Dynamic Time-Dependent Routing in Road Networks Through Sampling

Feb 2020

Motahhareh Nadimi

Abstract

The earliest arrival in road networks with:

- TIME DEPENDENT functions
- DYNAMIC UPDATES
- It compute with SMALL ERROR
- Doesn't suffer from MEMORY LACK on large instances
- This algorithm is the only that is able to answer to queries below 50 ML

Introduction

The road network is a weighted graph, directed graph :

Nodes: positions

Edges : road segments

Weight : travel time a car need to traverse the road segments .

A common assumption : travel times are time independent

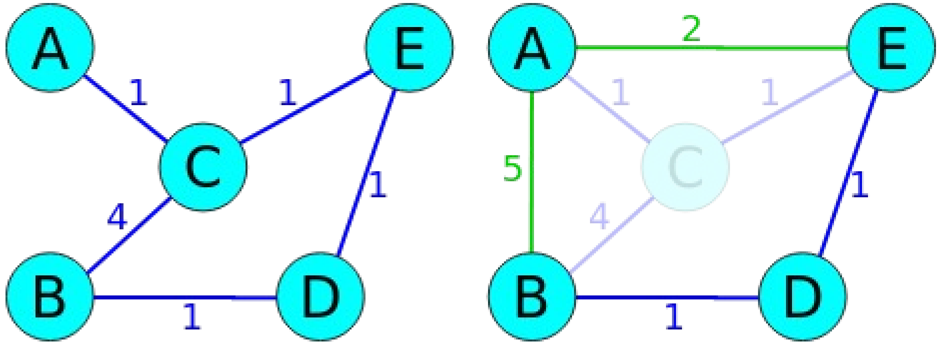
Result: Traditional algorithms for finding such routes include Dijkstra's Algorithm and the A* algorithm.

Problem : road networks are huge and this algorithm is slow!

Recap contraction Hierarchies

Pre processing the graph by "contracting" the nodes one at a time(iterative vertex contractions)

When contracting a vertex V t is temporarily removed from the graph G, and a shortcut is created between each pair { u , w } of neighboring vertices if the shortest path from u to w contains v



Computing Errors

When taking predicted congestion into account, many proposed algorithms compute paths with an error

The routing problem with no congestion and with only real time congestion can be solved efficiently and exactly, the computed paths are shortest paths

Let **d** denote the length of the computed path and **dopt** the length of a shortest path

Absolute error: $|d - dopt|$

Relative error : $|d - dopt| / dopt$.

Computing Errors

Unfortunately, the predictions do not quantify **uncertainties**.

and uncertainty is huge: The time a typical German traffic light needs to cycle though its program is between 30s and 120s and Traffic lights often adapt to the actual real time traffic.

PROBLEM DEFINITION

The input of earliest problem:

NODES > S AND T

Departure time > s

The task is consist of computing **ST- path with minimum arrival time.**

TD: Free Flow Heuristic: A solution to time-independent routing problem

TD-S : Solve the earliest arrival problem with **predicted congestion**

TD-S+P : solve **profile** problem

TD-S+D: take **real time congestion** into account

PROBLEM DEFINITION

Assuming that edges are weighted by a travel time function.

Predicted congestion are usually modeled using functions as edge weights. Every edge e is associated with a function fe(x) that maps the entry time x of a car into e to the travel time

fe (x)

PROBLEM DEFINITION

Earliest arrival problem:The input of the earliest arrival problem consists of nodes s,t, and a departure time τ. The task consists of computing a st-path with minimum arrival time

Profile problem:The input of profile problem consists only of s and t. The output consists of a function that maps a departure time onto the corresponding minimum arrival time.

Solve the earliest arrival time problem for every departure time

TD routing algorithm : Free flow Heuristic

The free flow travel time along an edge is the minimum travel time over the whole day.

The free flow travel time along an edge assumes that there is no congestion. Formally, the free flow travel time of an edge e is the minimum value of e’s travel time function fe.

