# Time-based Dynamic Controllability of Disjunctive Temporal Networks with Uncertainty: A Tree Search Approach with Graph Neural Network Guidance

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## INTRODUCTION

- Scheduling in the presence of uncertainty is an area of interest artificial intelligence due to the large number of applications.
- We study the problem of dynamic controllability (DC) for Disjunctive Temporal Networks with Uncertainty (DTNUs)
- We introduce Time-based dynamic controllability (TDC), a new form of controllability
- We design a tree search algorithm to identify TDC strategies for DTNUs, and a heuristic function to guide search based on message passing neural networks (MPNN)
- We carry out experiments comparing this work to previous state-of-the-art approaches

## DEFINITIONS

- DTNU = (A, U, C, L)

•A: Controllable timepoints

•U: Uncontrollable timepoints

•C: Set of constraints (*i.e*: $a_1 - a_2 \in [1,3] \vee a_4 - a_3 \in [10,20] \vee a_5 - u_1 \in [1,3]$ )

•L: Set of contingency links (*i.e* Which controllable timepoint triggers the activation of which uncontrollable timepoint)

- Dynamic controllability (DC): Type of scheduling strategy which allows instantaneous reactions to uncontrollable timepoints (*i.e* take a new decision as soon as an uncontrollable timepoint occurs)

To solve DTNU in DC: Find a DC strategy which ensures all constraints in C are satisfied at the end of the scheduling

## METHODS

### Time-based Dynamic Controllability (TDC)

- The time horizon is discretized into intervals, which correspond to 'wait' decisions
- Uncontrollable timepoints are assumed to either occur or not in these intervals. Every outcome is considered
- A timepoint is either scheduled at the start of the interval or permitted to be reactively scheduled in response to an uncontrollable timepoint during the interval
- TDC restricts when reactive scheduling can happen, TDC strategies are less flexible than DC. TDC implies DC

### Tree Search

- The search tree is built by the algorithm by discretizing time
- Tree nodes are made of either DTNU nodes (sub-problems of the original DTNU resulting from decisions taken), WAIT nodes, or logical nodes (OR, AND)
- All outcomes of uncontrollable events are developed when waiting
- A heuristic based on an MPNN is built for guidance at OR nodes, accelerates search
- Leaf nodes: Constraints are checked. True is assigned if all constraints satisfied, False otherwise. True/False values are propagated upwards in the tree (OR nodes: True if at least one child is true, False if all children are false ; AND nodes: False if at least one child is false, True if all children are true)
- True reaches root: There is a path from the root that ensures we reach a leaf node with true property

## HEURISTIC

- Data generation: Random DTNUs are generated, solved with a randomized tree search based on simulations with short timeouts, DTNUs are stored with their truth values
- MPNN is trained on the data. At d-OR nodes, a DTNU is converted into a graph where nodes and edges have attributes and fed into the MPNN. Output is a probability for children nodes (suggested visit order)

## EXPERIMENTS

- Fig.4 : Comparison with PYDC-SMT, state-of-the-art DC solver from (Cimatti et al. 2016) on the same benchmark as (Cimatti et al. 2016). Our approach achieves significant improvement upon state-of-the-art. Ninety seven percent of instances solved by PYDC-SMT are solved with the same conclusion
- Fig.5 : Experiment done on self-generated benchmark with harder DTNUs (25-30 controllable timepoints, 1 to 3 uncontrollable timepoints). True benefit of MPNN shown on harder problems. Different values are experimented for the parameter changing maximal depth use of the heuristic in the tree.

## CONCLUSION

- Introduced TDC, a tree search and a heuristic based on message passing neural networks for DTNUs
- Although TDC is a stronger form of controllability than DC, our approach achieves almost the same DC accuracy than the state-of-the-art DC solver, but with a much higher efficiency
- Our TDC solver is based on a tree search algorithm and can be coupled with learning heuristics, which allow very significant improvement for harder problems
- MPNN generalizes to problems of bigger size than trained on, which is significant for combinatorial problems, and in line with observations of related works on combinatorial problems

