Dynamic Time-Dependent Routing in Road Networks Through Sampling

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Abstract

Studying 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 as 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

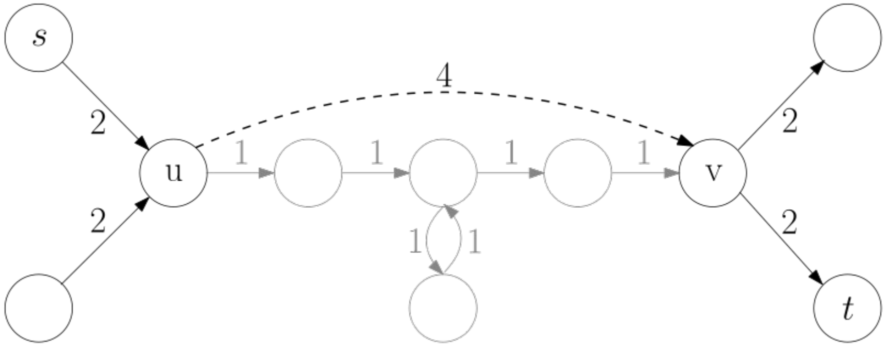
Result: problem will be a classical shortest path problem

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

Solution: contraction hierarchy (CH)

contraction Hierarchies

Contraction hierarchies (CHs) are a well-known algorithm for fast and exact route planning on road networks with constant travel costs



To find a path from s to t the algorithm can skip over the Grey vertices and use the dashed shortcut instead. This reduces the number of vertices the algorithm has to look at.

Overview on contraction Hierarchies

contraction Hierarchies:

- skip over unimportant vertices
- road networks are highly hierarchical. for example highway , are "more important" and higher up in the hierarchy than for example a junction leading into a dead end. the algorithm doesn't have to consider the full path at query time.

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.**

We want a routing system that accounts for predicted and real time congestion (dynamic time dependent routing)

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

Computing Errors

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

A shortest path with respect to the prediction is not necessarily shortest with respect to reality.

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.

Free flow Heuristic

A solution to the time-independent routing problem

assumption	**No Congestion**	The min value of e’s travel **time function** of fe
Step	Find the shortest time independent **path H**	Compute **time** dependent travel time along **H given departure time**

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

Free flow Heuristic

Sampling means the variety of departure time in free flow

TD-S

Free flow never reroutes based on the current traffic situation

Steps

1 Compute sub graph H

2 Run time dependent extension of Dijkstra algorithm on sub graph

Compute the sub graph using a sampling approach

TD-S

1	Define a constant number of **K** time intervals Better k <=10
2	For every interval : obtain a time – independent **graph** !

3	within each time intervals **average the time dependent travel times.**

IN STEP 3, THEY USE A SAMPLING APPROACH,
AVG THE TIME DEPENDENT TRAVEL TIME WITHIN EACH INTERVAL
FOR EX: 7:10, 7:15 , 7:50

TD-S

4	For every interval : obtain a time – independent **graph** !
5	For every graph we compute a shortest time independent **path**
6	The **union** of these paths is the sub graph H

It s time independent
Because we calculate avg

They use Dijkstra here !

TD-S

They compute for each time-interval
a time-independent CH

The first step of TD+S executes k CH-queries.

Computing profile: TD-S+P

Steps	1	Compute sub graph H
	2	Sample at regular intervals the travel time by running the time-dependent extension of Dijkstra's algorithm restricted to the sub graph H.

Just for example
For a sampling rate 10 minute

The sub graph computation step is the same as for TD-S.

TD-S+P

For a sampling rate of 10min,

1- algorithm first computes the sub graph H,

2- then runs Dijkstra's algorithm with the departure times 0:00, 0:10, 0:20...23:50 restricted to H.

Denote by a1, a2, a3...a144 the computed arrival times.

