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A zone-based traffic assignment algorithm for scalable congestion reduction☆

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Abstract

Traffic assignment networks are networks with pseudo-static behavior: the network topology is constant but the cost of each edge changes in real-time. Extensive work has been completed in the literature to develop efficient traffic assignment algorithms in order to reduce traffic congestion. While some of these algorithms have proven to be effective, little attention has been paid to the matter of scalability in traffic networks. In this paper, we use zones to develop a hybrid approach to traffic assignment. We divide a traffic network into zones where the path within each zone is proactively stored, and paths between zones are reactively evaluated. This reduces the cost of route discovery. Using the Simulator of Urban MObility (SUMO), experiments were conducted to compare the zone-based system coined Z-BAR against a zone-free system. Between Z-BAR and a zone-free system, initial results showed Z-BAR introduces a speedup factor of up to 1.22.
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Keywords: Zones; Traffic assignment; Congestion reduction; Scalability

1. Introduction

Intelligent Transportation Systems (ITS) improve urban travel experiences using modern technology, particularly through the development of smart cities. One criterion for the success of a smart city is the optimization of traffic flow. Recent work in the traffic assignment optimization literature aims to influence driver behavior without requiring individual drivers to embark on suboptimal routes. Traffic assignment algorithms must strike a balance between driver selfishness and system optimum. Traffic assignment is a research area of high social and ecological impact. Urban traffic optimization is crucial to addressing grand-scale socioecological issues such as carbon-based air pollution. In a natural system, drivers tend to exhibit selfish behavior. This creates significant congestion in key areas such as a city's downtown core. Unchecked congestion leads to runaway emissions of carbon-based pollutants, and causes strain on day-to-day productivity.

The goal of this paper is to investigate a novel strategy for scaling existing traffic assignment systems to very large networks. This includes both artificial and real-world traffic scenarios. The strategy is based on the concept of zones. We propose that traffic networks be organized into zones such that the path between all nodes within each zone is stored in advance. This is expected to reduce the time needed for vehicles to determine an optimal path. This zone-based approach is implemented in an algorithm dubbed Z-BAR (Zone-Based Assignment Algorithm for scalable congestion Reduction), examined in detail later in this work. A sample traffic assignment algorithm inspired by [1] is implemented in this work as a template for illustrating the scalability Z-BAR provides. Since Z-BAR's purpose is scalability as opposed to traffic assignment itself, any traffic congestion model which uses weighted edges will be compatible with Z-BAR. Multiple networks and vehicle populations are used to compare the speed of the sample traffic assignment algorithm with and without the use of zones. To the knowledge of the authors, this is the first work which specifically addresses the scalability of traffic assignment optimization algorithms, and does so using the concept of zones.

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The remainder of the paper is organized as follows: Section 2 covers an overview of related work; Section 3 describes the algorithm Z-BAR; Section 4 describes the simulation environment; Section 5 covers an analysis of experimental results. Finally, Section 6 presents the conclusions of this paper, accompanied by a discussion of future work.

2. Related work

The traffic assignment problem has been studied thoroughly in the literature with foundations as far back as [2] and [3]. In recent works, Ant Colony Optimization (ACO) has proved to be successful as a traffic assignment tool. Originally proposed in [4], ACO is implemented by with a set of ants acting upon a graph *G*. Ants deposit pheromone on the paths they traverse, signaling the cost of their path to future ants. In traffic assignment algorithms, vehicles leave pheromone on the roads they traverse, characterizing road density for routing purposes. This vehicle-as-ant approach has been explored in [1] and [5]. The results in both works show that traffic assignment with ACO reduces vehicle travel and wait times. Some vehicles may take physically longer routes to their destination, but none will embark on slower routes. Both approaches were tested for congestion reduction on artificial and real-world networks.

Outside of traffic optimization, the literature also includes work in networking algorithms and their scalability. Networking algorithms are divided into proactive, reactive and hybrid categories. Proactive routing requires nodes to continuously broadcast their routing tables to their neighbors. This guarantees consistency of optimal routes but has a high maintenance overhead. Alternatively, reactive routing involves nodes evaluating optimal paths on demand. While routes do not need to be maintained in a reactive protocol, the cost of evaluating new routes can be high in large networks. Hybrid routing protocols are those which combine both proactive and reactive aspects. One example of a hybrid protocol is the Zone Routing Protocol (ZRP). The ZRP was first introduced in [6] and has since been used in a variety of applications. In a zone routing environment, the network is divided into zones, where nodes belong to at least one zone. Within each zone, the path between each pair of nodes u, v is stored and frequently updated proactively. Between zones, single-zone paths are reactively concatenated to form an optimal path. This reduces the total amount of message delivery by resorting to reactive routing only when necessary. The concept of zones has been shown to be a valid network scalability tool in [7] and [8].

3. Z-BAR algorithm

The Z-BAR algorithm partitions a traffic network into multiple zones. Routes within each zone are proactively maintained by routing tables, while routes between zones are evaluated reactively. A zone consists of all nodes within a radius r of some center node. This includes the edges between all member nodes. The radius of a node is determined by the number of hops required to reach the node from the center. Fig. 1 shows a zone system with a radius of 2. If a node is exactly r hops away from its center, it is designated a border node. Border nodes are responsible for maintaining the paths between all of the zones in which they belong. The Z-BAR algorithm is divided into three components: zone formation, route maintenance and route discovery.

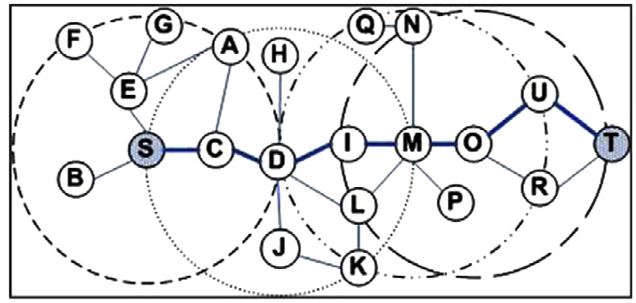

Fig. 1. Example of multi-zone routing.

3.1. Zone formation

The first step of Z-BAR is the division of the road network into zones. Each zone manages its routes with an intrazone routing table. The intrazone table stores the optimal path between each pair of nodes within a zone. Routing tables are allocated on zone creation and populated during route maintenance. The zone formation step of Z-BAR proceeds until the network is fully covered by zones. Zone formation considers each node in the network, corresponding to vertices in a graph *G*. Nodes not yet part of any zone are designated the center of the next zone, which is formed by a breadth-first search starting at the center node and extending to r hops. This continues until all nodes belong to at least one zone. Zone formation guarantees that the path between every pair of nodes in the network is covered by some combination of zones.

3.2. Route maintenance

Once the network has been divided into zones, each intrazone table is populated and regularly maintained. Routing tables store the optimal path between each pair of nodes within a zone. On a designated time interval, each zone updates its routing table based on fresh traffic data. This data is gathered by a peer-to-peer system such as a Vehicular Ad-Hoc Network (VANET). Dividing the network into zones eliminates the need for a central routing authority. Frequent routing table updates allow zones to capture the pseudostatic nature of traffic networks: the network topology is constant while the weight of each edge is subject to change. Route maintenance covers each zone on a regular schedule. This may correspond to daily, hourly, or minute-by-minute updates. The update schedule of routing tables may be adjusted depending on past and expected traffic fluctuations within the zone. Since intrazone routes are not dependent on other zones or any shared resources, the update procedure of each zone's routing table may be executed in parallel and distributed across multiple processors. Optimal paths between each pair of nodes u, v within the zone are discovered by the Floyd–Warshall algorithm. The route

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