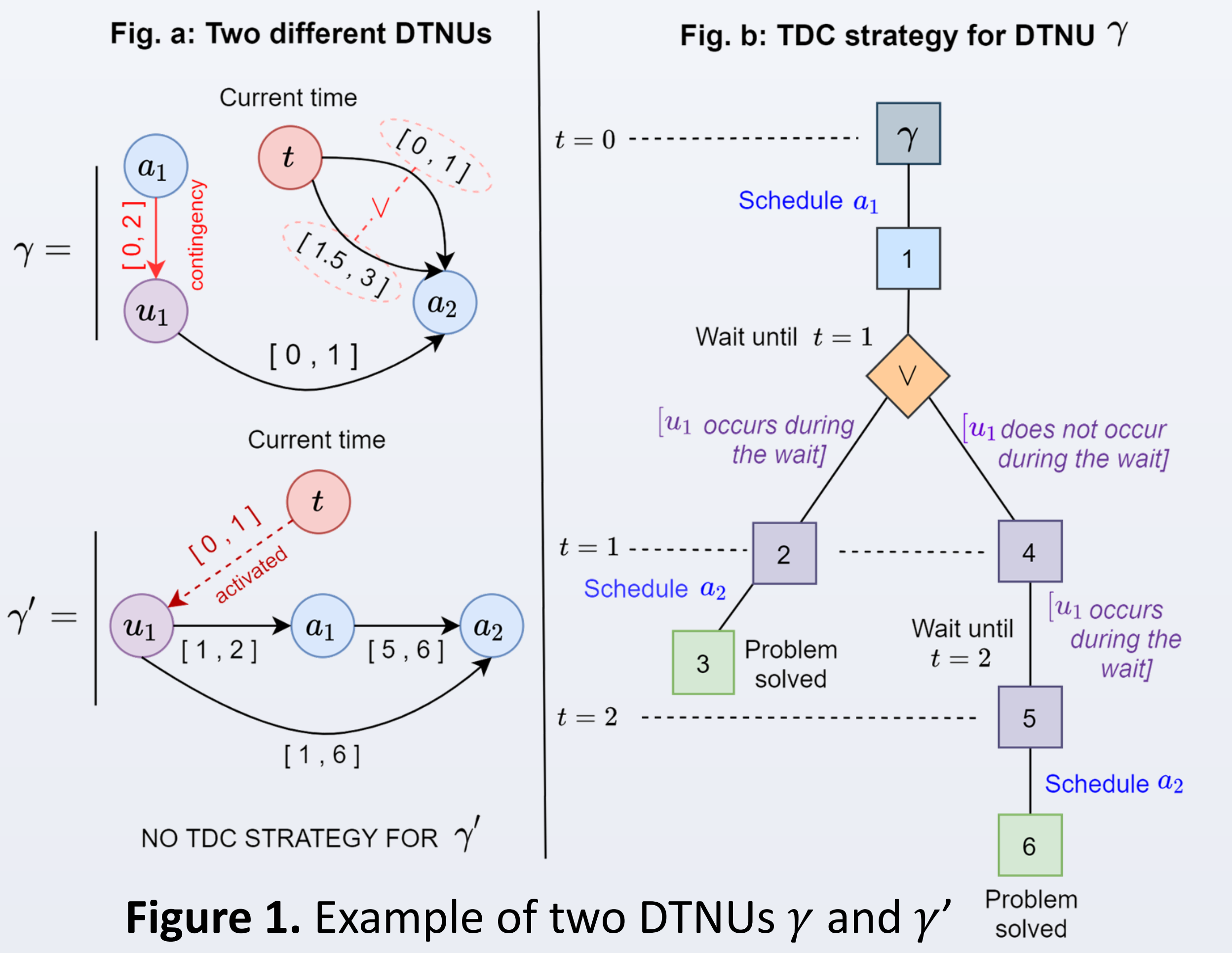

**Figure 1.** Example of two DTNUs $\gamma$ and $\gamma'$

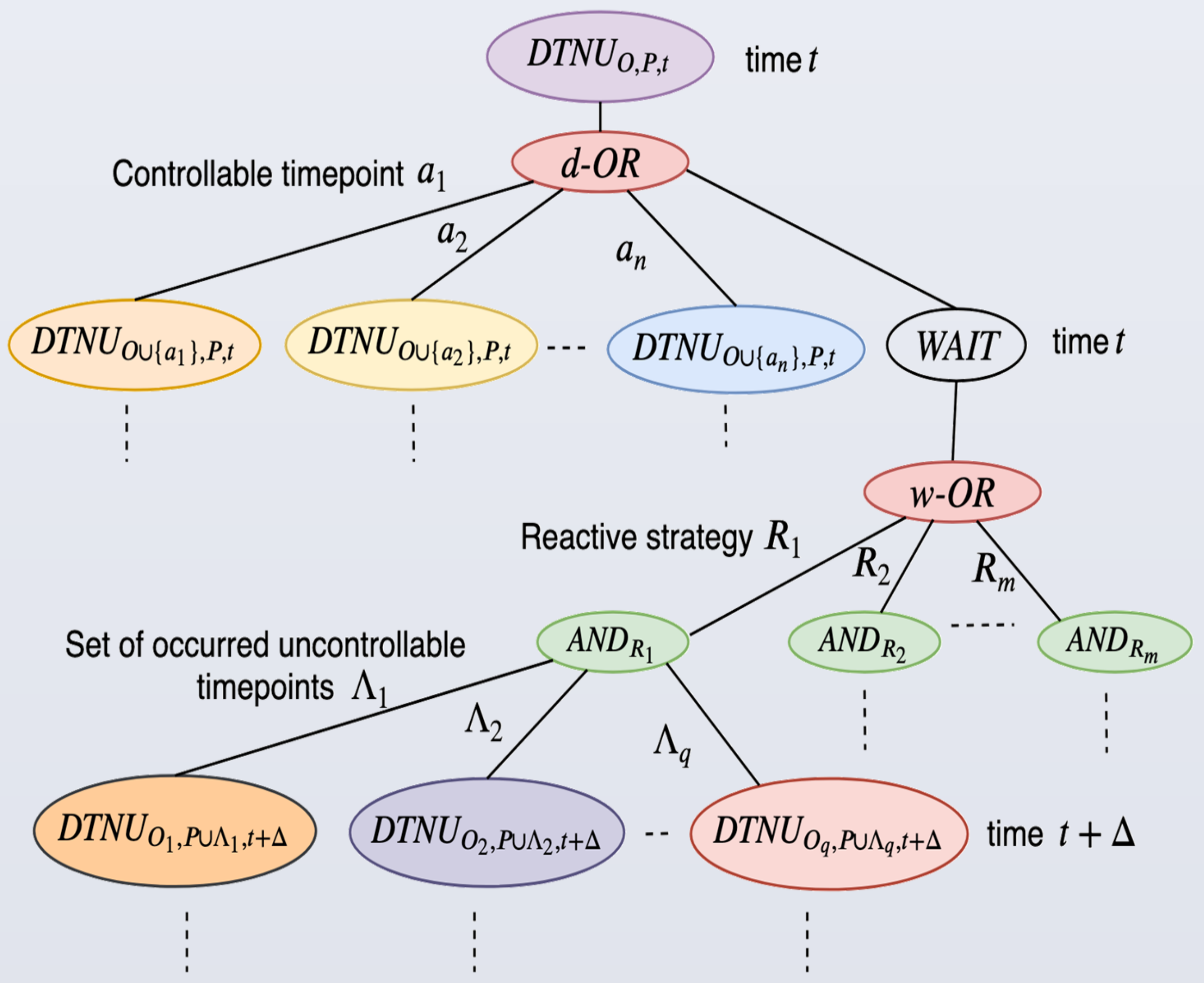

