Paratransit for the Masses: Can Technological Advances Mainstream this Niche Mode?

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Thinking Outside the Bus …

Let us say we have inter-galactic outsourcing ..

We give a consulting contract for mass transit solutions to aliens from an advanced civilization in an icy frictionless planet …

They have advanced technology for communication, computing and OR .. But “wheels”? – well, no clue …

Would they suggest fixed routes and schedules for mass transit?

Motivation

Aliens – *It is the information, stupid!* Get rid of the 20th century schemes with no information technology...

- Solution: Observe in real time, see where the vehicles and passengers are, where they want to go and simply optimize the system - using “intergalactic advanced technology and mathematics”
- General pick-up and delivery problem with random- dynamic demand in time and space (you may find some of the current routes and schedules in the solutions too!)
- High-coverage with vehicles: High responsiveness

Motivation

- Our Premise – What is called “paratransit” now, at a much larger scale, could really be the “mass transit” of the future.
- The need for fixed routes and schedules for public transport comes mainly from lack of real-time information on travel demand, and transportation supply, and the inability to use the info even if we know it.
- *High Coverage Point to Point Transit (HCPPT*) or P8 PPPPPPPP – ***Point to Point Passenger-Pooled Person-based Public- Private- Para- Transit***
- High-coverage of vehicles is a necessity for transit to be competitive. Can we run taxi/shuttle type service?

Motivation: A New RTRT Design

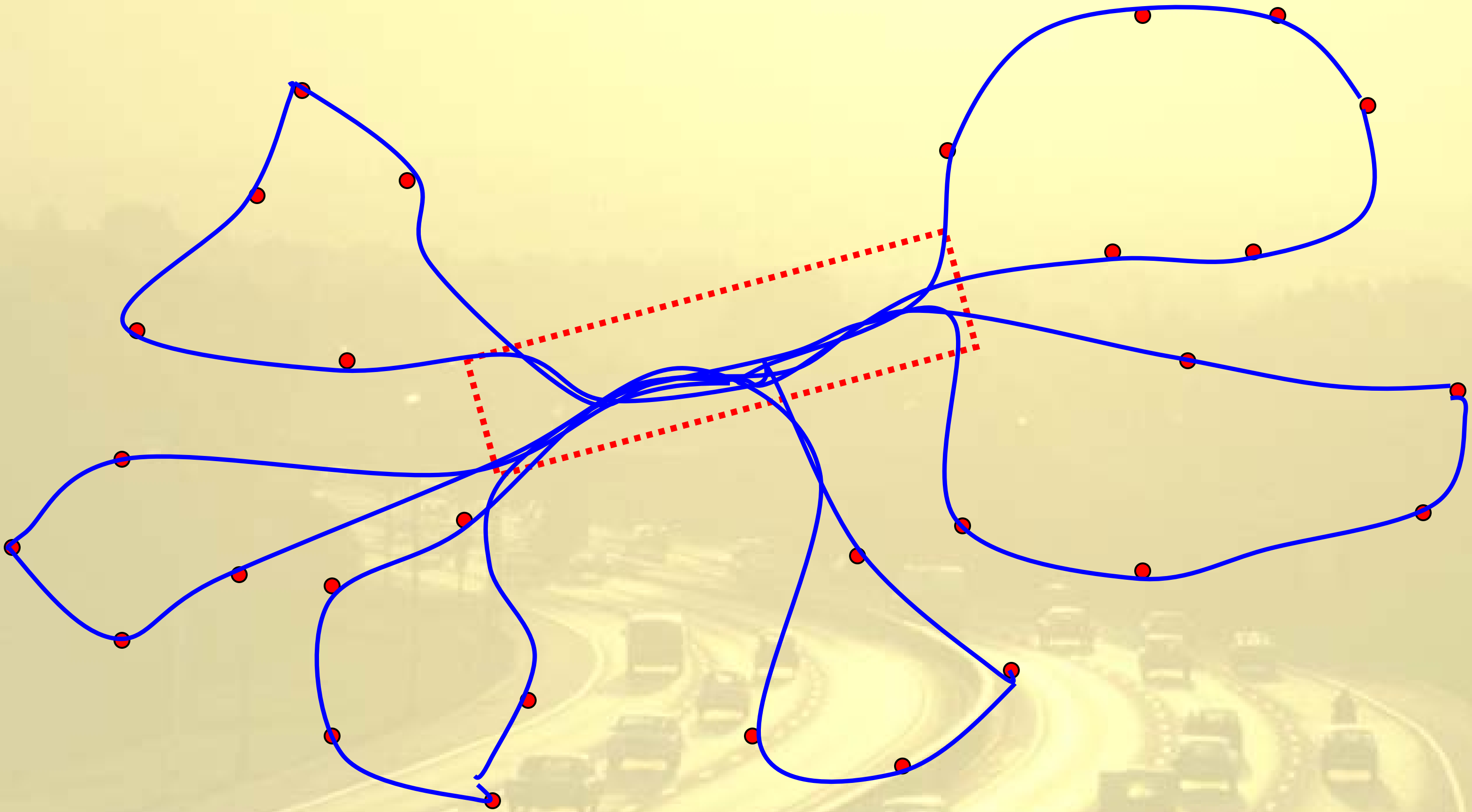
High Coverage Point to Point Transit (HCPPT)

- Uses complete information on passenger requests and vehicle positions in real time
- Shared rides
- Smaller vehicles
- Large fleet and “High coverage” (can include taxi company vehicles too)
- Passengers can “pool” at pick-ups but with different destinations

- Complete VRP optimization (say 1000+ passengers per hour served by 100s of vehicles) – nearly impossible
- Certain system designs and decomposition schemes with route-insertion type local optimization needed.

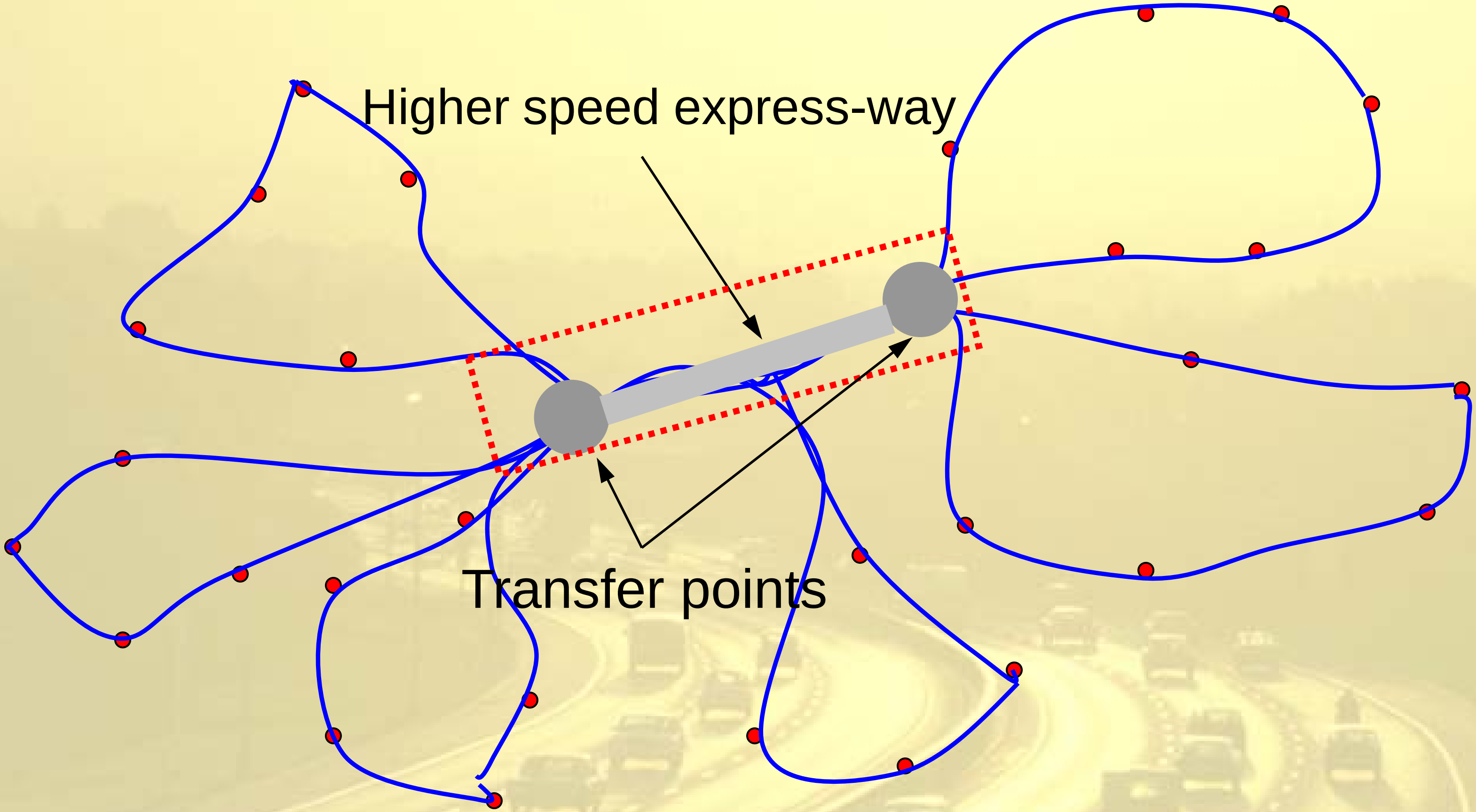
Vehicle Routes

Optimal solution would look like this (m-TSP tours)



