Probabilistic Connectivity of Underwater Sensor Networks

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Overview

Why UWSNs?

UWSNs fuelled by many important underwater sensing applications and services such as

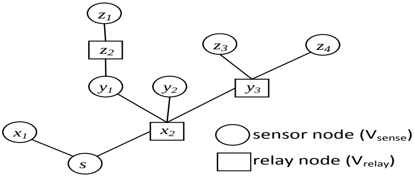
- Scientific applications
- Industrial applications
- Military and homeland security applications
- Humanitarian applications

Challenges of the underwater communication channel

- Water currents
- Communication

Node Locality Sets

- $V = V_{sense} \cup V_{relay}$ the set of nodes in a given UWSN
- The geographic area considered rectangles of a superimposed grid layout.
- At time T, each node x can be in any one of a possible set of grid rectangles denoted $\mathrm{Loc}(x) = \{x[1], x[2], \ldots\}$.
- Node x can be grid rectangle $x[i]$ with a certain probability $p_x(i)$.
- Truncate some locality sets of low probability for convenience thus, $\sum_{x[i] \in \mathrm{Loc}(x)} p_x(i) \leq 1$, if $\mathrm{Loc}(x)$ is truncated.



x_1	0.2, 0.5, 0.1 0.07, 0.05, 0.08	z_1	0.6, 0.2 0.1, 0.1
x_2	0.25, 0.3 0.16, 0.29	z_2	0.5, 0.25, 0.2
y_1	0.2, 0.3, 0.1 0.1, 0.15, 0.15	z_3	0.25, 0.36 0.14, 0.25
y_2	0.25, 0.35 0.25, 0.15	z_4	0.7, 0.15, 0.15
y_3	0.16, 0.18, 0.14 0.3, 0.22,	s	0.18, 0.1, 0.03 0.34, 0.1, 0.14

Figure 1: Network with Probabilistic locality set

Problem Definition

We define four probabilistic connectivity problem. They are

- A-CONN problem
- AR-CONN problem
- S-CONN problem
- SR-CONN problem

the A-CONN and AR-CONN problems

Definition (the *A-CONN* problem)

Given a probabilistic network G with no relay nodes, compute the probability $Conn(G)$ that the network is in a state where the sink node s can reach all sensor nodes.

Definition (the *AR-CONN* problem)

Given a probabilistic network G where V_{relay} is possibly non-empty, compute the probability $Conn(G)$ that the network is in a state where the sink node s can reach all sensor nodes.

Definition (the *S-CONN* problem)

Given a probabilistic network G with no relay nodes, and a required number of sensor nodes $n_{req} \leq |V_{sense}|$, compute the probability $Conn(G, n_{req})$ that the network is in a state where the sink node s can reach a subset of sensor nodes having at least n_{req} sensor nodes.

Definition (the *SR-CONN* problem)

Given a probabilistic network G where V_{relay} is possibly non-empty, and a required number of sensor nodes $n_{req} \leq |V_{sense}|$, compute the probability $Conn(G, n_{req})$ that the network is in a state where the sink node s can reach a subset of sensor nodes having at least n_{req} sensor nodes.

Thesis Contribution

Efficient dynamic programming algorithms

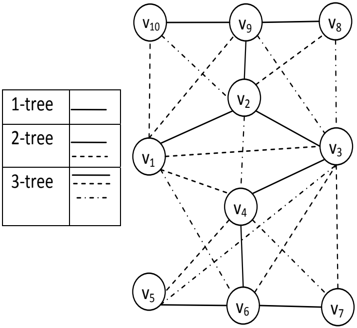
1. for the $\mathrm{SR\text{-}CONN}$ problem on probabilistic networks whose underlying graphs are trees.
2. for the $\mathrm{A\text{-}CONN}$ problem on partial k-trees.
3. for the $\mathrm{AR\text{-}CONN}$ and $\mathrm{SR\text{-}CONN}$ problems on partial k-trees.

All cases the algorithm runs in polynomial time for any fixed k.