**Figure 2.** Tree search structure

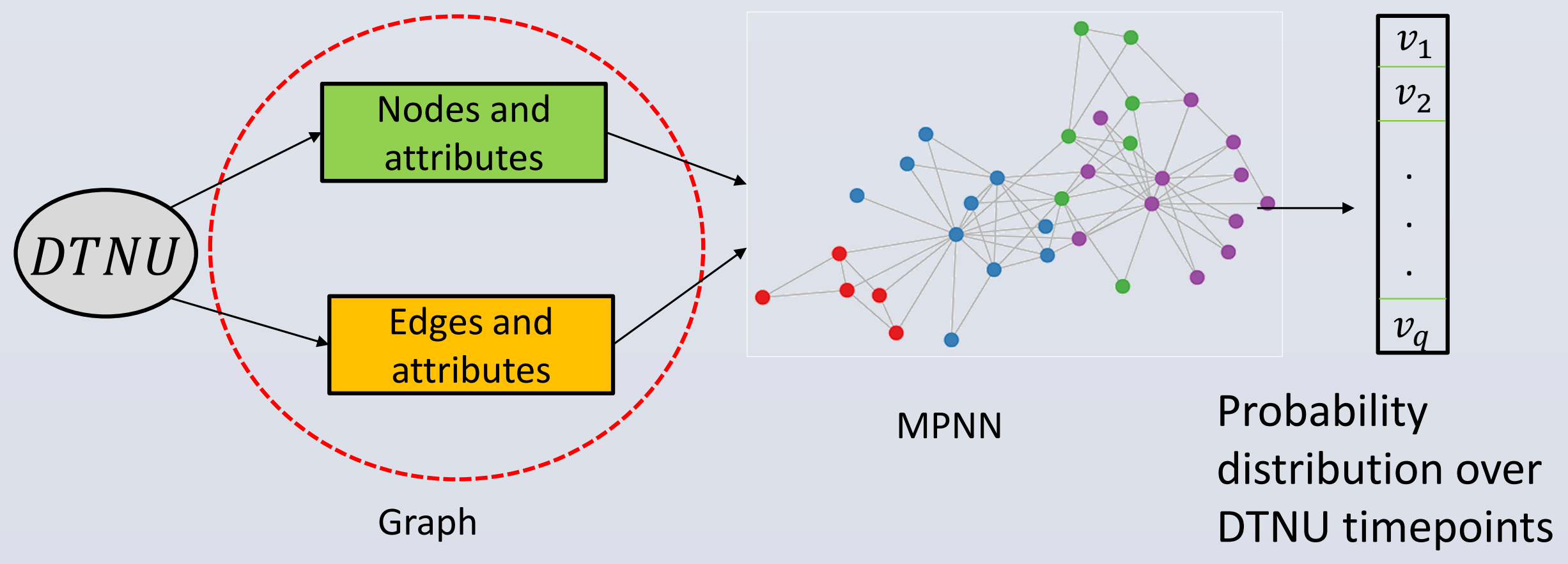

**Figure 3.