Collective Anomaly Perception During Multi-Robot Patrol: Constrained Interactions Can Promote Accurate Consensus

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Introduction

An important real-world application of multi-robot systems is multi-robot patrolling (MRP), where robots must carry out the activity of going through an area at regular intervals. While MRP algorithms show some maturity in development, a key potential advantage has been unexamined: the ability to exploit collective perception of detected anomalies to prioritize security checks. Here, we examine the performance of unmodified patrolling algorithms listed in Table 1, when they are given the additional objective of reaching an environmental perception consensus via local communication and a quorum threshold.

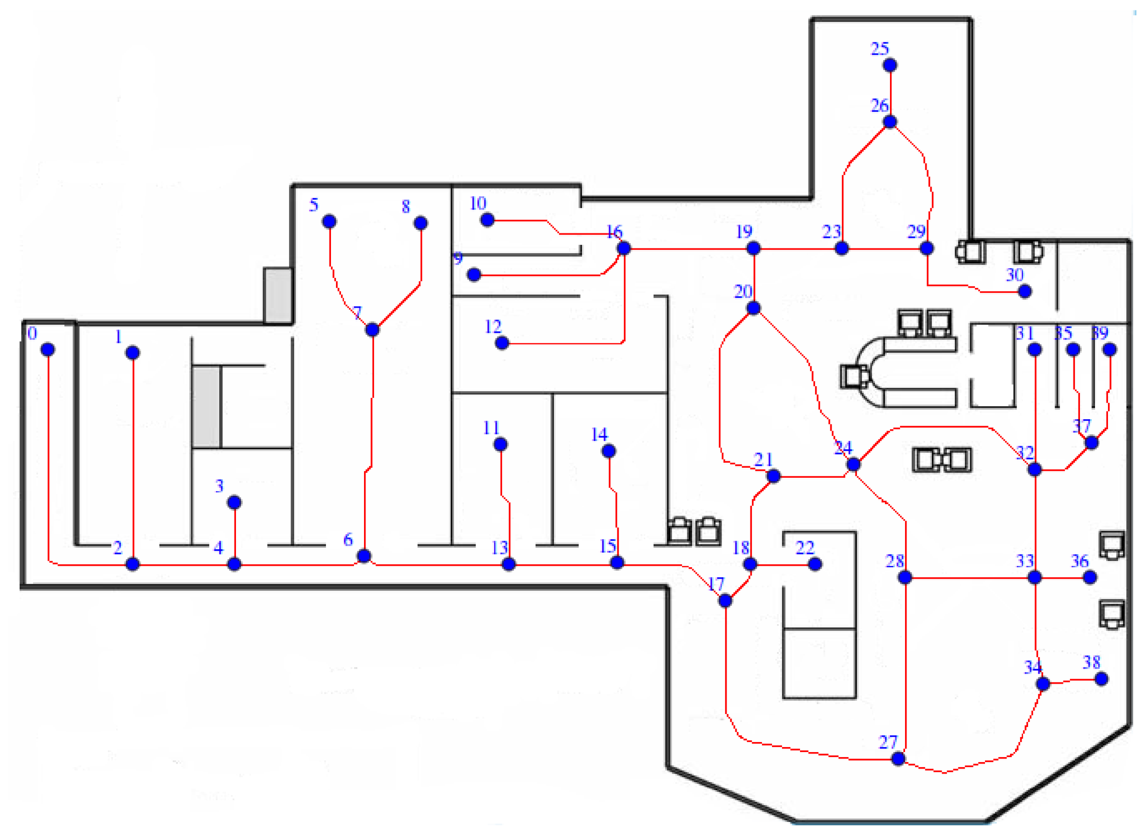


Figure 1: "Cumberland" map graph with 40 nodes.

Results & Discussion

We examine the behaviour of the patrolling algorithms by interpreting their differences in algebraic connectivity of the emergent communication networks between the agents. We calculate an *F-score* to quantify the performance, which provides a metric that weighs the agents' correct (true positive) and incorrect (false positive) beliefs about the world. It is noted that algorithms that result in moderate levels of algebraic connectivity in the communication networks are robust to noise levels and result in high F-scores, this behaviour is also observed in [1]. We find that algorithms SEBS, CBLS and CGG record the lowest number of false positives while maintaining high accurate anomaly detection. These algorithms correspond to a moderate level of communication between agents.