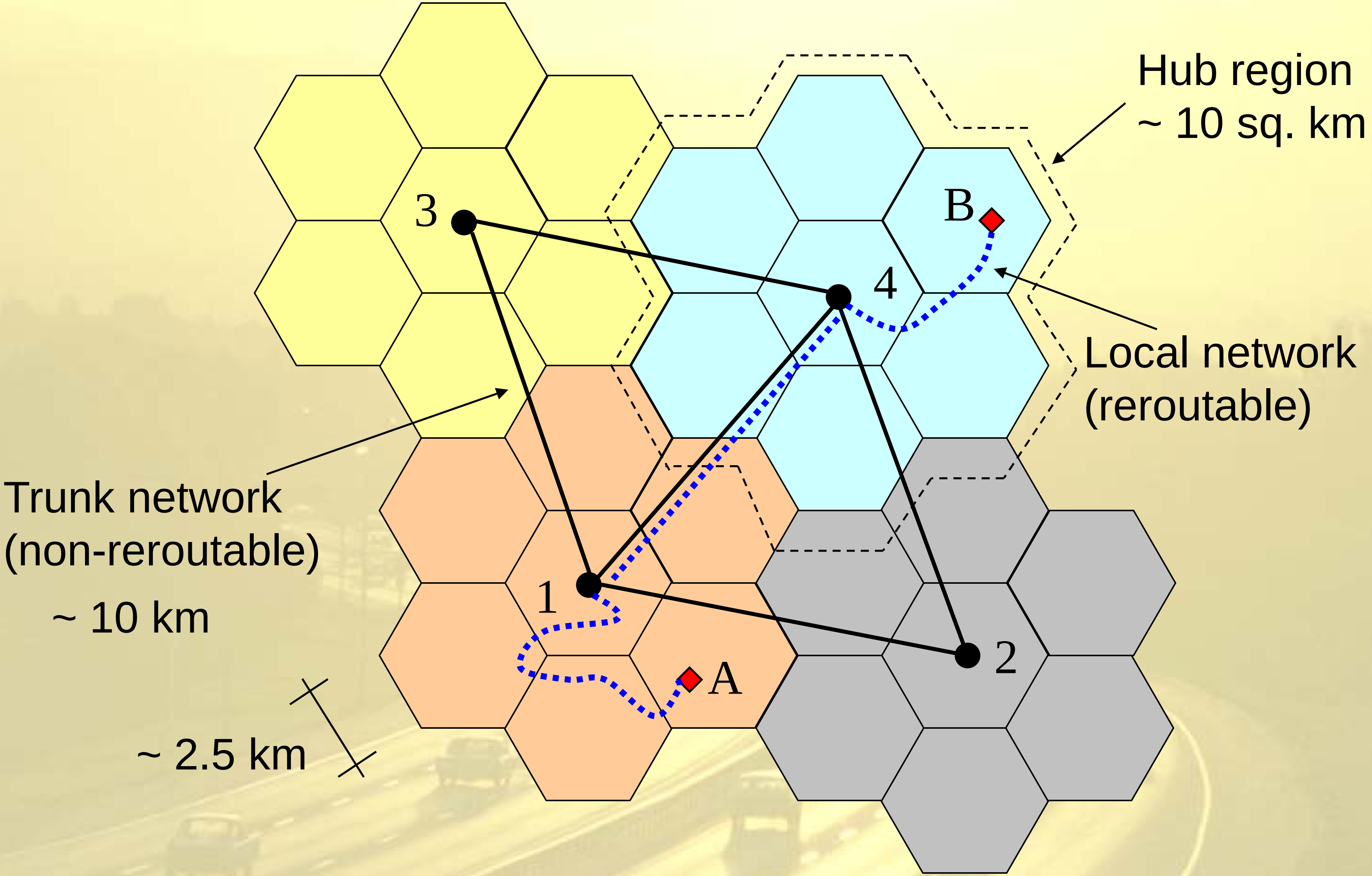
Vehicle Routing

Restrict the solution to a specific design
One way to efficiently use vehicle seats

