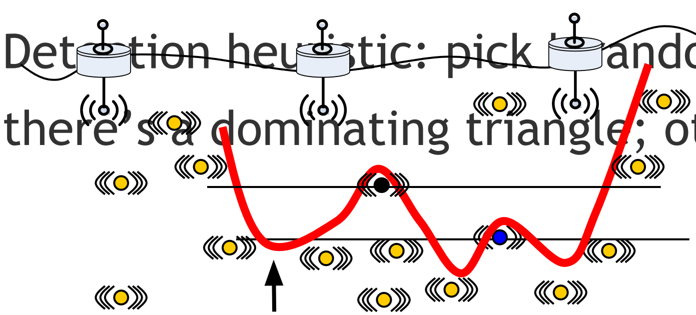
2D floor surface flooding for recovery path discovery

- Only nodes on the envelope (surface) participate in path discovery

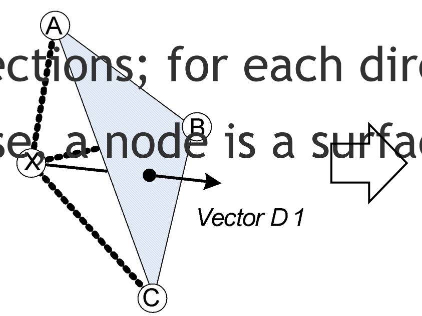
Surface node detection

- Non-surface node: if a node is completely surrounded by its neighboring nodes
  - Every direction has a dominating triangle
- Detection: tetrahedralization with length constraint (tx range) □ intractable

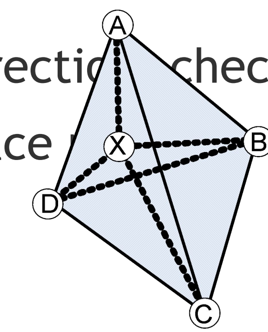
Detection heuristic: pick random directions; for each direction check if there's a dominating triangle; otherwise, a node is a surface



SEA-swarm's floor surface



X's dominating triangle in direction D1



X: Non-surface node

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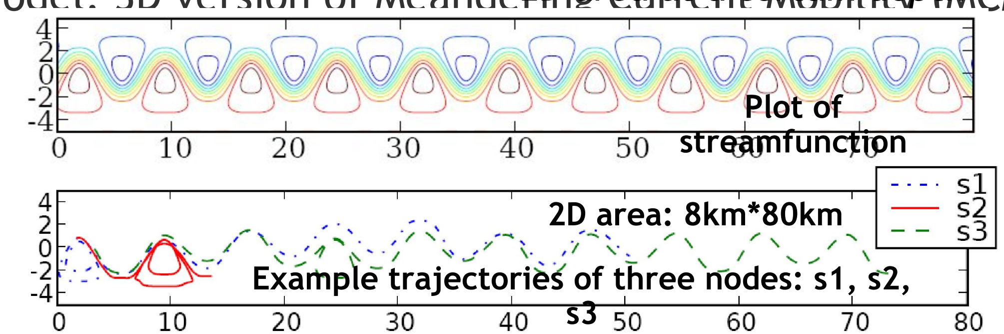
Simulation Setup

- QualNet 3.9.5 enhanced with an acoustic channel model
  - Urick's u/w path loss model: $A(d, f) = d^k a(f)^d$ where distance d, freq f, absorption $a(f)$
  - Rayleigh fading to model small scale fading
- Acoustic modem:
  - Modulation method: BPSK (Binary Phase Shift Keying)
  - Tx power: 105 dB u Pa, data rate: 50Kbps, tx range: ~250m
- Nodes are randomly deployed in an area of "1000m*1000m*1000m"
  - Mobility model: 3D version of Meandering Current Mobility (MCM) [INFOCOM'08]



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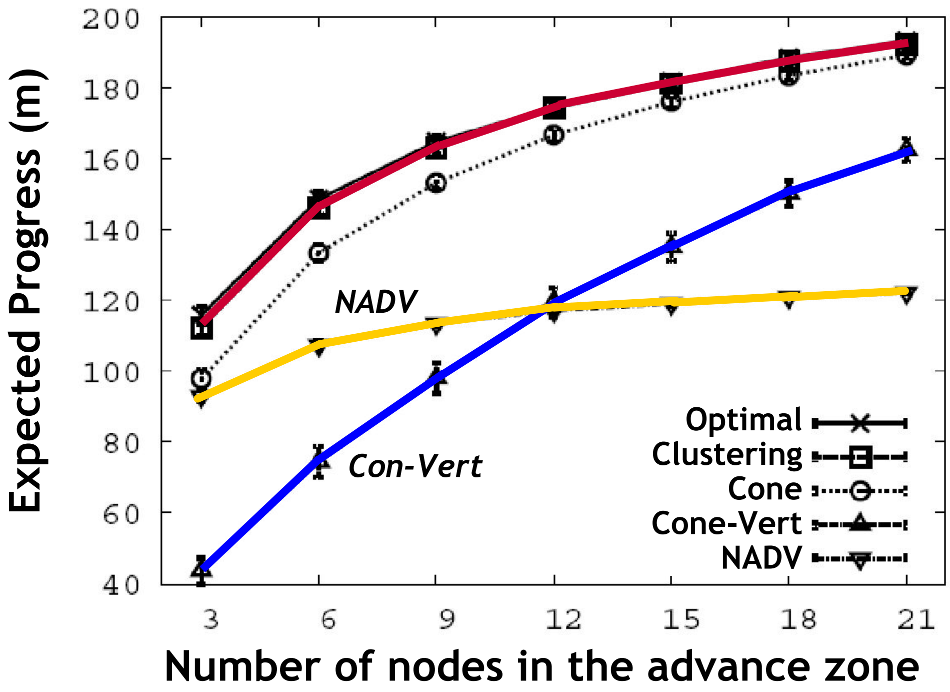
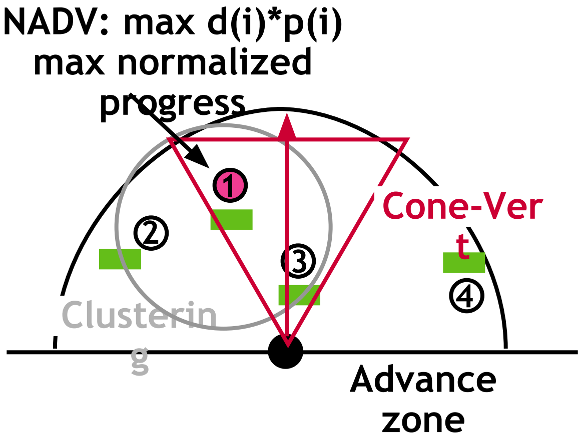
Results: Forwarding Set Selection

