DALI: An Agent-Plug-In System to "Smartify" Conventional Traffic Control Systems

Demonstration

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ABSTRACT

The DALI system aims at making existing conventional traffic control systems autonomous and smart. We achieve this goal by plugging-in a software agent into each existing intersection controller which becomes "the brain" of the controller. The agents analyze the traffic data, communicate with each other directly, and collaborate to execute a timing strategy that improves traffic flow.

KEYWORDS

Deployed Multi-Agent Systems, Intelligent Transportation Systems, Traffic Signal Timing

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1 INTRODUCTION

In the US, conventional traffic control systems consist of *traffic lights* that display traffic signals, *inductive loop detectors* (i.e., sensors installed under the surface of roadways) that detect the presence or passage of vehicles; and *intersection controllers* (i.e., electrical devices mounted in a cabinet at intersections) that control the operations of the traffic lights. Intersection controllers are connected to a central traffic management center which monitors and manages the operation of the system. In order to turn conventional traffic infrastructures into smart infrastructures it is necessary to acquire, install and maintain expensive equipment (e.g., fiber optic video receivers, cameras, radars, advanced detectors). The cost of a traffic infrastructure upgrade amounts to tens of millions of dollars [14] and years of installation. For these reasons, municipalities with limited resources opt to forgo intelligent traffic systems.

The purpose of the DALI (Distributed Agent-based traffic Lights) system [19, 21] is to provide an immediate, low-cost software solution to "smartify" existing conventional traffic control systems by enhancing their *digital capabilities* without expensive investment in the infrastructure. This is achieved by a) plugging-in software agents into existing intersection controllers; b) using existing communication links to establish communication between agents; and c) implementing a distributed, adaptive and collaborative agent-based traffic signal timing strategy. DALI was thoroughly tested through simulation, then deployed on three major intersections in the City of Richardson (Dallas-Fort Worth metroplex), Texas. The data collected for a three week period shows that on average, DALI reduced delay by 40.12% [1].

2 RELATED WORK

Modern Traffic Control Systems (TCS) have been deployed and in use for over forty years. Fully centralized TCS [12] are systems in which intersection controllers are fully controlled by one or several higher-level computing unit. Although they allow for efficient coordination under normal traffic conditions, fully centralized TCS are not scalable and do not perform well when major traffic disruptions occur. Partially centralized TCS [13, 15, 22] allow intersection controllers to have more decision-making responsibilities, but network-level decisions are still made at higher levels. Decentralized TCS [10, 11, 16] give full responsibility to controllers but suffer from several limitations: a) the use of complex optimization algorithms and dynamic programming [10, 11] severely limit their scalability; b) controller interactions are limited to accessing neighboring intersections' traffic data [10, 11, 16]; c) signal timing decision-making is done in isolation, at the intersection level [10, 11, 16]; and d) the need for expensive equipment [16].

From a research perspective, Multi-Agent Systems researchers have proposed the use of a variety of techniques (e.g., game theory [4, 6], neural networks [5, 17], fuzzy logic [7]), including the well referenced Reinforcement Learning (RL). RL-based-solutions attempt to address two types of traffic signal timing problems: non-coordinated [1, 8] and coordinated[3, 9]. Given the astronomical number of state-action pairs that need to be considered for any realistic traffic model, RL-systems have to simplify the traffic model.

DALI is a fully decentralized, collaborative multi-agent traffic control system. Its unique characteristics include: (1) DALI agents continuously communicate with each other through direct links (i.e., explicit communication). (2) A DALI agent's decision-making for a signal-timing change is collaborative

[1]Demo available at: http://utdmavs.org/demos/dali.mp4

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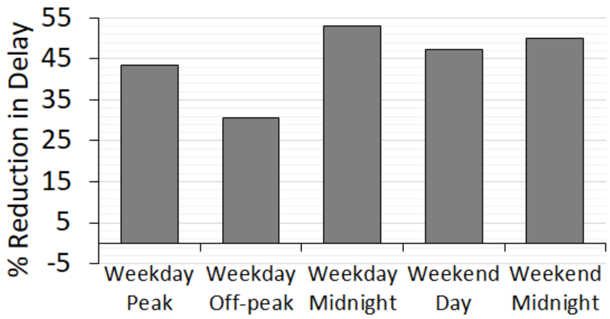

Figure 1: Delay Reduction

and involves the feedback of all controllers potentially impacted by the change. (3) As a software solution, DALI does not require the installation of additional expensive hardware.