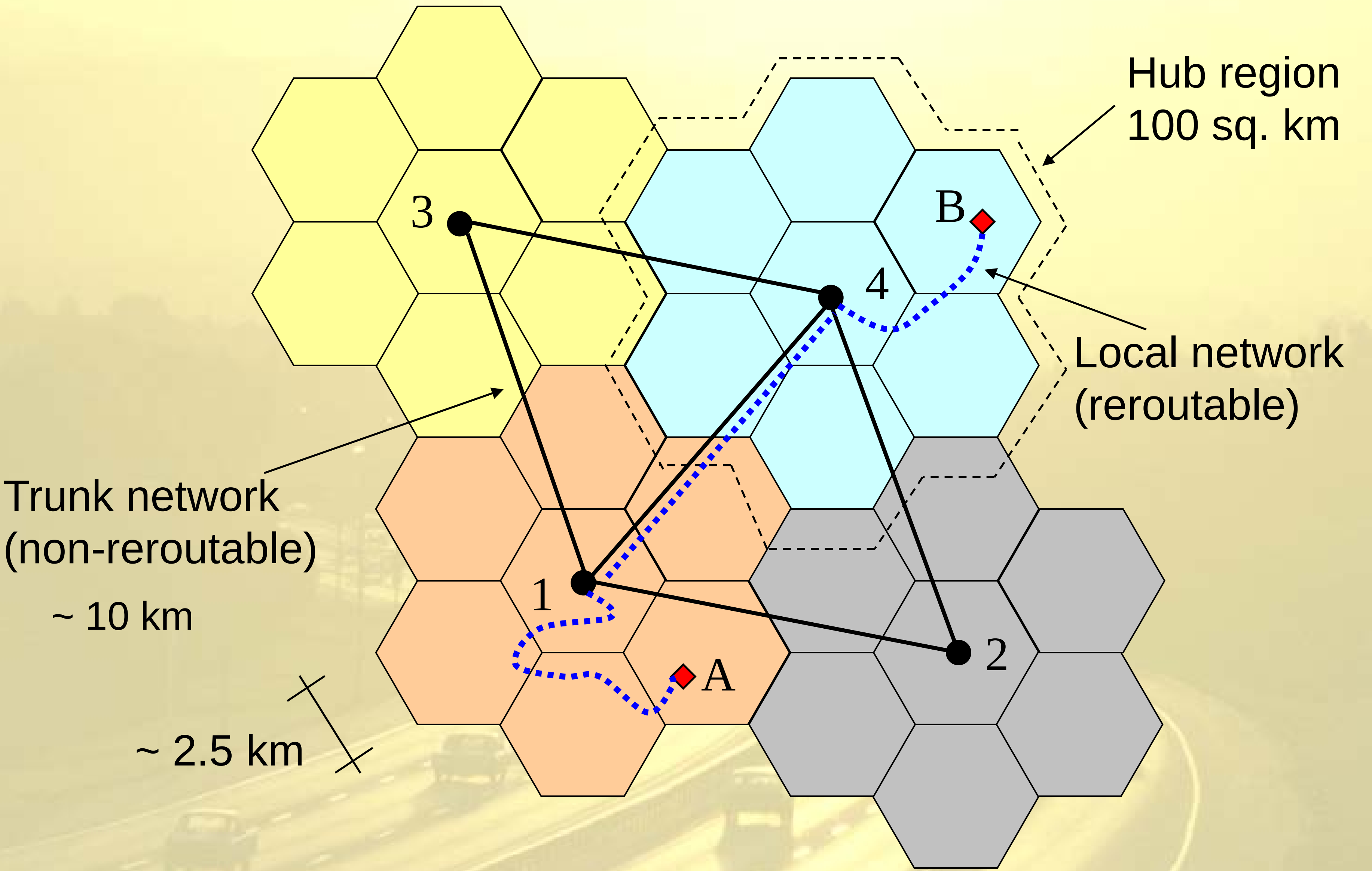


Problem: Two transfers needed

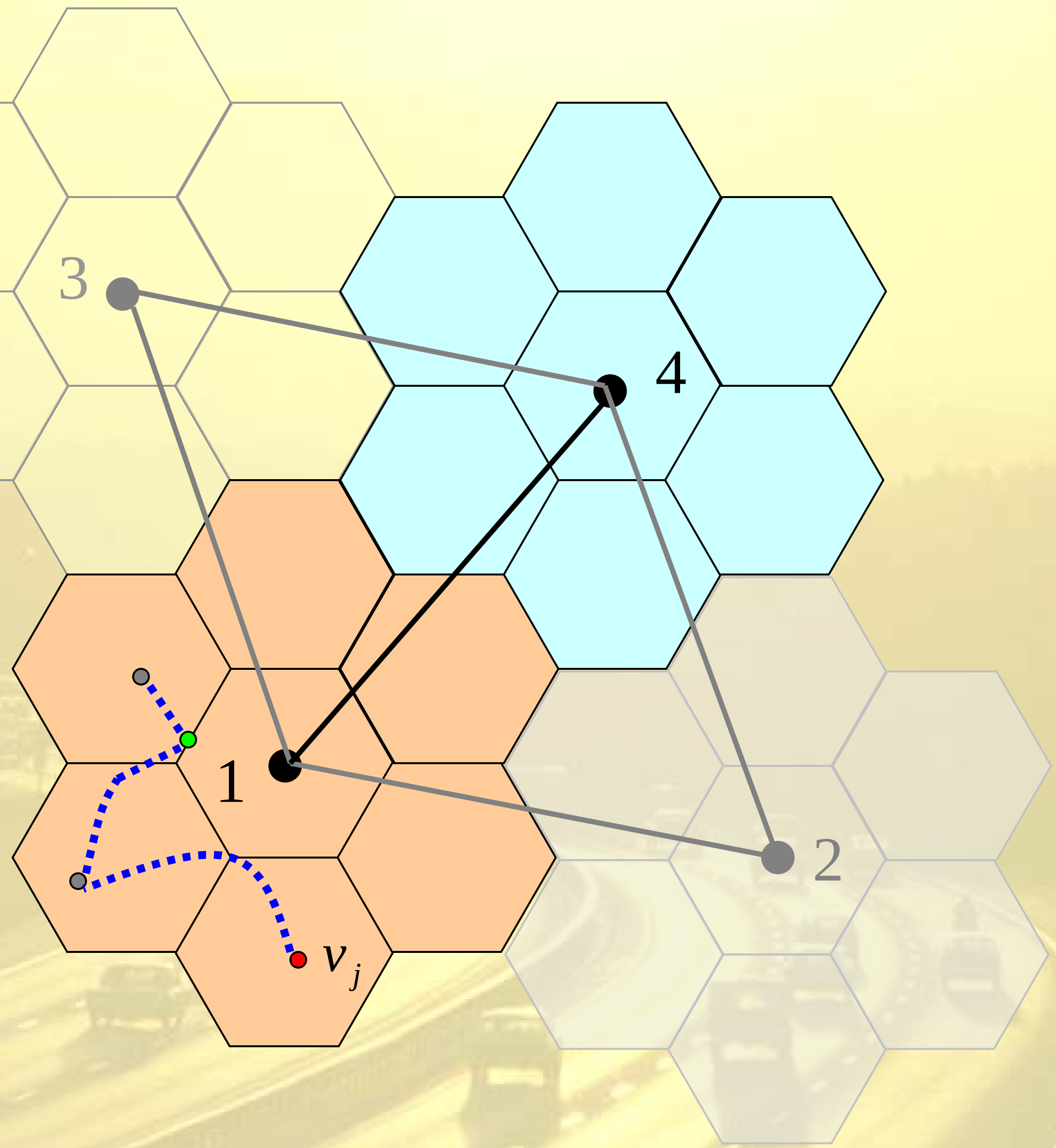
The proposed concept



The proposed concept

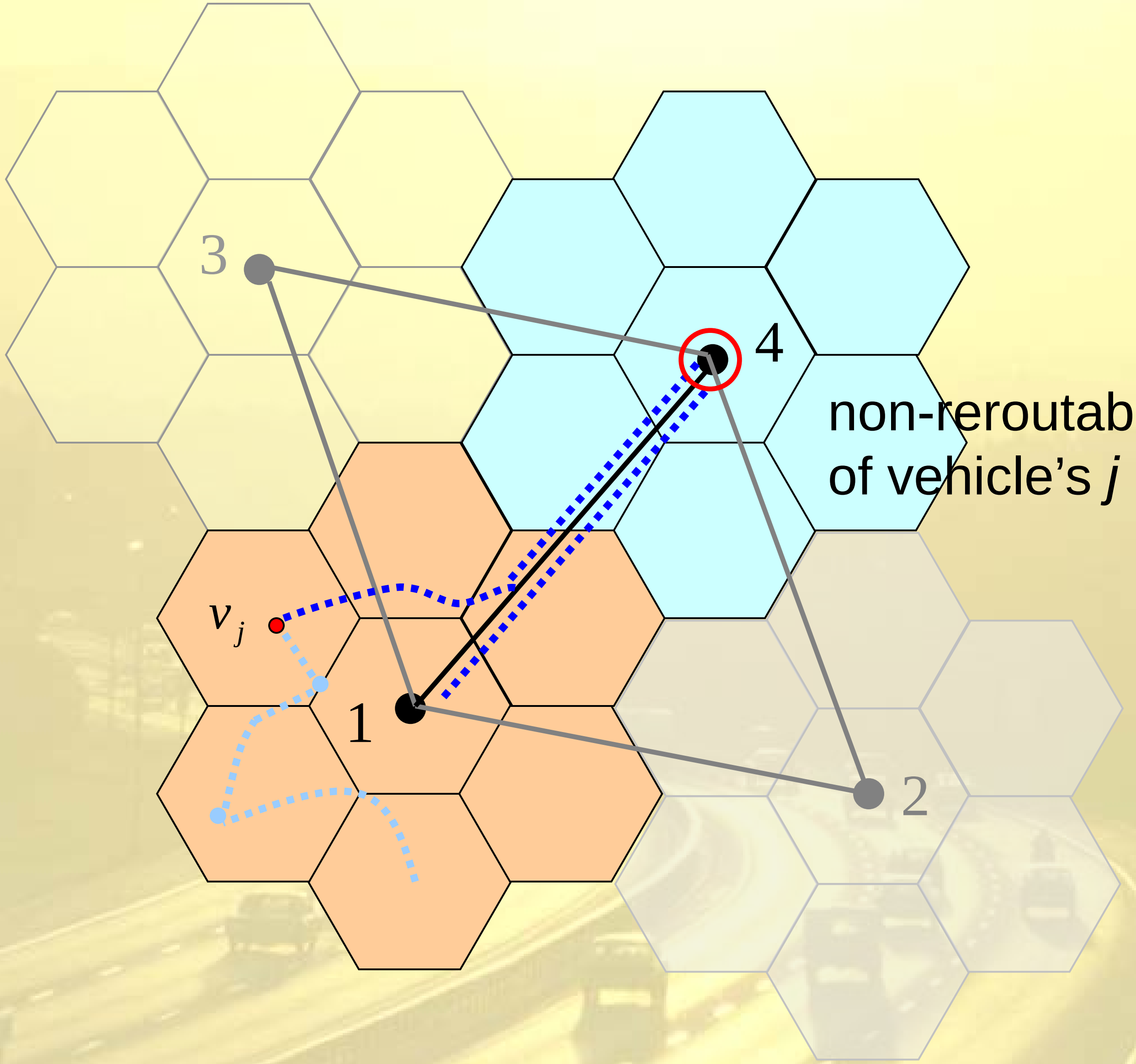


Operation of HCPPT vehicles

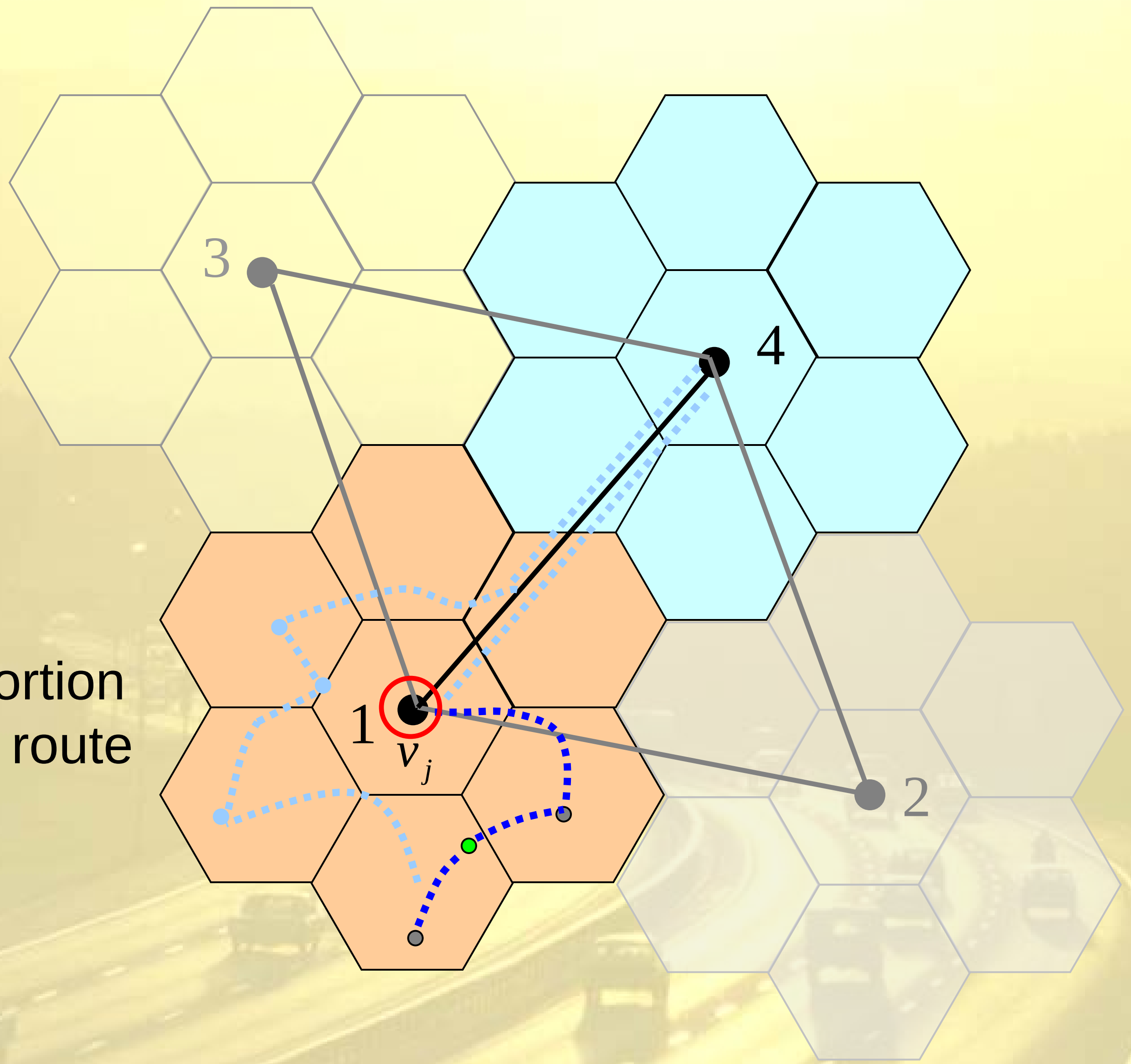