Step	Find the **shortest** time independent **path H with respect to the Free flow travel time**	Compute **time** dependent travel time along **H given departure time (sampling) - use function in this step**

The first step can be fasten using any time independent speed up: such as CH

Avg flow heuristic : the same but it use average travel time

The Free flow Heuristic

Free flow never reroutes based on the current traffic situation

The main problem is that the computed paths can potentially differ significantly from the optimal ones.

The computed solutions can have a significant error.

The Algorithm : TD-S

Pre processing phase

1	Fix a small set of time intervals called time windows. Better k <=10
2	In each time window for every single edge compute the **average travel time** in that window
3	For Each time window make a **time-independent graph using speed up technique**

It s time independent
Because we calculate avg

TD-S

Query phase

1	For every graph they compute a shortest time independent path St-path using CH and mark the edges in the path. UNION OF THESE PATHS: SUB GRAPH H
2	Compute a shortest time-dependent path in the original graph restricted to the marked edge

time-dependent extension of Dijkstra’s algorithm restricted to thesubgraph H.

Computing profile: TD-S+P

For a sampling rate of 10min, the algorithm would mark the edges as for TD-S

Then run the time-dependent extension of Dijkstra's algorithm restricted to the marked edges with the departure times 0:00, 0:10, 0:20...23:50

The algorithm is fast because they only have to mark the edges once then run the time-dependent search numerous times.

TD-S+P

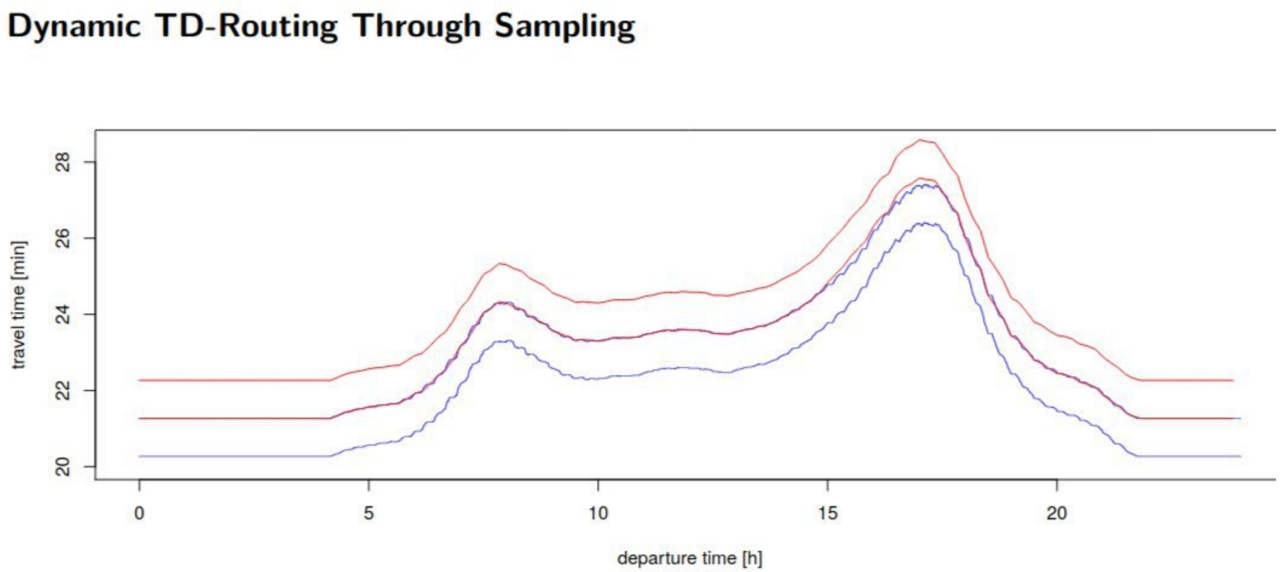


Figure 2

Example profile over 24h. The red curve (top) was computed with TD-S+P, while the blue one (bottom) is the exact solution. The middle overlapping curves are the actual profiles.

TD-S+D

TD-S and TD-S+P work with predicted congestion. However, in many applications we must also take real time congestion into account

Adapting TD-S by **modifying the computation of the sub graph H** yielding TD-S+D.

