Communication Mapping for Robot Team Deployments

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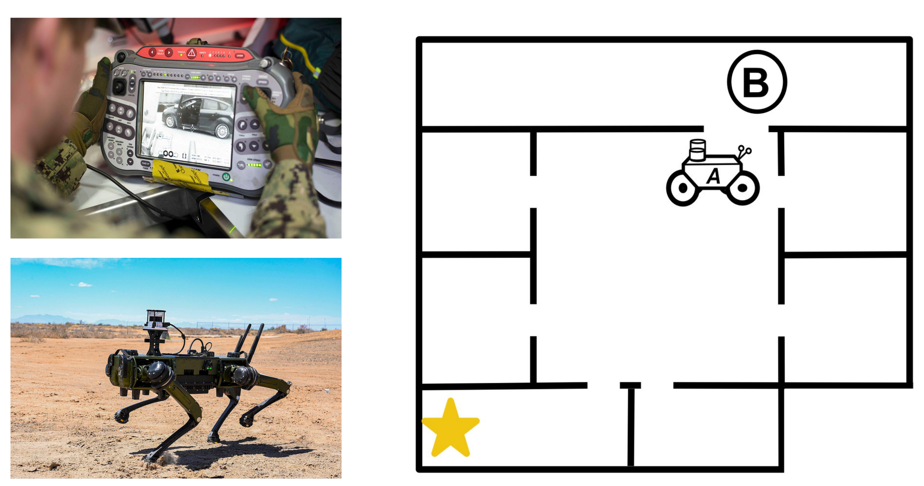
Intro & Motivation

- Wireless communication is required for multi-robot teams and human-robot collaboration

However…

- Predicting the ability for two devices to communicate is very challenging
- To maximize data throughput:
  - Not clear how many robots to deploy
  - Not clear where to position robots

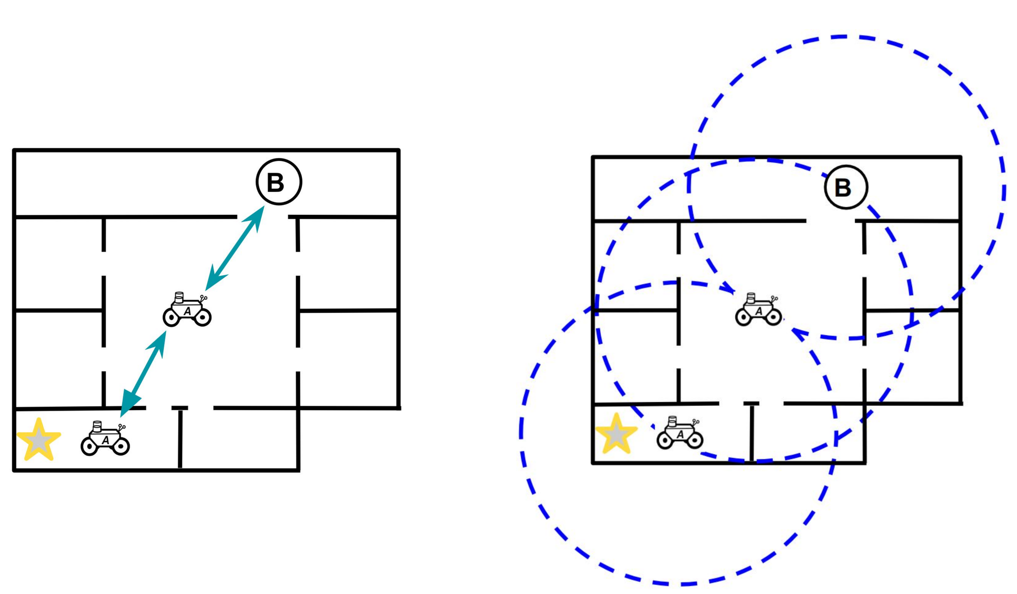


Considered Problem

- Predict the ability for two or more robots to communicate in a given environment
- Inform how to deploy teams of networked robots
  - Number of robots to optimize network throughput
  - Where to position robots to optimize network throughput