reroutable portion
of vehicle's *j* route

Operation of HCPPT vehicles



Operation of HCPPT vehicles



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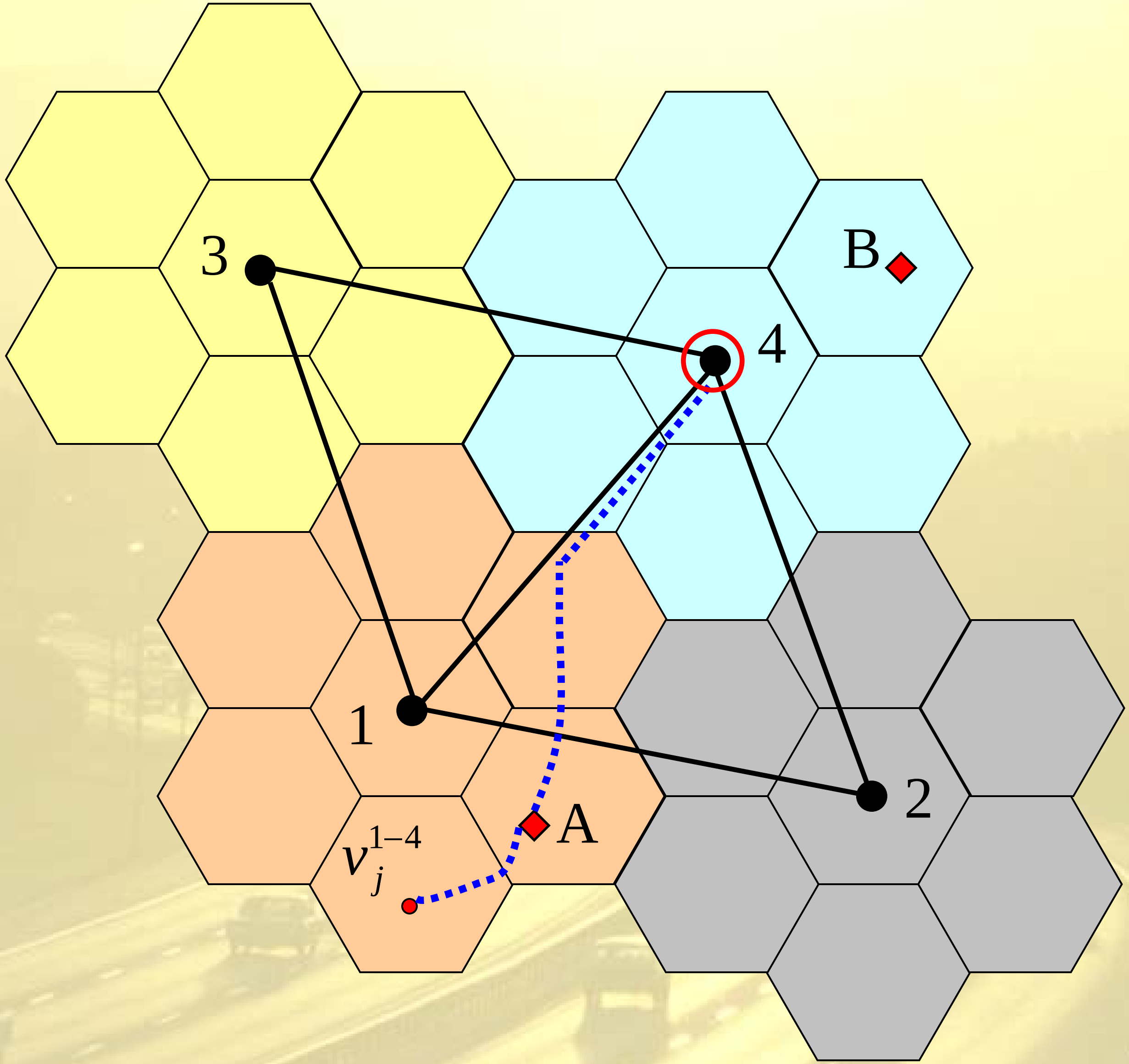
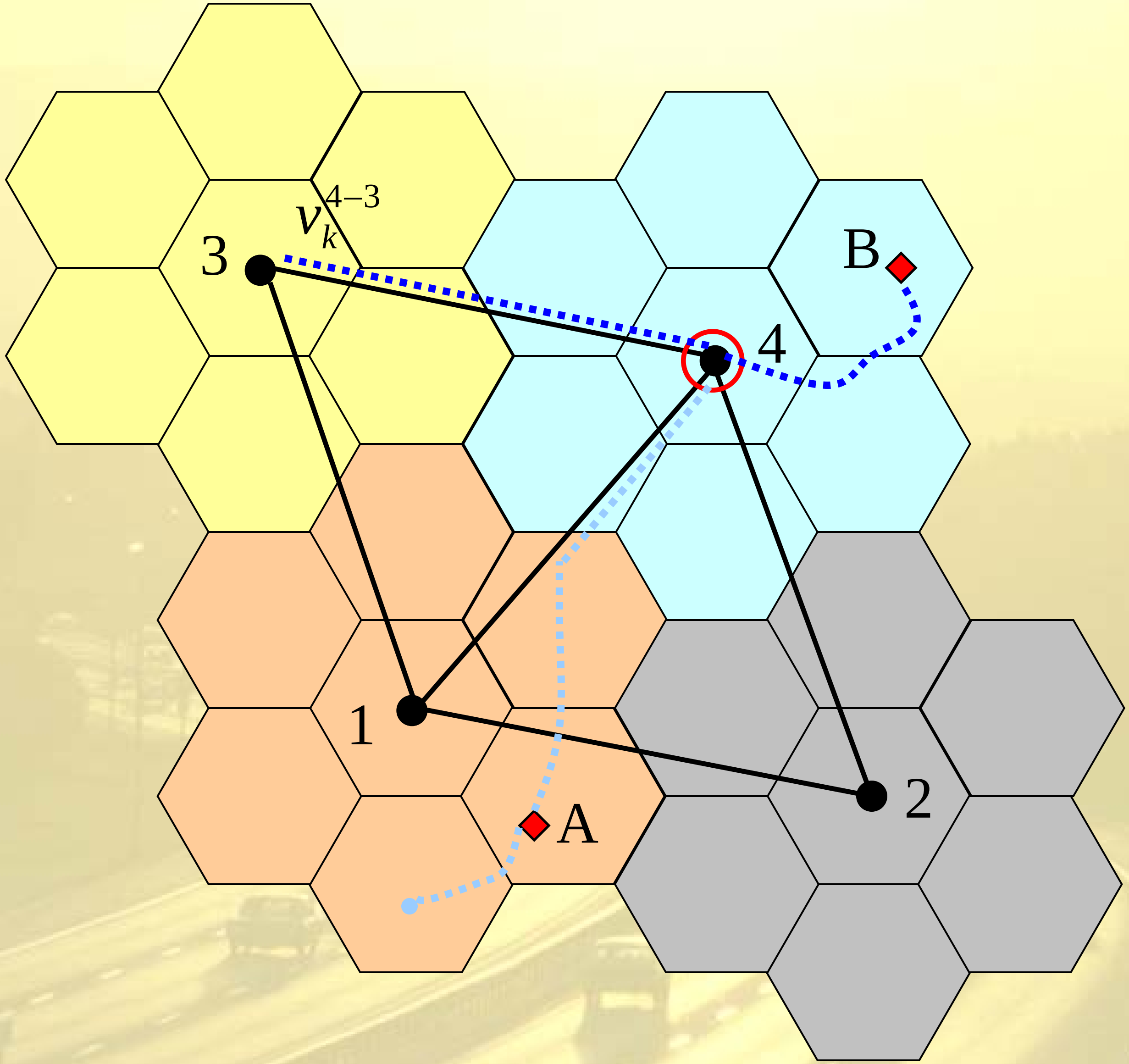
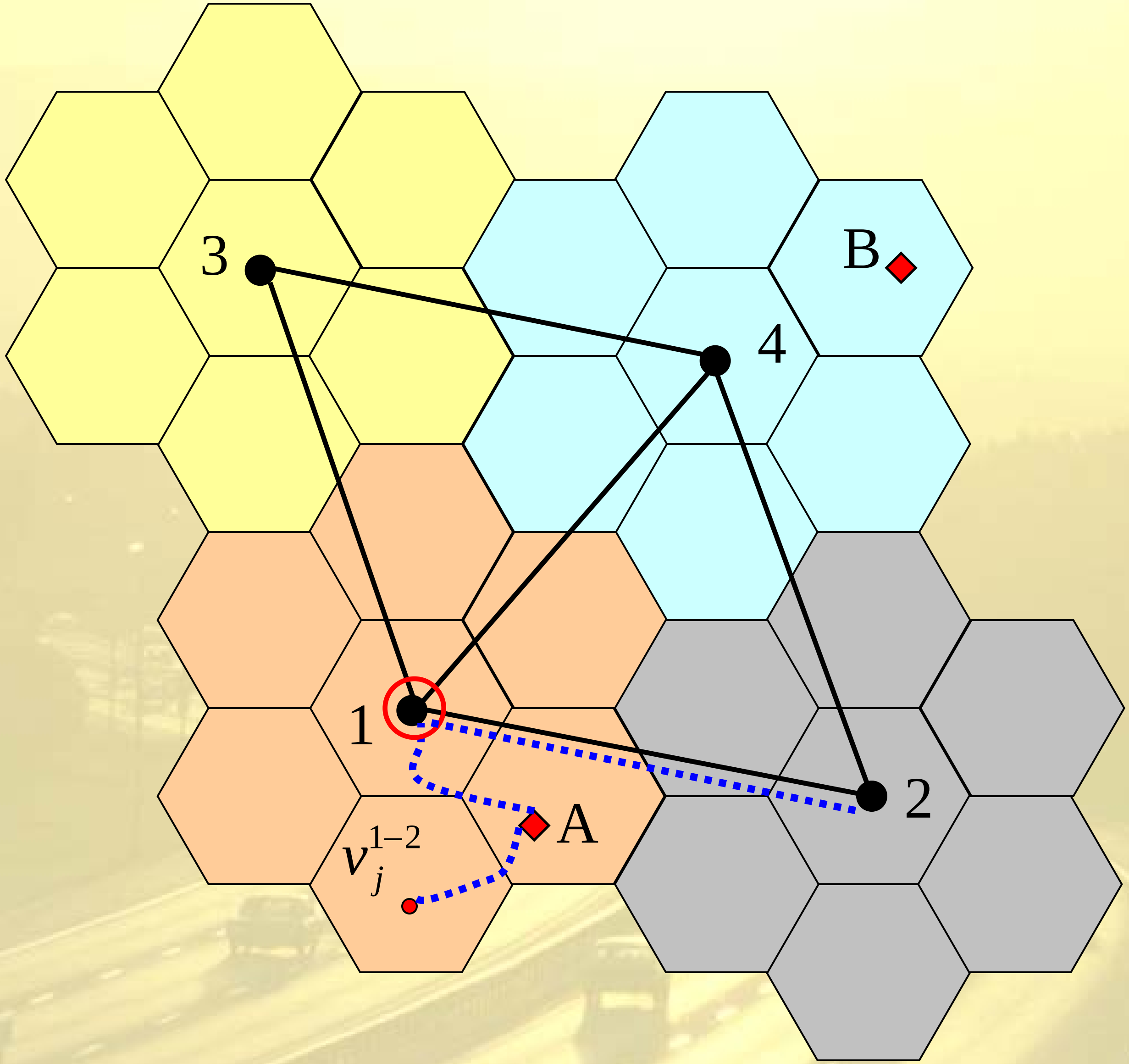