TD-S+D

The sub graph H is the union of k paths

TD-S+D adds a shortest st-path according to the current real time traffic as k+ 1-th path to the union.

A efficient solution to the routing problem with real time congestion is needed. (cch)

TD-S+D

Pre processing

In the pre processing step, TD-S+D computes one CCH in addition to the k CHs of TD-S.

query

The sub graph H is the union of the k+ 1shortest paths. Finally, the time-dependent extension of Dijkstra's algorithm is run restricted to the sub graph H

Simulating Traffic

Unfortunately, they do not have access to good measured real time traffic. they simulate real time congestion to study the performance of TD-S+D

Simulating Traffic

- For an earliest arrival time query from s to t with departure time τ, they **first compute the shortest time-dependent path P** with respect to the historic travel times
- On path P they **generate three traffic congestion** by picking three random start edge.
- **From each of these edges they follow P for 4min**, yielding three sub paths
- For every edge e in a sub path, they generate a congestion

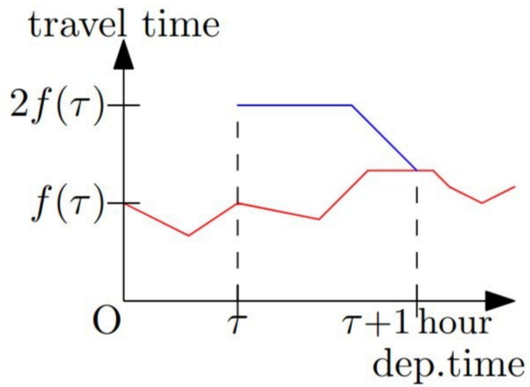
Simulating Traffic

1- Travel time function f of e

2- by doubling the travel time at f(τ)and assume that it remains constant for some time

3- The congestion should be gone at τ+ 1h.

4- FIFO-property :the modified function must have slope of -1 before τ+ 1 before joining the predicted travel time



The number of exactly solved queries decreases with instance size as the A longer path has more opportunities for errors

the absolute errors grow with instance size as the paths get longer

as most queries are answered exactly with TD-S

TD-S+4 has larger errors as it uses fewer time windows.

Table 2 Number of exact time-dependent queries and absolute and relative errors for Freeflow, TD-S+4, and TD-S+9. "Q99" refers to the 99%-quantile and "Q99.9" the 99.9%-quantile.

		Exact	Relative Error [%]				Absolute Error [s]			
Graph	Algo	[%]	Avg	Q99	Q99.9	Max	Avg	Q99	Q99.9	Max
Lux	Freeflow	80.0	0.244	5.1	11.5	28.1	5.0	106	235	356
Lux	Avgflow	81.0	0.123	2.5	6.4	19.4	2.5	49	143	329
Lux	TD-S+4	97.7	0.008	0.2	1.5	4.9	0.2	4	30	141
Lux	TD-S+9	99.6	<0.001	0.0	0.1	1.7	<0.1	0	3	27
Ger	Freeflow	67.9	0.085	1.5	3.1	12.4	11.1	200	417	825
Ger	Avgflow	69.2	0.044	0.8	1.9	10.3	5.9	113	284	587
Ger	TD-S+4	94.6	0.005	0.1	1.0	3.0	0.8	17	159	474
Ger	TD-S+9	98.2	0.001	<0.1	0.4	3.0	0.3	1	76	374
OGer	Freeflow	60.7	0.140	2.0	4.7	12.4	15.9	219	465	1 104
OGer	Avgflow	68.8	0.050	0.9	2.2	6.5	5.7	96	227	619
OGer	TD-S+4	96.4	0.002	0.1	0.4	2.0	0.3	6	47	333
OGer	TD-S+9	98.5	0.001	<0.1	0.2	2.0	0.1	1	24	276
CEur	Freeflow	54.9	0.089	1.4	2.7	10.8	26.4	428	833	1 477
CEur	Avgflow	55.8	0.048	0.8	1.7	6.6	14.2	235	507	1 069
CEur	TD-S+4	91.1	0.006	0.2	0.7	3.8	1.8	47	226	547
CEur	TD-S+9	96.8	0.001	<0.1	0.3	1.2	0.5	6	109	397

Time Window

TD-S with two selections of time windows:

TD-S+4 uses the windows 0:00–5:00, 6:00–9:00, 11:00–14:00, and 16:00–19:0

TD-S+9 uses the windows 0:00–4:00,5:50–6:10, 6:50–7:10, 7:50– 8:10,

10:00–12:00, 12:00–14:00, 16:00–17:00, 17:00–18:00

the query running times and the memory of TD-S+4 are lower.