** MPNN forward pass

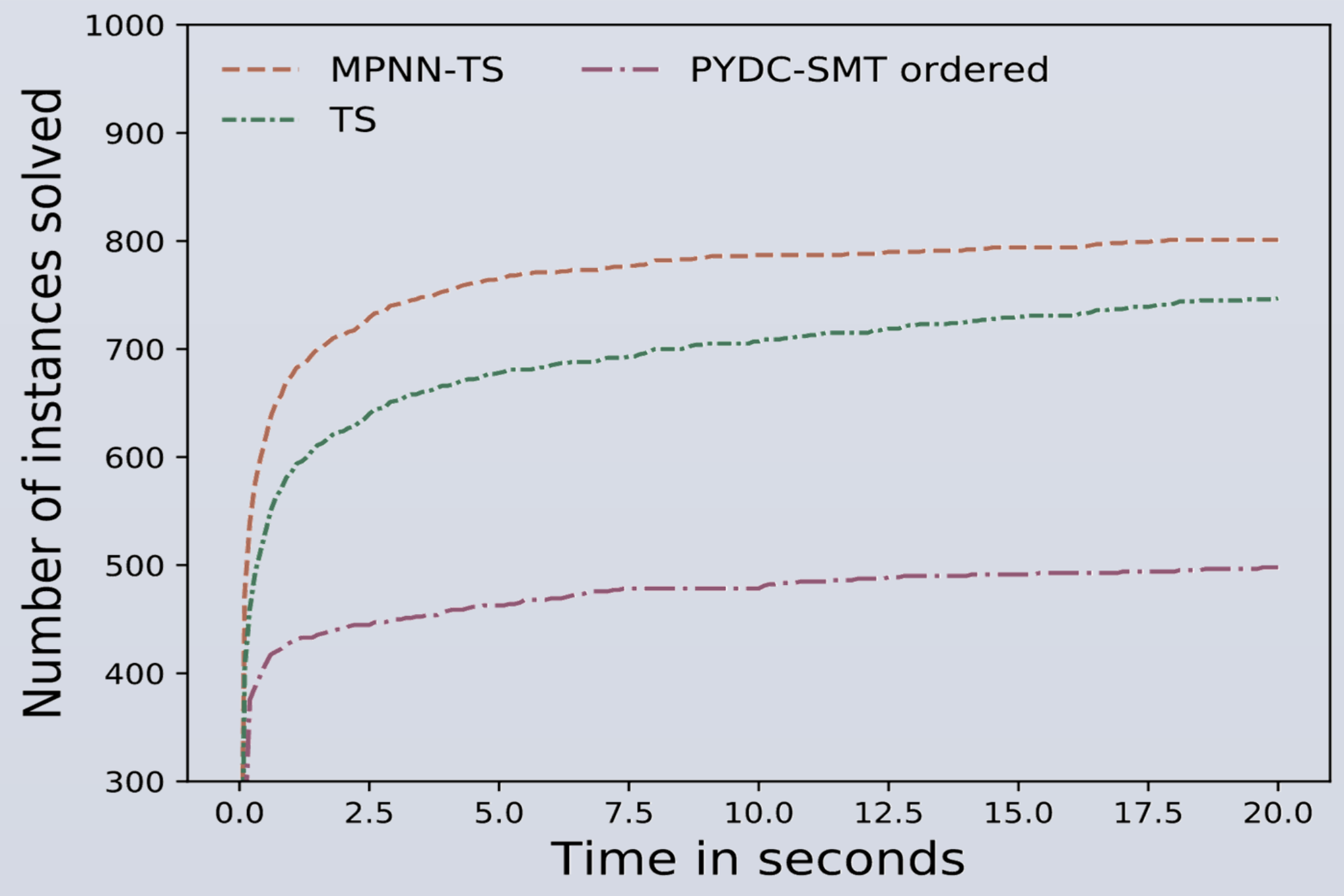

**Figure 4.** Experiments on (Cimatti et al)'s benchmark