Previous Methods

- *Disk Method*: Assume full communication when within a given distance and no communication outside of distance
- *Sign-To-Noise*: Maximize SNR between robots

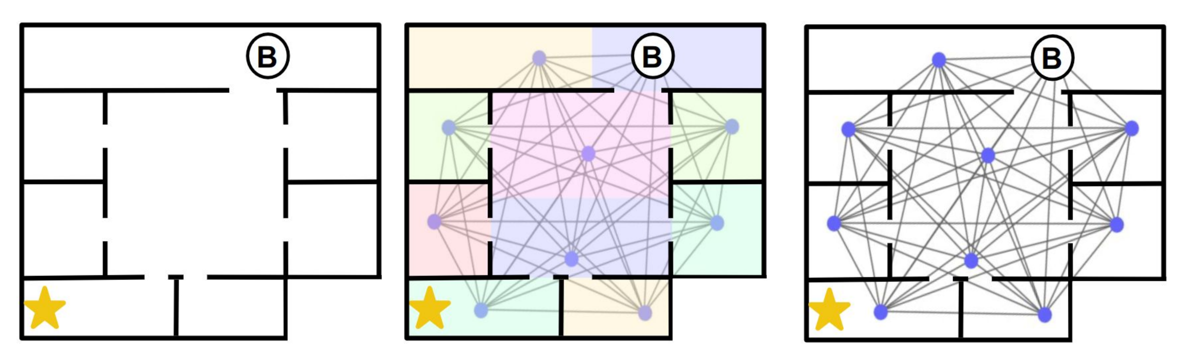


Proposed Methods

- We propose using ETX: a link quality metric for mesh networks[1]
  - Represents expected number of transmissions required to successfully deliver a data packet
- The ETX of a route is the sum of the ETX for each link in the route
- *Assumption*[1]: The minimum ETX route from A and B is the optimal data route from A and B