TCH is lacking from memory .they couldn't run on 128 gig

TD-S+4 only needs about 2.4 times the memory required by the input.

TD-S+9 needs 4.1 times the memory.

TD-S+4 has lower pre processing time than TCH

Table 3 Average preprocessing and running times and memory consumption of various algorithms.

Graph	TD-Dijkstra	Freeflow	Avgflow	TD-S+4	TD-S+9	TCH
Average Query Running Time [ms]						
Lux	4	0.02	0.02	0.11	0.26	0.18
Ger	1 116	0.19	0.20	0.99	3.28	1.81
OGer	813	0.12	0.14	0.97	2.09	1.12
CEur	4 440	0.42	0.29	3.83	6.85	OOM
Max. Query Memory [MiB]						
Lux	13	17	17	29	47	328
Ger	1 550	2 132	2 130	3 630	6 127	42 857
OGer	461	855	854	1 880	3 589	8 153
CEur	4 980	7 058	7 053	12 411	21 336	>131 072
Total Preprocessing Running Time [min]						
Lux	—	<0.1	<0.1	<0.1	0.1	0.6
Ger	—	1.6	2.2	7.6	14.7	86.2
OGer	—	1.5	1.6	5.9	16.4	26.8
CEur	—	8.6	8.1	33.9	70.7	381.4

Table 4 Average 24h-profile running times in milliseconds. "SubG" is the subgraph comp. time.

	Freeflow		Avgflow		TD-S+P4		TD-S+P9	
Graph	SubG.	Total	SubG.	Total	SubG.	Total	SubG.	Total
Lux	<0.1	2.6	<0.1	2.6	0.1	3.0	0.3	3.4
Ger	0.2	18.1	0.2	18.3	0.7	19.5	1.7	22.2
OGer	0.1	10.0	0.1	9.5	0.8	11.2	1.8	12.4
CEur	0.4	36.8	0.4	36.8	2.1	49.9	5.3	53.4

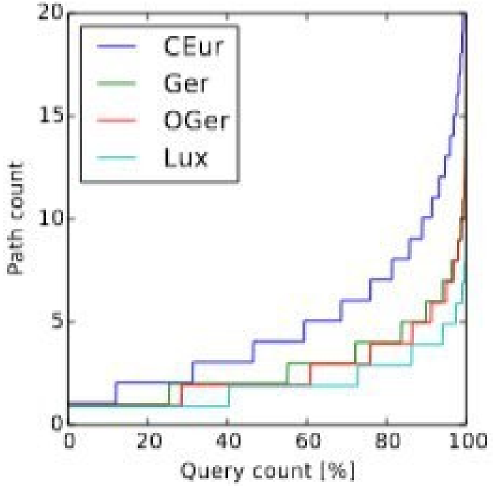


Figure 5 The number of optimal paths (y-axis) in function of number of queries (x-axis) for a 24h-profile of TD-S+P9.

Dynamic Time-Dependent Routing

In the dynamic scenario, we consider two types of congestion:

(a) the predicted congestion.

(b) the real time congestion.

The Predicted Path heuristic (Predict. P) as baseline, TD-S+D4, and TD- S+D9.

The Predicted Path heuristic computes a shortest path P with respect to only the predicted congestion NOT REAL TIME CONGESTION

P then is then evaluated with respect to both congestion types TD-S+D4, and TD-S+D9.

Predicted Path P

Free flow and Predicted Path are similar in spirit.

Free flow solves the time-dependent routing problem by **ignoring predicted congestion**.