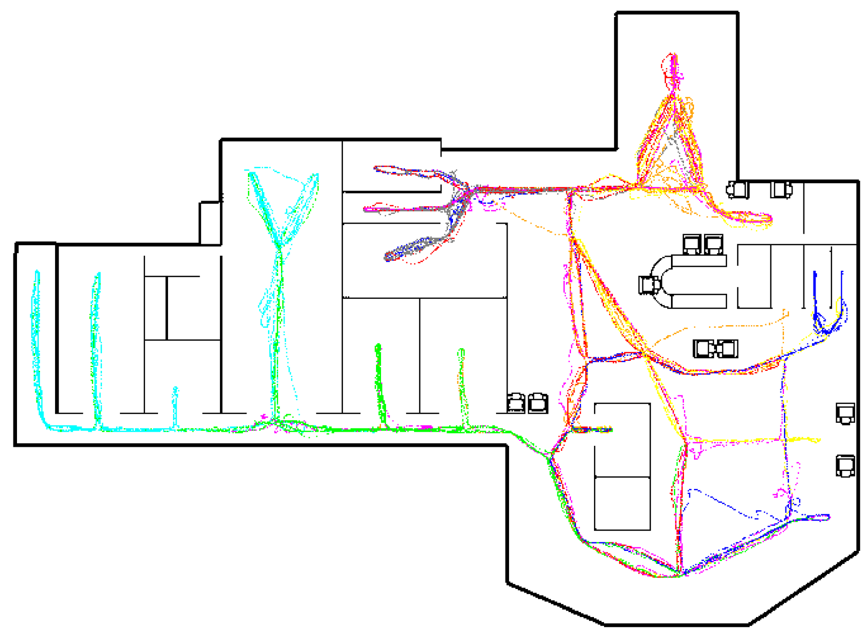
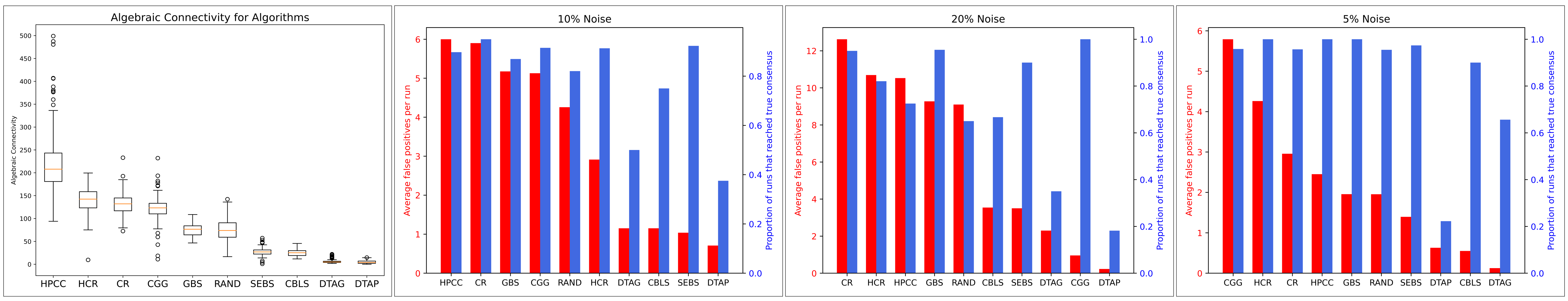


Figure 2: Trajectory plot of eight robots executing the SEBS algorithm for over an hour on the 'Cumberland' map, with each color representing a single robot.



(a) Boxplot of Algebraic Connectivity (b) 10% Anomaly measurement noise (c) 20% Anomaly measurement noise (d) 5% Anomaly measurement noise

Figure 3: Subfigures 3a, 3b, 3c show the ranked average performance of patrolling algorithms for different levels of measurement noise across 20 experiments. Red axis is the average count of false positives during a patrol run; blue axis shows proportion of runs that reached consensus on the particular node containing the anomaly. Subfigure 3d: Algebraic connectivity for each tested algorithm ranked.

Experimental Methodology

Simulation results are generated using a simulation package that models agents as a differential drive robot [2]. Robots are capable of local communication between one another within a communication radius. Upon visiting a node during a patrol, agents measure the node for an anomaly, with some measurement noise that may lead to a false positive reading. Agents then build a representation of the world according to the measurements they make, as well as measurements shared with them via pairwise communication. Agents navigate a graph map as seen in Figure 1 and decide on nodes to visit based on the patrolling algorithm.

Short name	Patrol Strategy	Decentralized?
CBLS	Bayesian Learning	Yes
CGG	Hamiltonian Path	No
CR	Reactive	Yes
DTAG	Utility Function	Yes
DTAP	Utility Auctioneer	Yes
GBS	Bayesian	No
HCR	Heuristic Reactive	Yes
HPCC	Heuristic Pathfinder	Yes
RAND	Random	Yes
SEBS	State & Bayes Exchange	Yes

Table 1: Multi-Robot Patrol algorithms examined

Future Work

Subsequent work will look at the behaviour of results across multiple environments, and scaling of results to larger graphs with varying numbers of agents. The influence of group size on speed of consensus and the false positive rate will be examined to see how these change the performance of each of the patrolling algorithms.

References

[1] Mohamed S. Talamali, Arindam Saha, James A. R. Marshall, and Andreagiovanni Reina. When less is more: Robot swarms adapt better to changes with constrained communication. *Science Robotics*, 6(56):eabf1416, July 2021.

[2] David Bina Siassipour Portugal. *Effective Cooperation and Scalability in Multi-Robot Teams for Automatic Patrolling of Infrastructures.* PhD thesis, Universidade de Coimbra (Portugal), Portugal, September 2013.

Acknowledgements & Contact

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