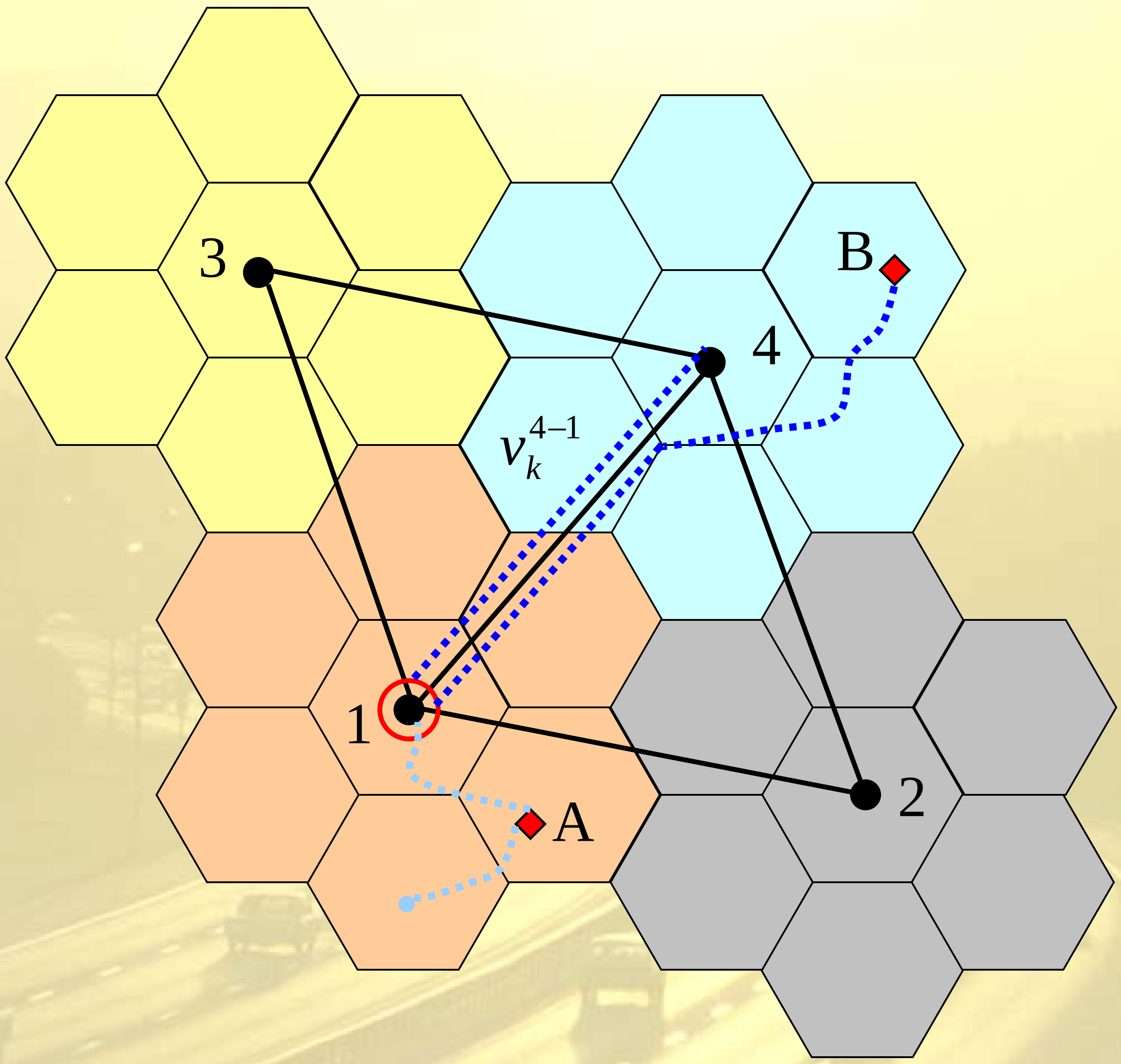
Operation of HCPPT vehicles



Operation of HCPPT vehicles



Operation of HCPPT vehicles



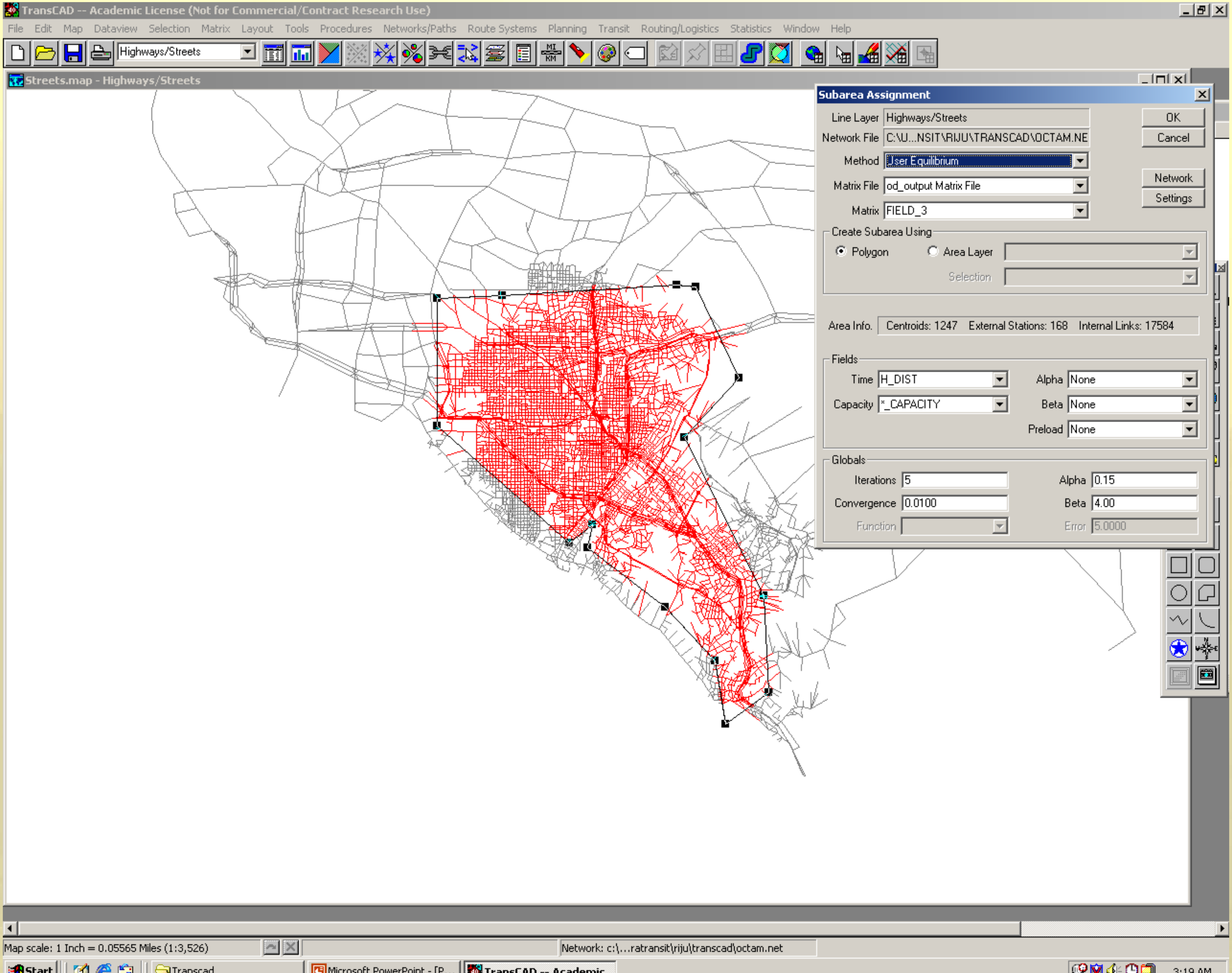
A comment ..

Somewhere in there, there is a fundamental vehicle routing problem called the

Mass Transport Vehicle Routing Problem (MTVRP)

n passengers, *m* vehicles, both large. Route the passengers with minimum total cost.

This basic problem of how to make people travel optimally, has never been attempted in past research!! Isn't it the first one transportation researchers should look at?


TransCAD -- Academic License (Not for Commercial/Contract Research Use)
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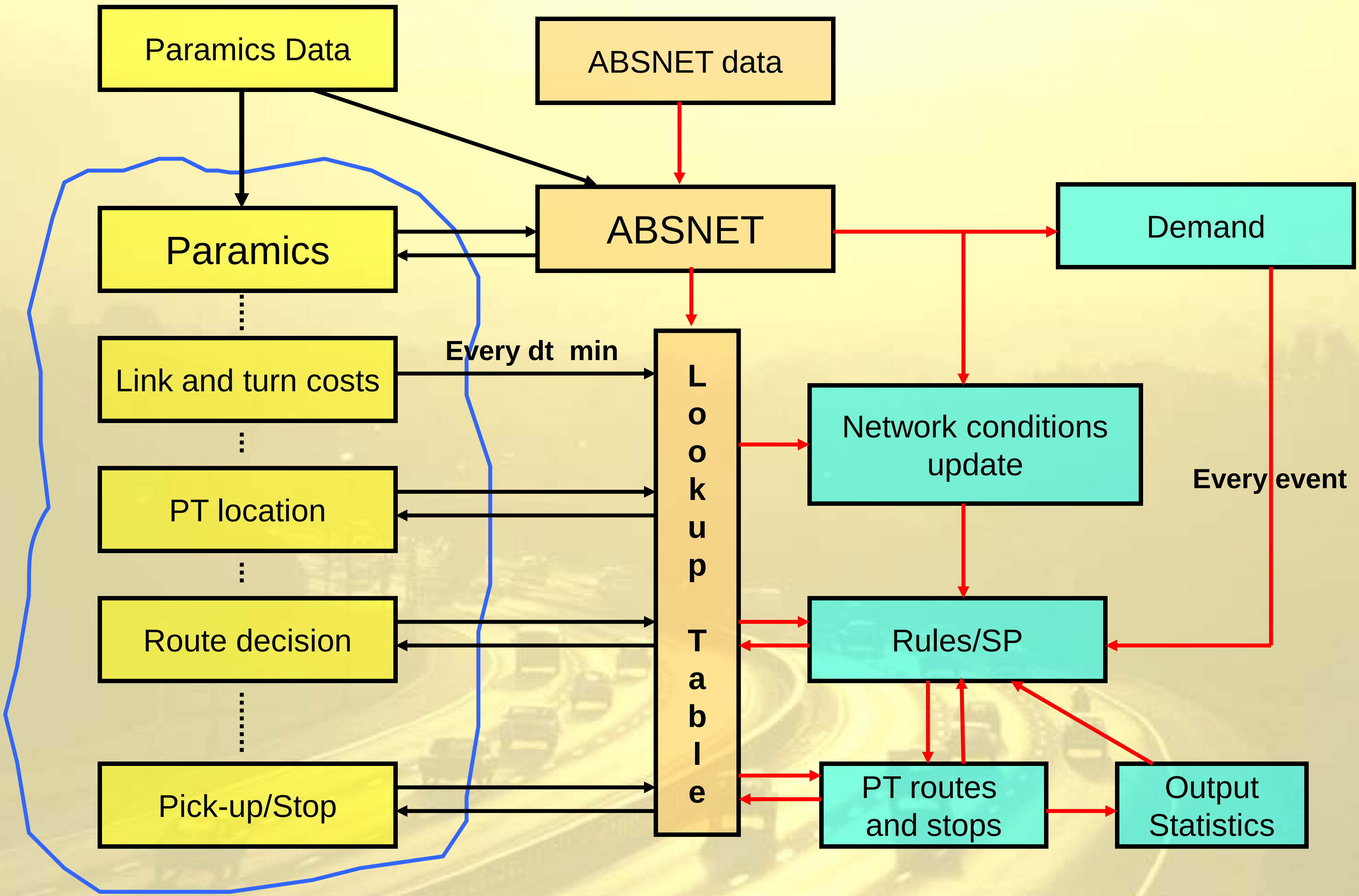
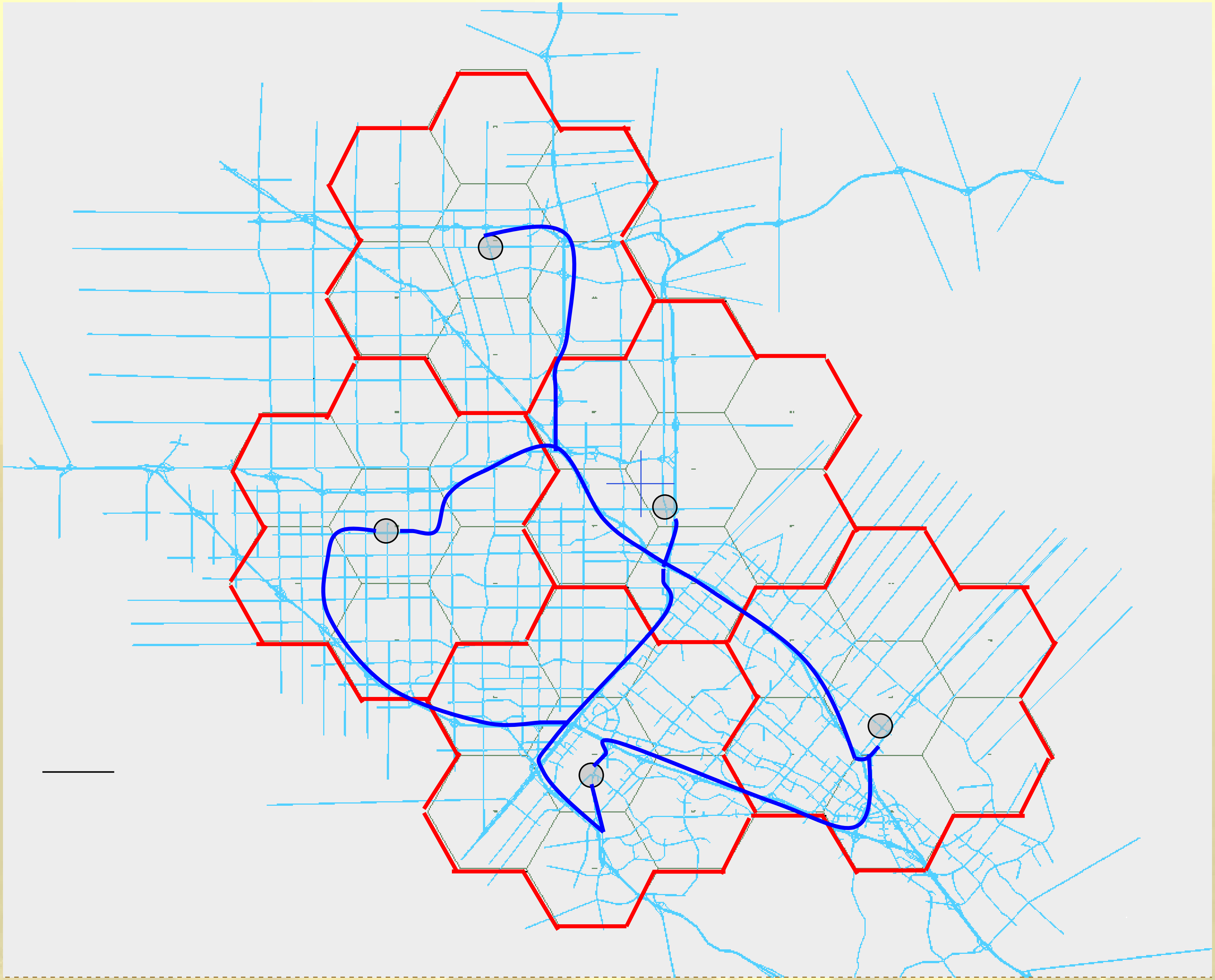
PARAM-TRANSIT platform