Similarly, Predicted Path solves the dynamic time-dependent routing problem by **ignoring real time congestion.**

The Free flow heuristic produces surprisingly small errors

On the Luxembourg instance only 1.6% of the queries are solved optimally.

TD-S+D reduces these errors.

The minimum number of optimally solved queries is 92.9%.

Graph	Algo	Exact [%]	Relative Error [%]				Absolute Error [s]			
			Avg	Q99	Q99.9	Max	Avg	Q99	Q99.9	Max
Lux	Predict.P	1.6	17.228	56.1	75.0	93.8	323.0	739	826	997
Lux	TD-S+D4	94.7	0.017	0.5	2.3	6.2	0.6	15	93	231
Lux	TD-S+D9	95.0	0.016	0.5	2.2	6.2	0.5	14	89	231
Ger	Predict.P	55.1	1.2	17.9	36.9	79.3	78.5	552	741	1 001
Ger	TD-S+D4	90.9	0.032	1.0	2.6	7.0	3.5	116	233	474
Ger	TD-S+D9	93.4	0.026	0.9	2.5	6.2	2.8	99	216	469
OGer	Predict.P	52.3	1.352	18.7	38.3	65.8	84.9	563	738	934
OGer	TD-S+D4	91.5	0.031	1.0	2.6	5.4	3.2	108	224	462
OGer	TD-S+D9	92.9	0.028	0.9	2.5	5.4	2.9	102	219	462
CEur	Predict.P	72.6	0.392	7.0	25.9	81.9	41.0	443	653	1 870
CEur	TD-S+D4	89.5	0.015	0.5	1.6	5.2	3.3	106	244	547
CEur	TD-S+D9	94.0	0.011	0.3	1.4	5.2	1.9	69	205	397

Number of exact dynamic, time-dependent queries and absolute and relative errors for the predicted path, TD-S+D4, and TD-S+D9.

Table 7 Comparison of earliest arrival query algorithms. "n/r" = not reported. We report the running times as published in the corresponding papers (ori) and scaled by processor clock speed.

A*
CONTRACTION
ARC-FLAGS
LINK AND MERGE
+ Large memory

	Numbers from		Link & Merge?	Relative Error [%]			Run T. [ms]	
				avg.	Q99.9	max.	ori	scaled
TDCALT-K1.00	[10]	OGer	•	0	0	0	5.36	3.77
TDCALT-K1.15	[10]	OGer	•	0.051	n/r	13.84	1.87	1.31
eco SHARC	[8]	OGer	•	0	0	0	25.06	19.7
eco L-SHARC	[8]	OGer	•	0	0	0	6.31	5.0
heu SHARC	[8]	OGer	•	n/r	n/r	0.61	0.69	0.54
heu L-SHARC	[8]	OGer	•	n/r	n/r	0.61	0.38	0.30
TCH	Tab. 3	OGer	•	0	0	0	1.12	
TDCRP (0.1)	[6]	OGer	•	0.05	n/r	0.25	1.92	
TDCRP (1.0)	[6]	OGer	•	0.68	n/r	2.85	1.66	
Freeflow	Tab. 2 & 3	OGer	○	0.140	4.7	12.4	0.12	
Avgflow	Tab. 2 & 3	OGer	○	0.050	2.2	6.5	0.14	
FLAT-SR_{2000}	[22]	OGer	○	1.444	n/r	n/r[3]	1.28	1.18
CFLAT-BC3K+R1K,N=6	[23]	OGer	○	0.031	n/r	19.154	4.10	4.73
TD-S+4	Tab. 2 & 3	OGer	○	0.002	0.4	2.0	0.97	
TD-S+9	Tab. 2 & 3	OGer	○	0.001	0.2	2.0	2.09	

51 GB
16.1 GB
1.8 GB

Conclusion

Introducing TD-S, a simple and efficient solution to the earliest arrival problem with predicted congestion on road graphs.

We extend it to TD-S+P which is the only algorithm to solve the profile variant in at most **50ms** on all test instances.

Further, we demonstrated with TD-S+D that additional real time congestion can easily be incorporated into TD-S.