HydroCast's clustering is very close to the optimal solution

Vertical cone based approach (CBR, FBR) performs poorly

- When density is low, its performance is even lower than NADV





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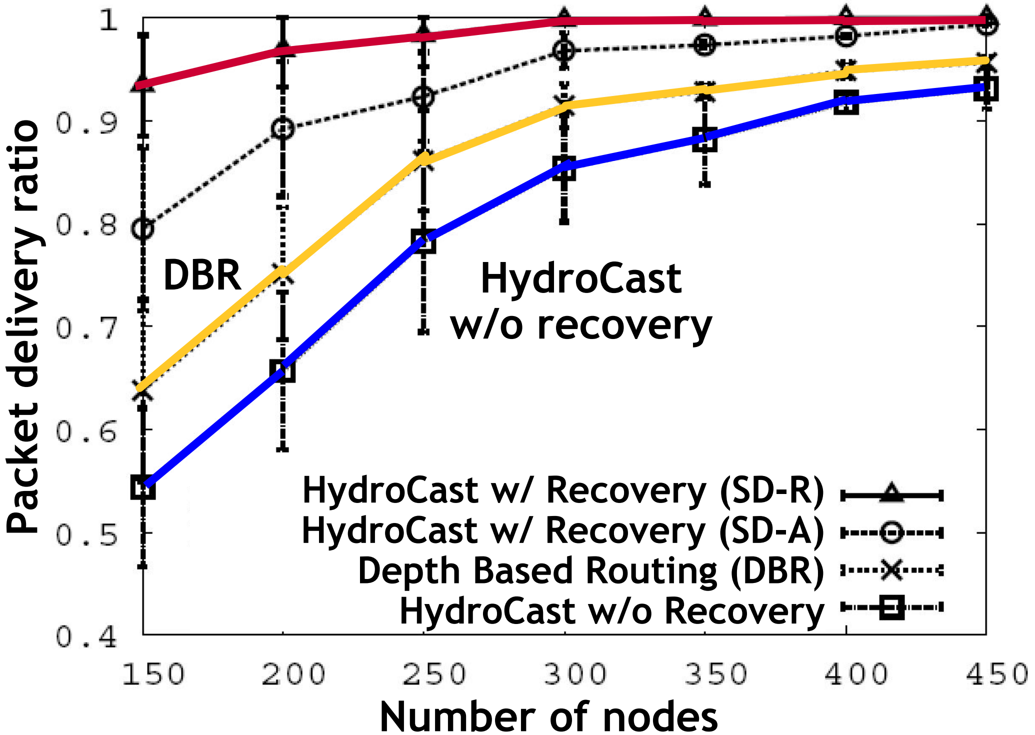
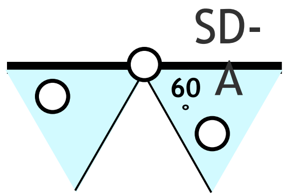
Results: HydroCast Performance

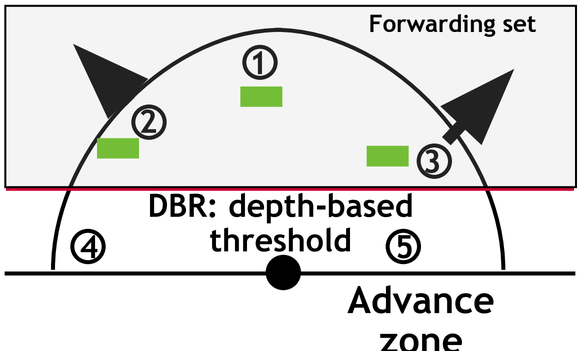
HydroCast w/ SD-R performs the best

- SD (surface detection): SD-R (our heuristic), SD-A (angle-based, 60˚)

DBR performs better than HydroCast w/o recovery (due to multi-path delivery)







Depth Based Routing: DBR

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Conclusion

Hydraulic pressure-based anycast routing allows report time-critical sensor data to the sonobuoys on the sea level using acoustic multi-hopping

HydroCast:

- *Novel opportunistic routing mechanism* to select the subset of forwarders that maximizes greedy progress yet limits co-channel interference
- *Efficient dead-end recovery mechanism* that outperforms recently proposed approaches (e.g., random walk, 3D flooding)

Research directions:

- Mobility prediction (using low power sensors)
- Dynamic topology control/maintenance
  - Mechanical (depth control/replenishing) + electronic (transmission power)