The Approach

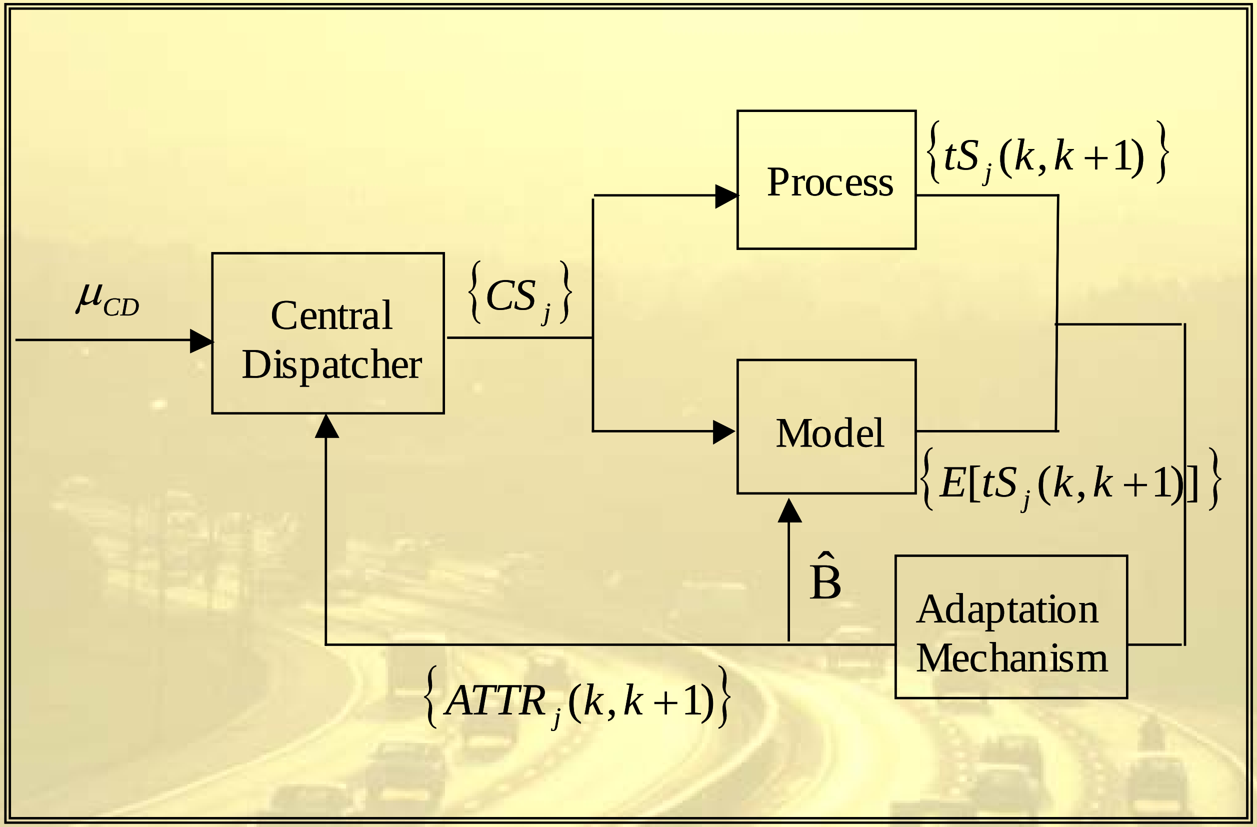
- Predictive control incorporates the prediction of a system behavior into its formulation. Need a good model to describe *a priori* the dynamic relationship between the system input and outputs.

- Adaptive control uses information about the present state of the plant so as to *identify* the process - it compares the present system performance to the desired or optimum performance and make a *decision* to adapt the system so as to tend it toward optimum performance.

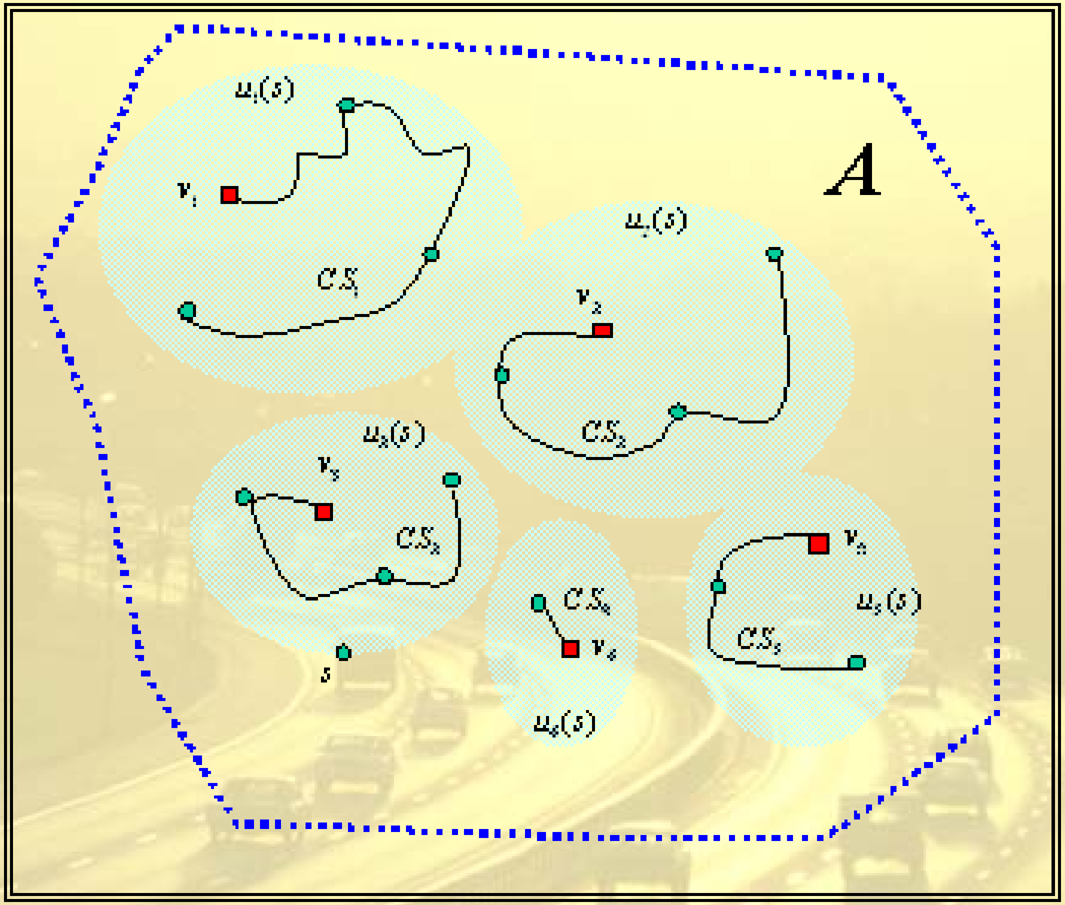
- Hybrid systems typically arise when *continuous* plants are coupled with controllers that involve *discrete* logic actions
  - System performance model is continuous
  - Controller action (select the vehicle and route) is discrete.

- Proposed approach: **Hybrid Adaptive-Predictive Control**. First time that Mass Transportation is looked at as a control problem.

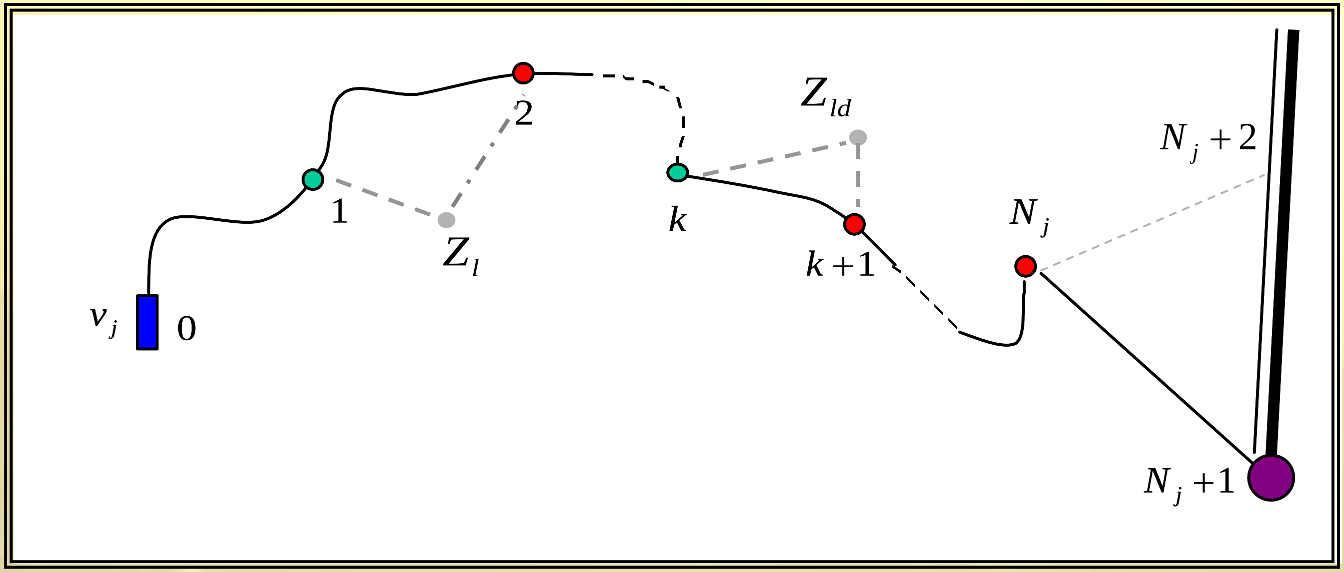
Hybrid Adaptive-Predictive Control (H-APC)



