Title

Strategic Deployment in the Presence of Lossy Communication Links (SYS 21)

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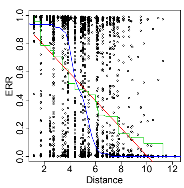
Introduction: Deployment for sensing may not be efficient for communication due to lossy communication links in the environment.

Lossy communication links are difficult to predict

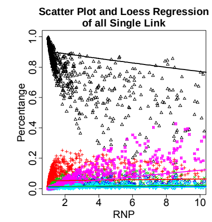


- Deployment typically addresses sensing coverage requirements, not communication.
- Lifetime of network is dictated by communication cost.

On-line link prediction is needed for rapid link evaluation in deployed network

- Maximum likelihood from observed packet reception.

• Maximum Likelihood $\arg\max_{\theta_i}(P(\theta_i)) = \prod_{j=1}^{6} p_j^{K_j(\theta_i)}$



Problem Description: Strategically deploy, remove, or reposition sensor nodes in the existing network to improve lifetime based on the knowledge of existing communication link qualities.

Strategic Deployment in Observed Environment

Given: A deployed set of wireless nodes with ***characterized link data***, ***models***, and ***power model***.

Question: Is there k additional positions in the physical environment for placement of k radios such that the lifetime of the network is increased by a factor of m?

Related Problems: Removal of nodes, repositioning of nodes, simultaneous sensing and communication

Proposed Solution: Force-directed optimization framework

Step 1: Network Characterization

Link Quality Estimation
Augmented Floyd-Warshall All Pairs Shortest Path

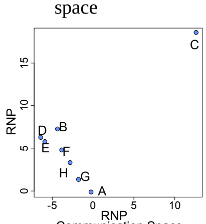
- Input:
  - Euclidean positions of each node
  - On-line link estimates for each communication link
- On-line characterization of links
- All-Pairs shortest path with consecutive link effects
  - Augmented Floyd-Warshall APSP - $O(n^3)$
  - Consider benefits of consecutive links on paths
- Output:
  - Graph with weighted edges that are used in minimum cost paths

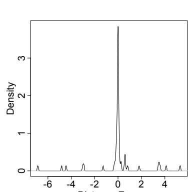
Step 2: Essential Edge Identification

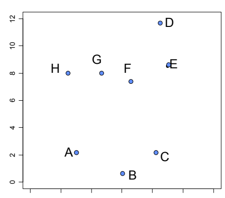
- Input:
  - Graph with weighted edges that are used in minimum cost paths
- Necessary and sufficient communication edges to create APSPs in network
- Output:
  - Graph with weighted edges, only edges required for APSP

Step 3: Embedding in *k*-D Communication Space

- Input:
  - Graph with weighted edges, only edges required for APSP
- NLP formulation for positioning nodes at distances relative to F-W communication costs
- Distance is proportional to communication cost
- Output:
  - Positions of each node in *k*-D communication space







	A	B	C	D	E	F	G	H
A	0	31.13	-	-	26.3	10.22	2.05	-
B	17.19	0	20.2	-	2.34	2.41	-	-
C	-	16.72	0	-	-	16.12	-	-
D	-	-	-	0	-	2.57	-	-
E	-	2.28	-	-	0	2.19	-	-
F	6.12	2.51	26.45	2.84	2.23	0	4.32	2.04
G	2.06	-	-	-	-	11.6	0	2.3
H	-	-	-	-	-	2.06	2.56	0

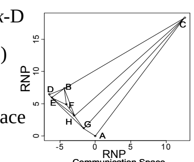
	A	B	C	D	E	F	G	H
A	-	8.93	29.13	9.26	8.64	6.41	2.05	4.35
B	8.53	-	20.20	5.26	2.34	2.41	6.73	4.46
C	22.24	16.72	-	18.96	18.35	16.12	20.44	18.17
D	8.69	5.08	25.28	-	4.80	2.57	6.89	4.62
E	8.32	2.28	22.48	5.04	-	2.20	6.52	4.25
F	6.12	2.51	22.71	2.84	2.23	-	4.32	2.04
G	2.06	6.87	27.07	7.21	6.59	4.36	-	2.30
H	4.62	4.57	24.77	4.91	4.29	2.06	2.56	-

TOTAL COST: 505.73

Power Expense: TX @ 3.0V = 30.3438W

Step 4: Delaunay Triangulation

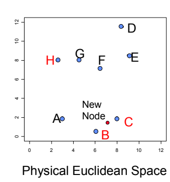
- Input:
  - Positions of each node in *k*-D communication space
- Delaunay Triangulation $O(n^2)$
- Output:
  - Delaunay Triangulation of nodes in communication space



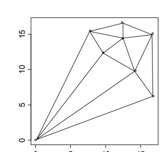
Step 5: Node Repositioning

Triangle Identification
Non-linear Programming

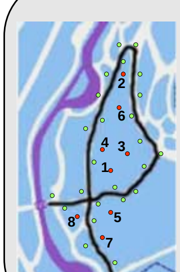
- Input:
  - Delaunay Triangulation of the communication positioned nodes
- Identify largest triangle(s) → most expensive communication
- In Euclidean space, apply NLP to position around 3 identified nodes
- Output:
  - Location in Euclidean space for positioning additional node



Physical Euclidean Space



Experimental Results



Additional Nodes	Lifetime Extension (Per Amount of Energy)
1	2.7 / 2.59
2	4.5 / 4.15
3	6.2 / 5.51
4	7.5 / 6.42
5	8.3 / 6.86
6	9.1 / 7.28
7	9.9 / 7.66
8	10.6 / 7.95