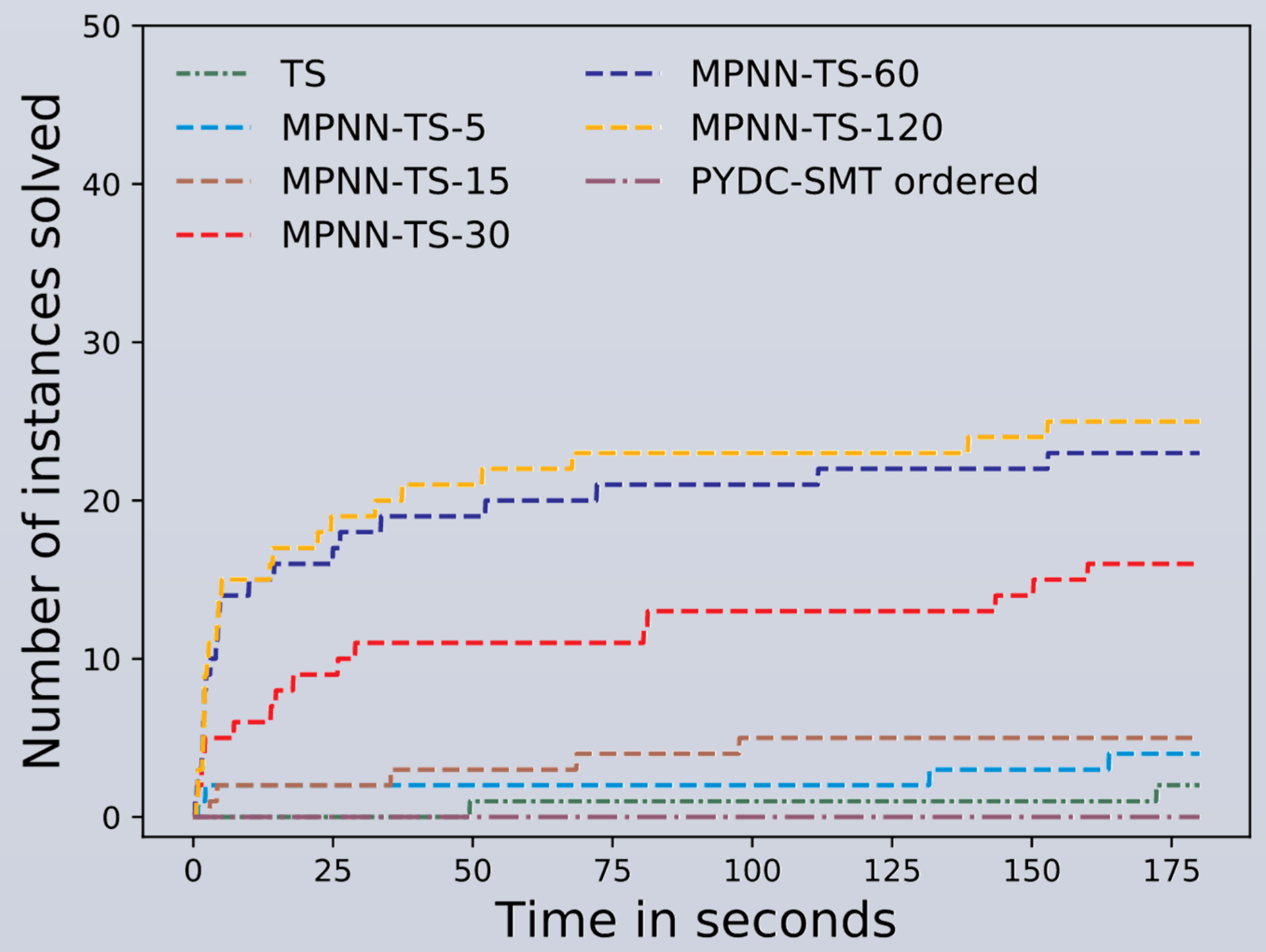

**Figure 5.** Experiments on self generated benchmark with bigger DTNUs (25-30 controllable timepoints)