Vehicle Routing



Rerouting Insertion Cost

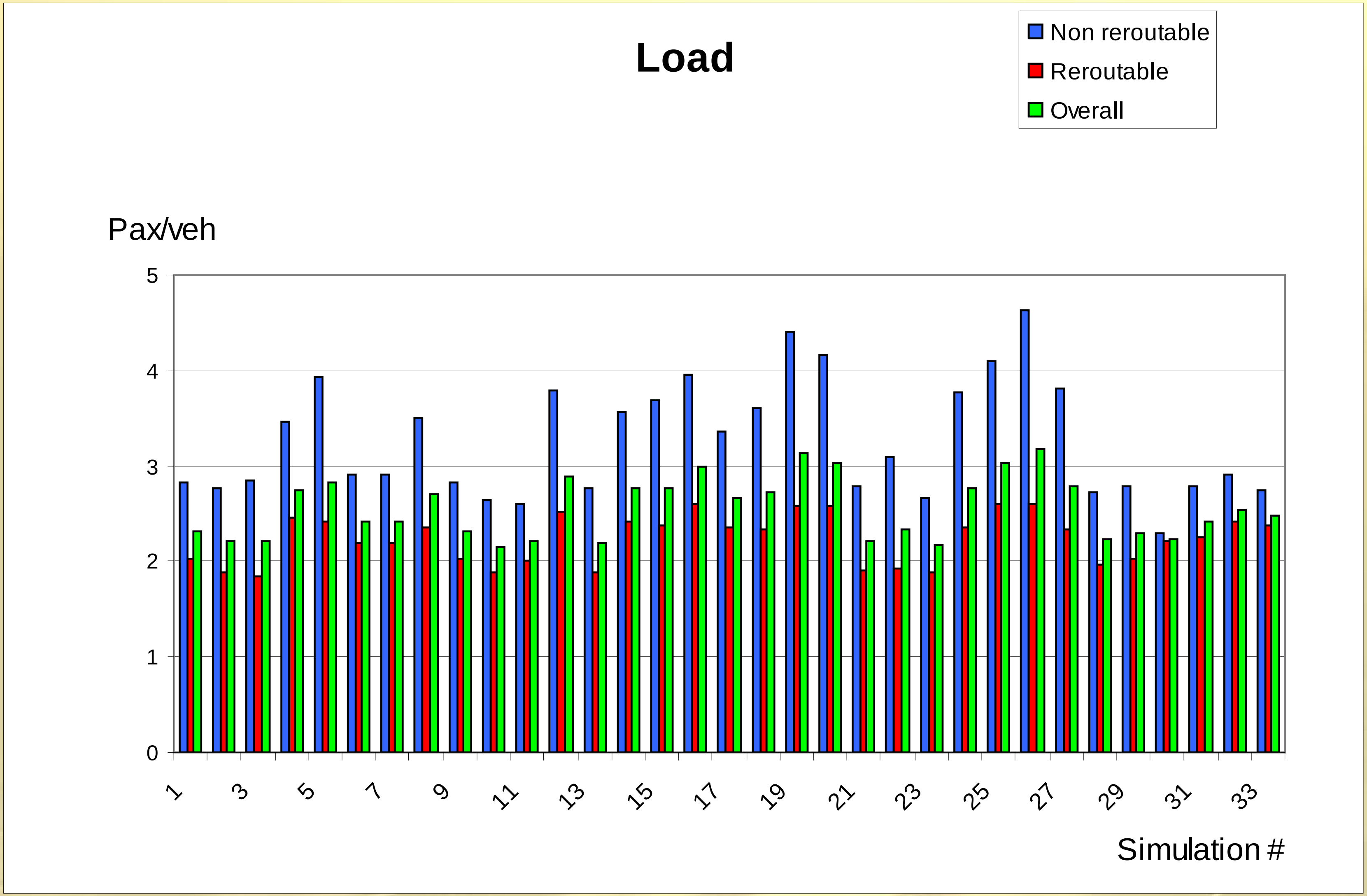


Consider unknown information on future - extra expected delay due to further rerouting during any incremental cost calculations

Get the system to learn of travel propensities..

Results

(Series of Simulations with Varying conditions – Orange County)



HCPPT – Practical?

Current transit systems: $ 8.5 per trip

10-15 miles average trip

- Current DRT system (occ. 1.0-1.3): $ 20 per trip
- Taxi services: $ 30 per person trip (occ. 1.0)
- *HCPPT*: $ 20 - 30 per trip (occ. 3.0-3.5)
  $ 7 per person trip
  $ 4 per person trip (w/ some subsidy)

How to control these kind of systems?

– Local information – local optimization
– Heuristic insertion in real time

How do we bring in global optimization?

See Cortés (2003), Pagés (2006)

Examples of MTVRP

•HCPPT (High Coverage Point to Point Transit System)

Vehicles distributed in an area. Only up to one transfer is allowed for all the trips performed. The system is composed of two main parts: reroutable zones and non-routable links.

Cortes and Jayakrishnan (2003)

•MAST (Mobility Allowance Shuttle Transit)

Vehicles run in a fixed path (compulsory checkpoints), but they are allowed to deviate from the fixed path to pick up and drop off passengers at their desired locations.

Quadrifoglio, L., Dessouky, M.M. and Palmer, K. (2005)

•ADART (Autonomous Dial-a-ride Transit)

Vehicles are distributed in an area. They communicate between each other to decide their routing schemes. There is no fixed path.

Dial (2003)

