# Spatio-Temporal Reconnection for Multi-Robot Networks using Adaptive Prescribed-Time CBFs


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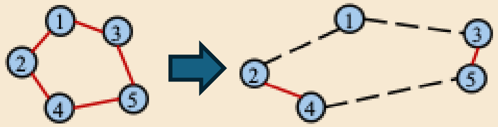
## Motivation

Multi-robot systems rely on communication links to support **coordination** and **information exchange**. Existing approaches often enforce **persistent global connectivity**, which may unnecessarily limit robot motion in large-scale task with limited communication range.



Persistent connectivity

Temporary disconnection and reconnection

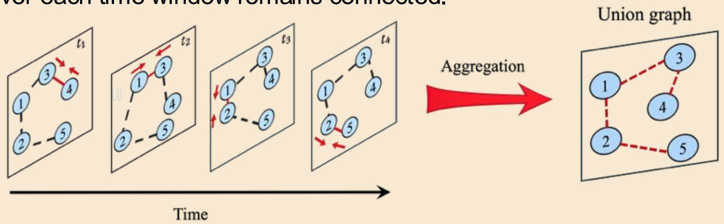
Challenges:

- Communication connectivity requirements constrain robot motion
- Predefining reconnection time may be infeasible
- Maintaining connectivity can interfere with task execution

## Problem Formulation

**Problem:** Allow **temporary** disconnection across the time while guaranteeing periodic reconnection.

**Formulation:** We enforce joint global connectivity, the union graph over each time window remains connected.




**How to adaptively determine when and which edge to connect using spatial and temporal information and finish reconnection without overly disrupt the task execution?**

## Method

### A. Adaptive Prescribed-Time Control Barrier Functions

- **Prescribed-Time CBFs (PT-CBFs) [1]:** To reach the safe set within a **manually selected prescribed time**.
- **Finite-Time CBFs (FT-CBFs) [2]:** Reach the safe set in finite time with **state-dependent** convergence.
- **Adaptive PT-CBFs:** Compute the prescribed time **adaptively** from the initial state. $\dot{h}(x) + c\,\mu(t)\,\mathrm{sign}(h(x))\,|h(x)|^{\rho} \geq 0$

$$\mu(t) = \left(\frac{T_{\mathrm{p}}}{T_{\mathrm{p}} - t}\right)^{m} + \alpha, \quad t \in [0, T_{\mathrm{p}}) \qquad \boxed{T_{\mathrm{p}} = \frac{|h(x_0)|^{1-\rho}}{c(1-\rho)\mu_0},} \qquad \mu_0 = 1 + \alpha > 1$$

### B. Spatio-temporal Trigger Mechanism

Each communication edge must be reconnected within a time window $[t_k, t_{k+1}]$

Define the edge weight as

$$w_{ij}(t) = w_{\mathrm{spatial}}(i,j) + w_{\mathrm{temporal}}(t)$$

$w_{\mathrm{spatial}}(i,j)$ measures the effort required to reconnect the edge

$w_{\mathrm{temporal}}(t)$ measures how close the system is to the reconnection deadline

If $w_{i,j}(t) > 0 \rightarrow$ activate reconnection constraint between robot $i$ and robot $j$

Solve QP :

$$\mathbf{u}^*(t) = \arg\min_{\mathbf{u}} \sum_{i=1}^{N} \|\mathbf{u}_i - \mathbf{u}_i^{\mathrm{nom}}(t)\|^2$$

s.t. collision avoidance constraints

adaptive PT-CBF reconnection constraints

control input bounds

The controller computes a safe control input that satisfies safety and reconnection constraints.

Nominal Control Input $\mathbf{u}_i^{\mathrm{nom}}$ → Edge Priority Evaluation → Edge Activation

$w_{ij}(t) = w_{\mathrm{spatial}}(i,j) + w_{\mathrm{temporal}}(t)$

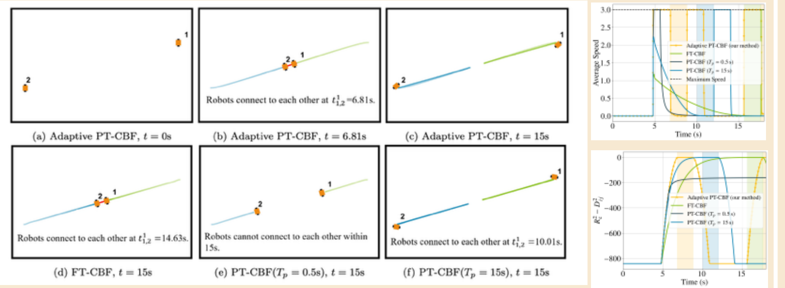
If $w_{i,j}(t) > 0$

Adaptive PT-CBFs Constraint (Compute $T_{\mathrm{p}}$ adaptively) → Solve QP → Control Output $\mathbf{u}_i^*$ → Robot Motion → Nominal Control Input $\mathbf{u}_i^{\mathrm{nom}}$

## Results

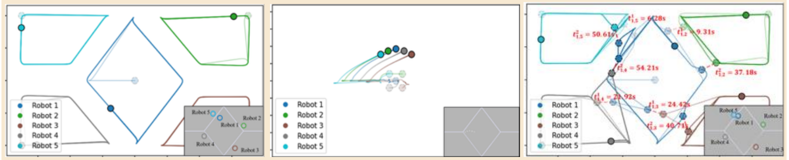
### A. Two-robot-scenario Comparison

Two robots start outside the communication range and are initially stationary. The experiment compares different CBF formulations for communication reconnection.




Adaptive PT-CBF enables **feasible** and **less** conservative reconnection.

### B. Multi-robot Case




Original Task | Persistent Connectivity | Our Adaptive PT-CBFs

- ➢ Task-only execution cannot ensure timely information exchange.
- ➢ Maintaining persistent connectivity overly restricts task execution.
- ➢ Our method achieves both **efficient** task execution and **timely** information exchange.

## Conclusion

- **Adaptive PT-CBF** computes feasible reconnection time and enforce the constraint automatically
- **Spatio-temporal triggering mechanism** balances task execution and communication urgency
- Guarantees **reconnection within each time window**

Project Website


[1] Abel, Imoleayo, et al. "Prescribed-time safety design for strict-feedback nonlinear systems." *IEEE Transactions on Automatic Control* 69.3 (2023): 1464-1479.

[2] Li, Anqi, et al. "Formally correct composition of coordinated behaviors using control barrier certificates." *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2018.