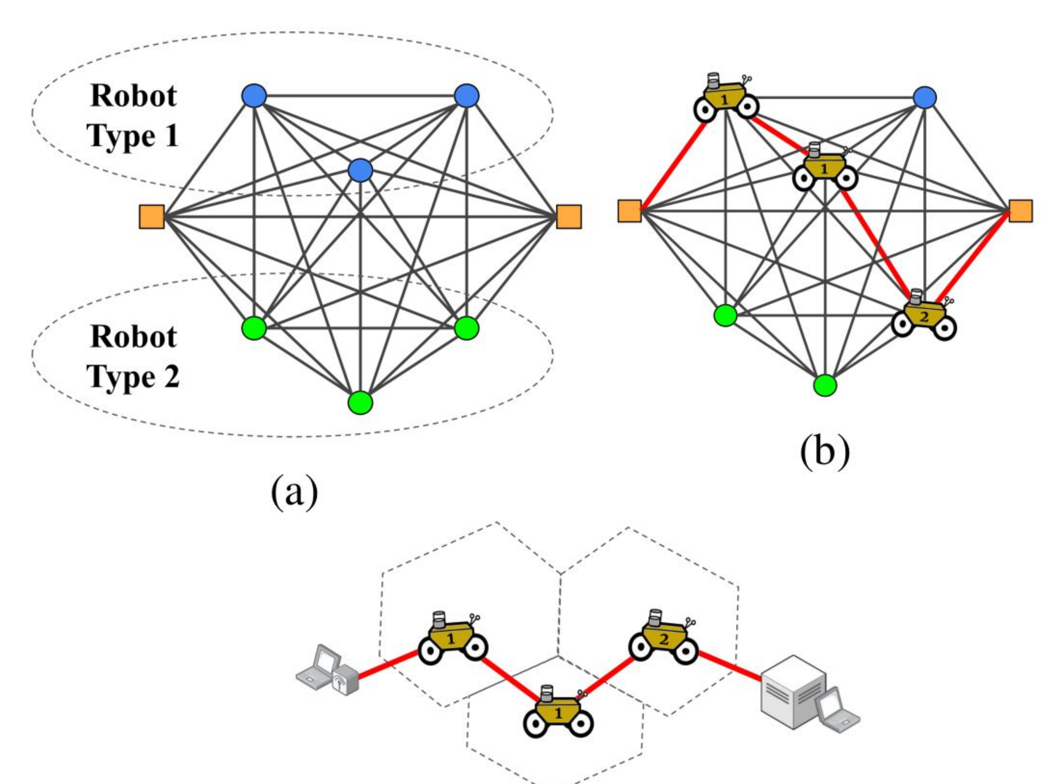
Communication Map

- We propose the Link Quality Communication Map (LQCM), a fully connected directed graph where:
  - Each vertex in the map represents a potential robot deployment location
  - Each edge weight between vertices *i* and *j* in the map is the predicted link quality between points *i* and *j*



Heterogeneous Robots

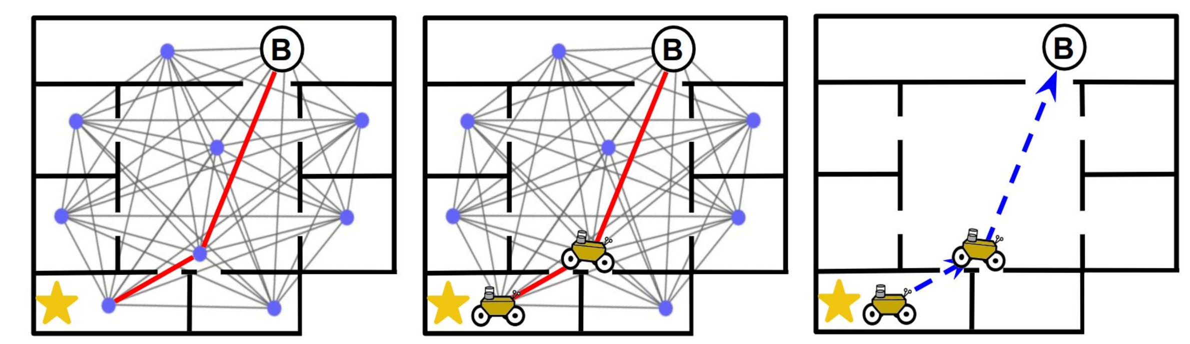
- To expand our LQCM for heterogeneous robots, we add layers to graph based on unique robot types.



(a) (b) (c)

Determining Robot Deployments

1. Find shortest path through map from data source to data sink
2. Deploy robots at vertices along path



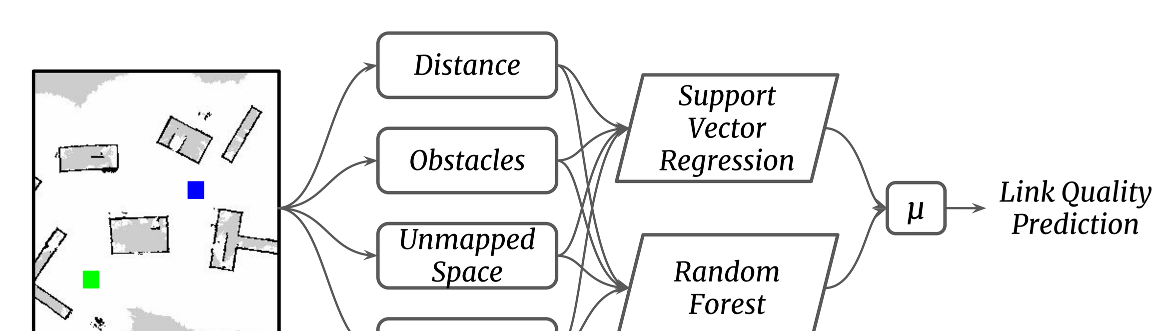
Why Use an ETX Deployment Map?