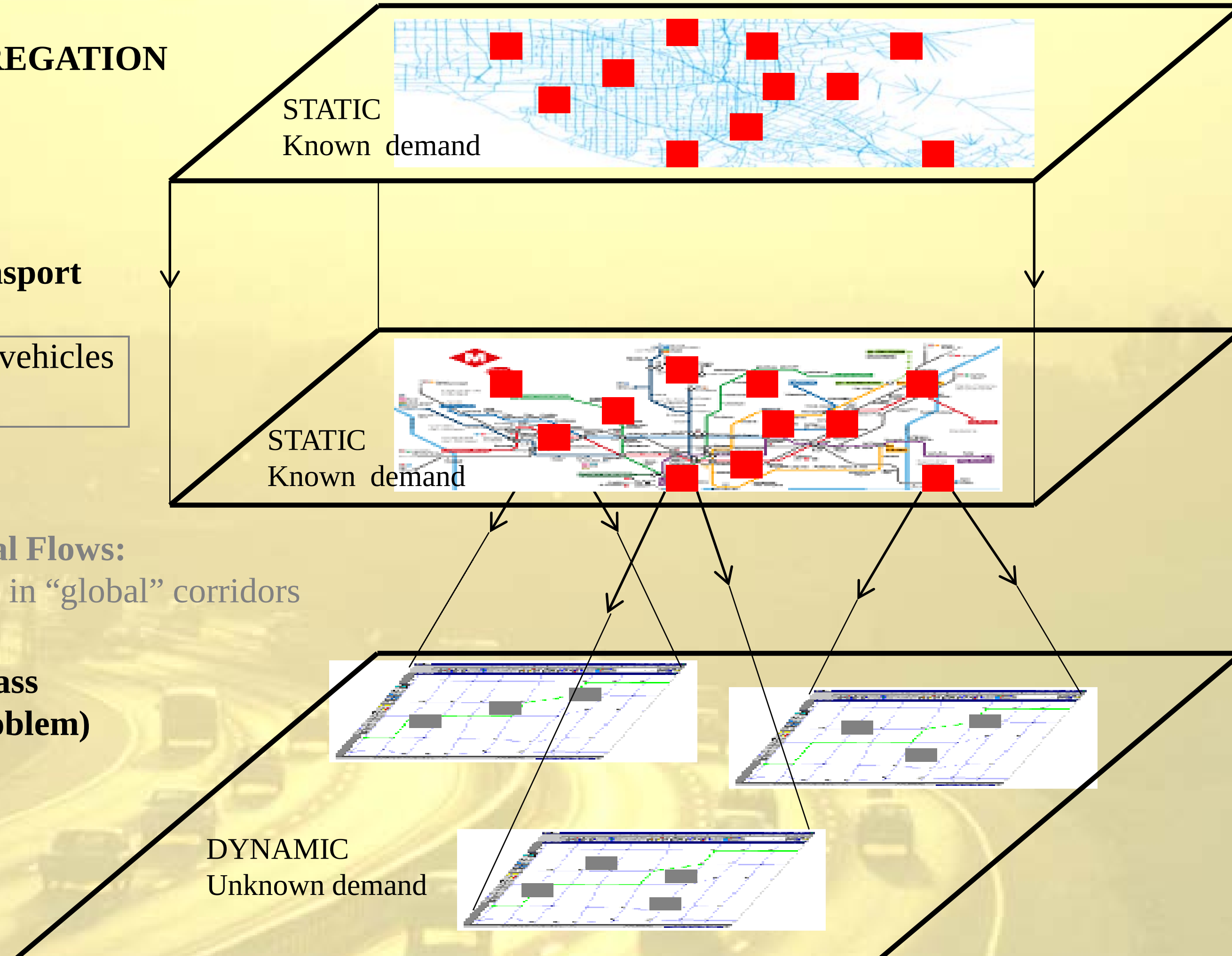
Hierarchical Solution Scheme for MTVRP

STAGE 1 NETWORK AGGREGATION
Position of Centroids and distribution of zones

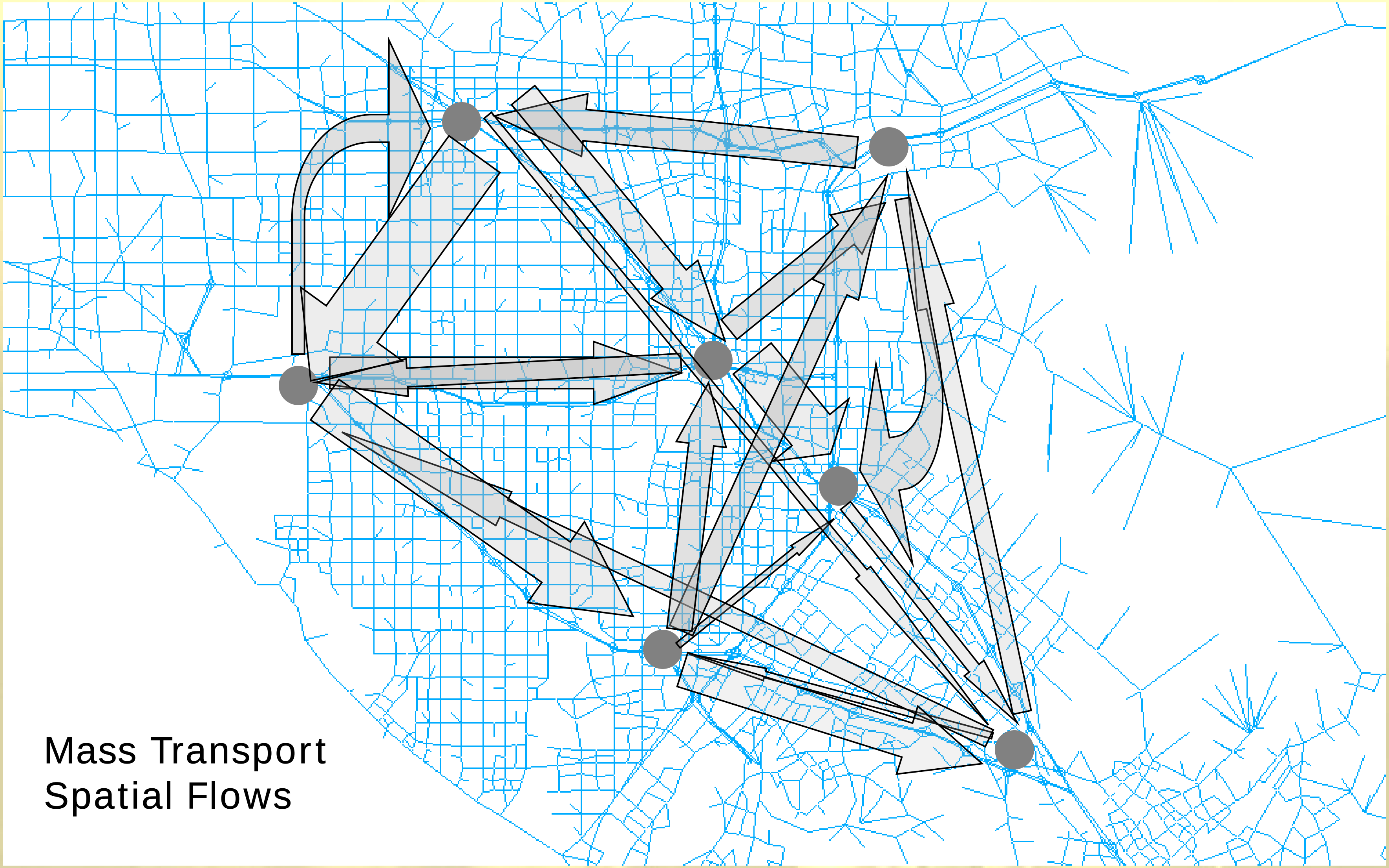
STAGE 2 MTNDP (Mass Transport Network Design Problem)
Set the lanes and frequencies of vehicles in the aggregated network

Global level question:
Mass Transport Spatial Flows:
Flow of passenger seats in "global" corridors

STAGE 3 LMTVRP (Local Mass Transport Vehicle Routing Problem)
Routing of vehicles at each zone independently in the detailed network



Transit "Corridor" Seat Flows



MTVRP Formulation

$$Min\sum_{i}\sum_{j}\sum_{k}\sum_{l}\sum_{m}\sum_{n} f_{ijk}^{lm}\, x_{lm}\left(tt_{ijk}^{lmn}+wt_{ijk}^{lmn}\right)\delta_{ijk}^{lmn}$$

subject to

$$\sum_{i}\sum_{j}\sum_{k} f_{ijk}^{lm}=1 \qquad \text{Continuity Constraint}$$

$$\sum_{l}\sum_{m} f_{ijk}^{lm}\, x_{lm}\,\phi_{ijk}^{a}\,\delta_{ijk}^{lmn}\le C r_{ijk} \qquad \forall\ \text{i, j, k Link capacity constraint}$$

$$\sum_{\mathrm{i}}\sum_{\mathrm{j}}\sum_{k} tt_{ijk}^{ijk}\, r_{ijk}\le N \qquad \text{Total Fleet constraint}$$

p_{ijk} = k$^{\mathrm{th}}$ path between node i and node j

r_{ijk} = rate of vehicles on path $\mathrm{p}_{\mathrm{ijk}}$ (vehicles/unit time)

x_{ij} = rate of demand from node i to node j (passengers/unit time)

t_{ijk}^{lmn} = in-vehicle travel time from l to m using path $\mathrm{p}_{\mathrm{lmn}}$, child of $\mathrm{p}_{\mathrm{ijk}}$ (unit time)

wt_{ijk}^{lmn} = expected waiting time from l to m using path $\mathrm{p}_{\mathrm{lmn}}$, child of $\mathrm{p}_{\mathrm{ijk}}$ (unit time)

f_{ijk}^{lm} = fraction of x_{lm} traveling on path p_{ijk}, parent of p_{lmn}

δ_{ijk}^{lmn} = 1 if p_{lmn} is a child of $\mathrm{p}_{\mathrm{ijk}}$, = 0 otherwise

ϕ_{ijk}^{a} = 1 if p_{ijk} goes over link a, = 0 otherwise

C = Capacity of buses (passengers/vehicle)

Minimize “Total Travel time of Pax”

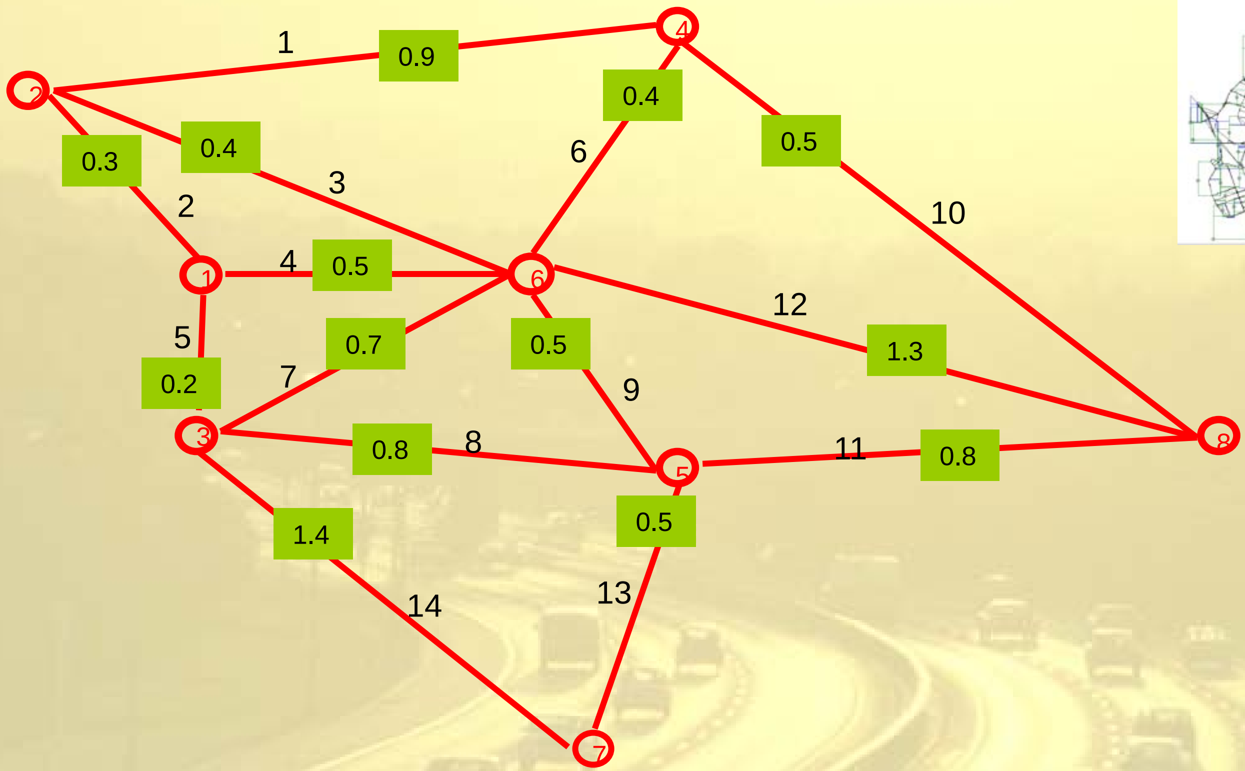
Subject to

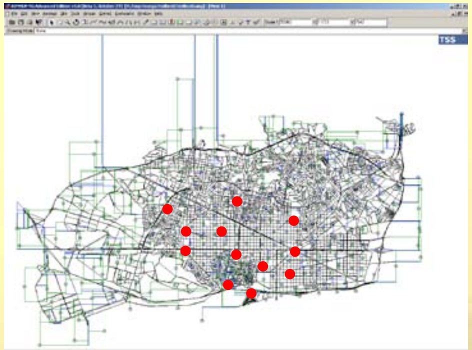
Continuity Constraint.
Capacity in each “link” or “global corridor”.
Maximum fleet.

UNKNOWNS: r and f

Looks simple but even the aliens would find trouble to solve it for large networks. We have found a scheme.

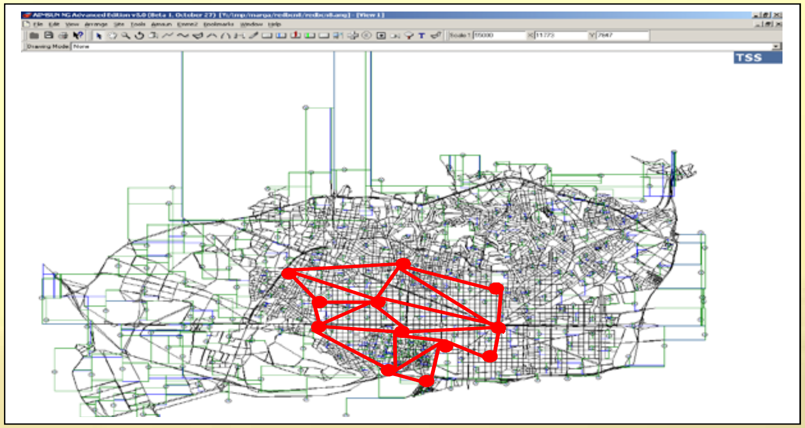
Solution for MTNDP. Barcelona





Fleet feeder system in Barcelona

- UCI's MTVRP in the City of Barcelona, Spain
- From "Agencia Local d'Ecologia Urbana de Barcelona" and "Universitat Politecnica de Catalunya"
- Peak hour OD matrix (8-10am and 430,860 trips) extracted from 24 h OD matrix (2,845,008 trips)
- Results showed significant benefits from using global optimum parameters for local MTVRP.



- City Simulations done with AIMSUN microscopic simulator
- UCI-Barcelona joint research led to an important new module for large fleet modeling to be added to AIMSUN, called "AIMSUN City Logistics"
- See www.aimsun.com/papers/ROUTE2005-DSS_for_City_Logistics.pdf (Barcelo et al).

Summary Comments

- The analytical schemes to run real-time-routed-transit (True Paratransit) are beginning to be available. Technology has been there for a decade.
- Time to take a new look at DRT systems which were thrown in the dustbin in the 60s to 80s due to poor computational and communication schemes.
- Point to point shared-vehicle travel that is competitive with personal auto travel, is possible.
- Consider large number of small vehicles, some private, some public, with coordinated shared rides? Drivers offering rides on-the-fly for a price?
- If and when energy and environmental characteristics of individual vehicles improve and reduce the relative advantage of larger vehicles with many pax (buses, trains), better efficiency requires small vehicles to have more pax in them. So HCPPT has longer-term relevance even in future transportation scenarios not based on fossil-fuels.