For example, the computed arrival time for departure time 0:07 is 0.3 a1+ 0.7 a2

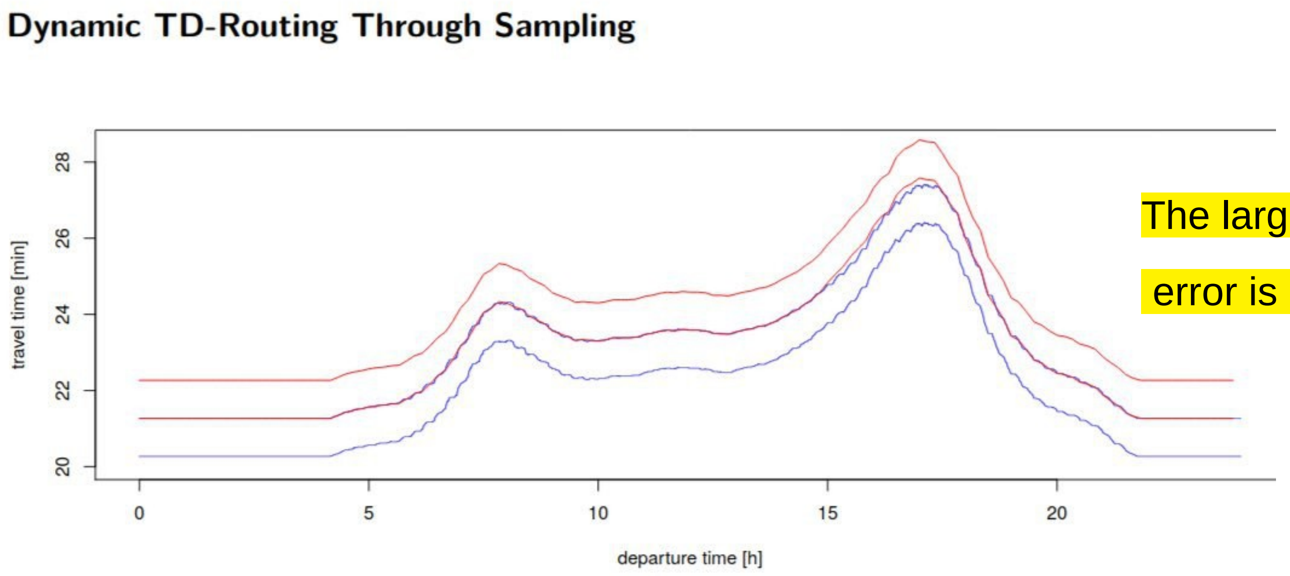
TD-S+P

TD-S+P is faster than iteratively running TD-S as the sub graph is only computed once.

Further, Dijkstra’s algorithm iteratively runs on the same small sub graph H.

The first run loads H into the cache and thus all subsequent runs incur nearly no cache misses

TD-S+P



The largest absolute

error is 19s,

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. To improve readability

TD-S+D

However, in many applications we must also take real time congestion into account.

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

2-The second step is left unchanged

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. They use CCH algorithm .

TD-S+D

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

At regular time intervals, such as every 10s, TD-S+D updates the CCH edge weights to reflect the real time traffic situation

A TD-S+D query consists of running k CH queries and one CCH query.

The sub graph H is the union of the k+ 1 shortest paths. Finally, Dijkstra's algorithm is run 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, we **first compute the shortest time-dependent path P** with respect to the historic travel times
- On P we **generate three traffic congestion** by picking three random start edges.
- **From each of these edges we follow P for 4min**, yielding three sub paths

Simulating Traffic

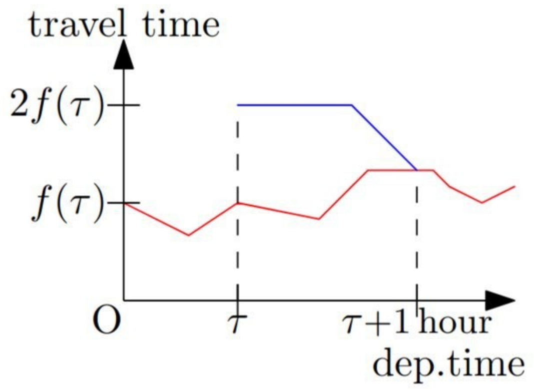
1- Travel time function f of e

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

5- ON THIS 2f(τ)< f(τ+ 1h), we do not generate a congestion.



The number of exactly solved queries decreases with instance size as the paths lengths grow with size

as most queries are answered exactly.

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

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

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.

Graph	Algo	Exact [%]	Relative Error [%]				Absolute Error [s]			
			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

Analysis

TD-S with two selections of time windows:

TD-S+4 uses the windows0:00–5:00, 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 footprint of TD-S+4 are lower.

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

TD-S+4 only needs about2.4 times the memory required by the input. TD-S+9 needs 4.1 times the memory.

TD-S+4has an about a factor 10 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

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

TD-S+D reduces these errors. Over all instances, 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

Table 6Number of exact dynamic, time-dependent queries and absolute and relative errors for the predicted path, TD-S+D4, and TD-S+D9.

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

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.