- *Proposition*: The vertices on the least cost path between two deployment locations in map shows where to deploy robots to maximize data throughput
- *Proposition*: The number of vertices on the least cost path between two deployment locations in the map is the optimal number of robots to deploy to maximize data throughput

Proofs provided in paper[2]

Link Quality Prediction Method

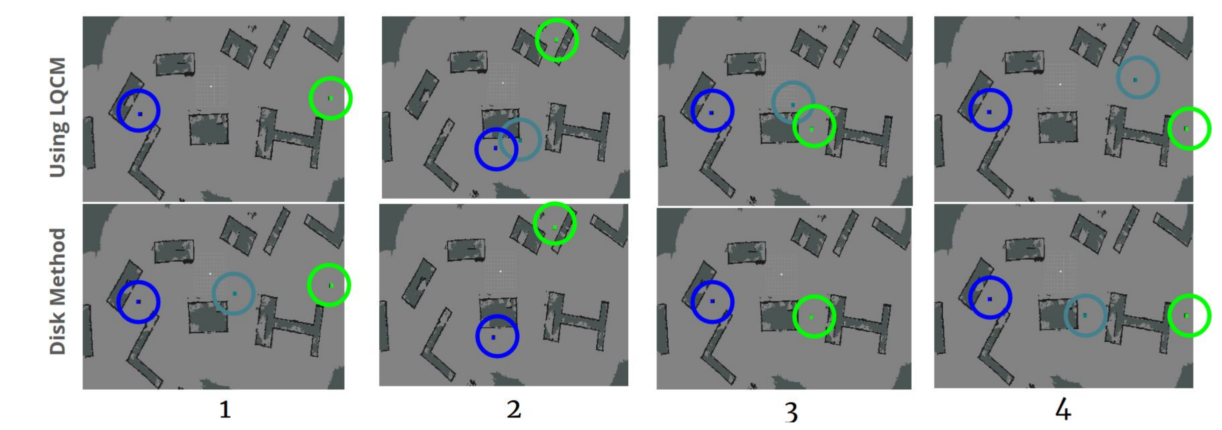
- We predict ETX between two points in a map by extracting features from an occupancy grid then feeding these features into a regression model
- Features used:
  - Distance between robots
  - Number of obstacles between robots
  - Unmapped space between robots
  - RF noise at each robot
  - Radio TX power of each robot



Field Experiments

- Experimental Setup: Stream data from source to sink robot
- Baseline: Distance based (Disk Method)
- Metric: Data transfer rate

Scenario	1	2	3	4
Percent Improvement	174%	1,640%	-45%	2,550%



Link Quality Prediction Accuracy

- *Data Set*: Collected 200 Link Quality measurements in outdoor environment
- *Training*: Used 85-15 training-test split

	training set MSE	R2	*test set* MSE	R2
sigMod	$4.504{\cdot}10^2$	0.076	$4.597{\cdot}10^2$	0.028
BR	$2.638{\cdot}10^2$	0.459	$2.750{\cdot}10^2$	0.419
RF	$\mathbf{0.383{\cdot}10^2}$	**0.921**	$2.180{\cdot}10^2$	0.535
SVR	$1.085{\cdot}10^2$	0.777	$2.316{\cdot}10^2$	0.505
SVR + RF	$0.592{\cdot}10^2$	0.878	$\mathbf{2.057{\cdot}10^2}$	**0.562**

Prediction Accuracy with Changing RF Noise

- Collected ETX data with and with WiFi jamming in same environment
- Trained prediction model on data with jammer, compared accuracy when jammer was removed
- *Results*: prediction model had an **MAE of 0.195** on test data (with WiFi Jamming) and an **MAE of 0.186** on new data after RF environment changed (no WiFi Jamming)

Future Work

- Further develop link quality prediction method
- Merge communication mapping with environment mapping

References

[1] Douglas SJ De Couto, Daniel Aguayo, John Bicket, and Robert Morris. "*A high-throughput path metric for multi-hop wireless routing.*" In Proceedings of the 9th annual international conference on Mobile computing and networking, 2003.
[2] Jonathan Diller, John Rogers, Neil T. Dantam and Qi Han. "*Communication Mapping for Robot Team Deployments.*" Submitted to the IEEE International Conference on Robotics and Automation, 2024.

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