Simulation Results for $\mathrm{A\text{-}CONN}$ problem

- Test Networks
- Running Time
- Connectivity for different partial k-trees

Test Networks



v_1	0.2 | 0.5 | 0.1 0.15 | 0.05	v_6	0.6 | 0.2 0.1 | 0.1
v_2	0.25 | 0.3 0.16 | 0.29	v_7	0.5 | 0.25 | 0.2
v_3	0.2 | 0.3 | 0.1 0.1 | 0.15 | 0.15	v_8	0.25 | 0.36 0.14 | 0.25
v_4	0.25 | 0.35 0.25 | 0.15	v_9	0.7 | 0.15 | 0.15
v_5	0.16 | 0.18 | 0.14 0.3 | 0.22	v_{10}	0.18 | 0.24 0.34 | 0.1 | 0.14

Figure 2: G_{10}

Test Networks(Cont.)

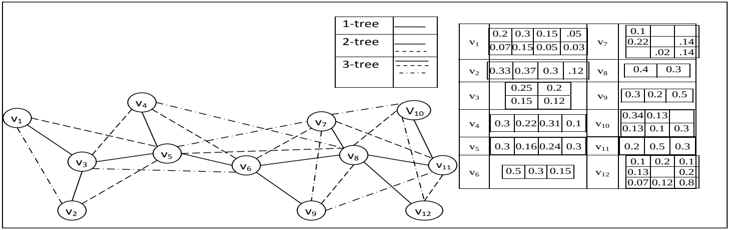


Figure 3: G_{12}

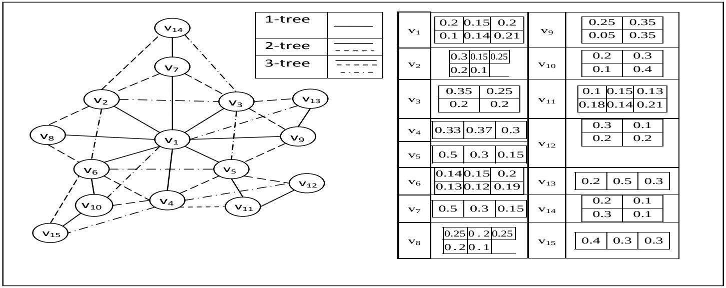


Figure 4: G_{15}

Running Time

k	Network G_{10}	Network G_{12}	Network G_{15}
1	90	130	200
2	1000	1380	1480
3	60000	875000	940000

Table 1: Running time in milliseconds

Connectivity for different partial k-trees

k	Network G_{10}	Network G_{12}	Network G_{15}
1	0.62	0.336	0.82
2	0.71	0.36	0.99
3	0.75	0.37	1

Table 2: Connectivity lower bounds using different partial k-trees

Simulation Results for AR-CONN and SR-CONN problems

- Test Networks
- Running time
- Effects of Adding Relay nodes

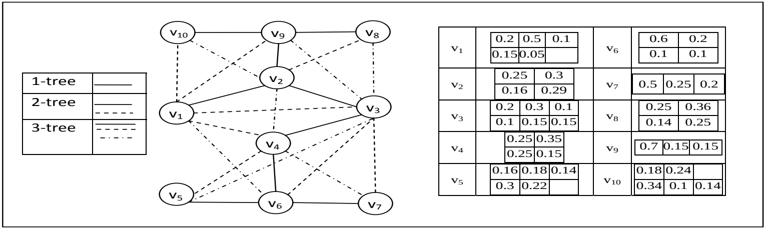


Figure 5: Network G_{10}

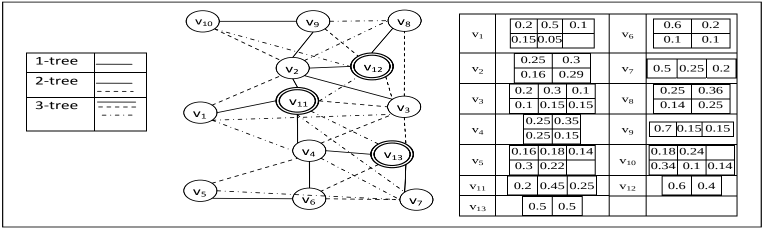


Figure 6: Network $G_{10,3}$

Running Time

k	Network G_{10}	Network $G_{10,3}$
1	90	110
2	1000	6000
3	6000	8000

Table 3: Running time in milliseconds

Effect of adding relay nodes

k	Network G_{10}	Network $G_{10,3}$
1	0.30	0.86
2	0.54	0.96
3	0.60	0.98

Table 4: Connectivity with respect to k

Effect of adding relay nodes for various node R_{tr}:

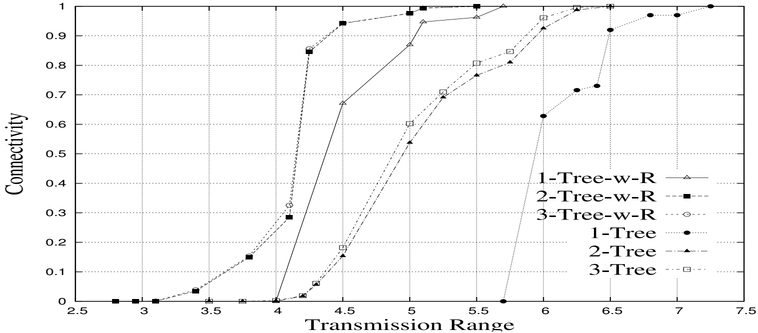


Figure 7: Connectivity versus transmission range

SR-CONN Simulation Results

A designer has at least 3 options to achieve a minimum required $Conn(G, n_{req})$ value:

- tuning the n_{req} parameter,
- tuning node transmission range R_{tr}, and
- tuning the number of deployed relay nodes.

Effect of varying n_{req}

- Figure 8 illustrates the achieved $Conn(G, n_{req})$ as n_{req} varies in the range $[1, 10]$.
- Figure 9 illustrates the achieved $Conn(G, n_{req})$ as n_{req} varies in the range $[1, 10]$, and R_{tr} varies in the range $[2.5, 5.5]$.

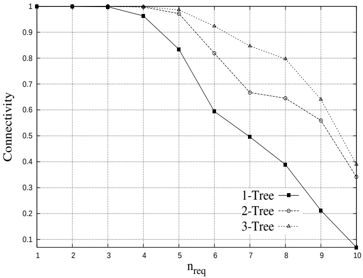


Figure 8: Connectivity versus n_{req}

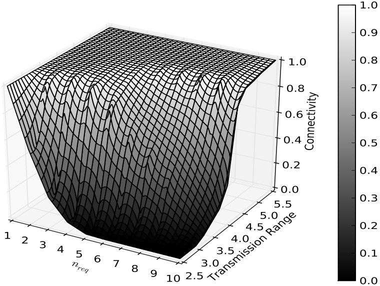


Figure 9: Connectivity versus n_{req} and transmission range

Concluding Remarks

- This thesis is motivated by recent interest in UWSNs as a platform for preforming many useful tasks.
- A challenge arises since sensor nodes incur small scale and large scale movements that can disrupt network connectivity.
- Thus, tools for quantifying the likelihood that a network remains completely or partially connected become of interest.
- To this end, the thesis has formalized 4 probabilistic connectivity problems, denoted $\mathrm{A\text{-}CONN}$, $\mathrm{S\text{-}CONN}$, $\mathrm{AR\text{-}CONN}$, and $\mathrm{SR\text{-}CONN}$.
- The obtained results show that all of the 4 problems admit polynomial time algorithms on k-trees (and their subgraph), for any fixed k.
- The running time of the algorithms, however, increase exponentially as k increases. Thus, more work needs to be done towards obtaining more effective algorithms.

Future Research Directions

- Investigating the applicability of our algorithm to some other classes of graph to be a worthwhile direction.
- It is interesting to analyze the delays incurred in typical data collection rounds.
- It is worthwhile to investigate area coverage assuming a probabilistic locality model of the nodes.

Thanks!