3 DALI AGENTS AND OPERATION

A DALI agent consists of four modules: 1) the **Interaction Module** handles the agent's interaction with the external world. It includes the *Traffic Environment Sensing Module* which processes traffic sensor information, and the *Agent Communication Module* which implements agent-to-agent communication; 2) the **Knowledge Module** maintains external and internal knowledge. The *External Knowledge Module* serves as the portion of the agent's memory that is dedicated to maintaining knowledge about traffic data, and neighboring agents. The *Internal Knowledge Module* serves as the portion of the agent's memory that is dedicated to storing self-knowledge, including the agent's current state, timing constraints, and behavioral limitations; 3) the **Task Module** manages the atomic tasks that the agent can perform; and 4) the **Planning and Control Module** serves as the brain of the agent. It uses information provided by the other modules to plan, make decisions, initiate tasks, and achieve goals.

Irrespective of the traffic conditions, DALI agents continuously communicate with one another. They exchange information about detected vehicles and the status of their intersection with their neighbors. They continuously use the received information, their observations and timing constraints to compute and execute optimum timing plans.

When an agent detects congestion, it deliberates and computes the optimal timing plan to alleviate congestion at its intersection. It then communicates the plan and requests feedback from the neighboring agents that may be affected by the plan execution. They in turn communicate with those agents that may be affected, and the process continues until all potentially affected intersections are informed of the plan evaluation request. Then, each farthest affected agent determines its level of agreement with the new timing plan in terms of a real number. Each agent sends its level of agreement to the requesting agent which incorporates it in the computation of its own level of agreement. The backward propagation continues until the initiating agent receives the feedback from the immediate agents. The initiating agent then deliberates and decides whether to execute or ignore the plan, based on the received feedback. In case the plan is to be executed, the initiating agent requests that all affected agents update their timings accordingly. For the collaborative process to be adaptive, an RL-based approach is used to dynamically assign values to a number of thresholds (e.g., agent sensitivity to detect congestion, duration a phase needs to be flagged as congested in order to be considered as congested, agent collaboration scope) that are central to the agent decision-making algorithm [20].

4 DALI SIMULATION

The DALI agent algorithms were thoroughly tested through simulation on a variety of complex traffic networks in MATISSE, a large-scale multi-agent based traffic simulation system [2, 18]. In addition, a full replica of the City of Richardson's traffic network comprising 1365 road segments, 128 signalized intersections and 965 non-signalized intersections was created in MATISSE, and extensive simulations of DALI were conducted using historical data provided by the City. Next, controllers in the field were integrated in the simulation model and extensive V&V was performed in a hybrid simulation setting using real-time data.

5 DALI DEPLOYMENT

Three intersections on the Waterview Corridor were identified as candidates for the deployment of DALI. These intersections are managed by controllers which integrate web servers accessible remotely via VPN. The DALI agents were implemented in JAVA. Each agent runs on a PC (located in the lab) with 2 gigabytes of RAM and 3.33 GHz clock, and communicates with the other agents through a Broadcom gigabit ethernet net link with a minimum speed of 100 mbps.

A DALI agent connects to its controller's web server through VPN. Once connected, the agent changes the controller's configuration and takes control of the signal timing decision process for the intersection. As a safety measure, a DALI agent uses its controller's built-in security features. In addition, when the connection is interrupted or any technical problem occurs, the agent releases control to the controller which then resumes its normal operation.

In order to evaluate the performance of DALI, we ran DALI and gathered data for 260 hours, then gathered data for the conventional system for 260 hours. We considered week days and weekends and divided days into peak hours, off-peak hours and nighttime. Figure 1 shows that on average, DALI reduced delay by 40.12%.

6 CONCLUSION

DALI is an agent-plug-in, software solution to turn existing traffic control systems into smart, collaborative systems without the need for additional equipment. With the demonstrated success of DALI in the initial deployment phase, work on the expansion of DALI to nine intersections has started and more intersections are being considered for the coming months.

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