A vehicle-to-infrastructure communication based algorithm for urban traffic control

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Communicating vehicles

A vehicle that can measure, compute, communicate some data. Use cases :

- V2V : vehicle to vehicle communication
- V2I : vehicle to infrastructure communication
- V2X : vehicle to device communication

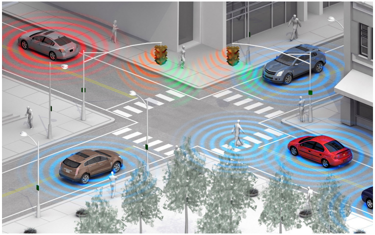


Figure: Communicating vehicles

Context

- Penetration rate of communicating vehicles is expected to increase in the next years
- High resolution data will be available for road traffic applications : speed, location, acceleration rate, origin and destination of equipped vehicles

Problematic

- Urban road traffic control can benefit from these high resolution data
- There exists a bidirectionnaly coupled communication and microscopic road traffic simulator that enables fine grained evaluation of new road traffic control strategies

A communication based algorithm for urban traffic control

- we extended the reference simulation framework VEINS
- so we were able to design and evaluate a new vehicle to infrastructure communication (V2I) algorithm
- IEEE 802.11p protocol communication and road traffic performances of the algorithm are presented

Simulation tools

We used VEINS Framework [1] which includes SUMO [2] as microscopic traffic simulator and OMNET++ [3] as communication network simulator.

Simulation tools : road traffic simulator SUMO

Simulation of Urban Mobility is

- a microscopic and mesoscopic, space-continuous, and time-discrete traffic flow simulator
- evolving to multi-modality
- suite of portable and modular binaries
- mainly developped by DLR, the national aeronautics and space research centre of the Federal Republic of Germany.

Simulation tools : discrete event communication simulator OMNET++

OMNET++ features models from physics to computer science protocols. All communication layers are modeled accurately in C++ and inter-connected with a component based language.

- electromagnetic wave propagation : models for different antennas, different propagation environments (with or without obstacles)
- physical layer modeling
- many communication protocols are implemented

Simulation tools

We modified and extended VEINS Framework in order to get TCP/IP support over IEEE 802.11p. To do this, “inet” models and Veins framework have been integrated and connected together.

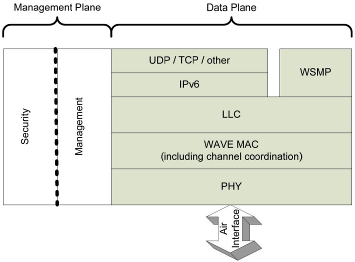


Figure: The IEEE WAVE protocols stack [4]

Simulation tools

With this extension we made, we now have a communicating vehicles simulator which includes all internet protocols based available (such as routing protocols for example).

Implementation

Some application modules have been written :

- map, car, road side unit, TCP client and server, UDP client and server applications.
- commands to control the TLS states have been added.
- the MAC1609 module of VEINS framework module has been modified to connect TCP/IP to IEEE 802.11p layers.

A first application example

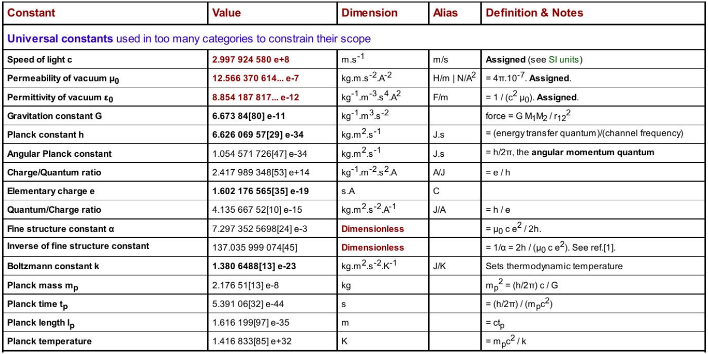
We present in this section a first application using the framework VEINS as we modified and extended it.
It is a V2I based algorithm to control urban traffic light signals.

Some traffic light signal

Figure: Traffic light signal

Assumptions I

Some physics :)



Constant	**Value**	**Dimension**	**Alias**	**Definition & Notes**
Universal constants used in too many categories to constrain their scope				
Speed of light c	**2.997 924 580 e+8**	m.s^{-1}	m/s	**Assigned** (see SI units)
Permeability of vacuum μ_0	**12.566 370 614... e-7**	kg.m.s^{-2}.A^{-2}	H/m | N/A^2	= $4\pi.10^{-7}$. **Assigned**.
Permittivity of vacuum ε_0	**8.854 187 817... e-12**	kg^{-1}.m^{-3}.s^4.A^2	F/m	= 1 / (c^2 μ_0). **Assigned**.
Gravitation constant G	**6.673 84[80] e-11**	kg^{-1}.m^3.s^{-2}		force = G M_1M_2 / $r_{12}{}^2$
Planck constant h	**6.626 069 57[29] e-34**	kg.m^2.s^{-1}	J.s	= (energy transfer quantum)/(channel frequency)
Angular Planck constant	1.054 571 726[47] e-34	kg.m^2.s^{-1}	J.s	= h/2π, the **angular momentum quantum**
Charge/Quantum ratio	2.417 989 348[53] e+14	kg^{-1}.m^{-2}.s^2.A	A/J	= e / h
Elementary charge e	**1.602 176 565[35] e-19**	s.A	C	
Quantum/Charge ratio	4.135 667 52[10] e-15	kg.m^2.s^{-2}.A^{-1}	J/A	= h / e
Fine structure constant α	7.297 352 5698[24] e-3	**Dimensionless**		= μ_0 c e^2 / 2h.
Inverse of fine structure constant	137.035 999 074[45]	**Dimensionless**		= 1/α = 2h / (μ_0 c e^2). See ref.[1].
Boltzmann constant k	**1.380 6488[13] e-23**	kg.m^2.s^{-2}.K^{-1}	J/K	Sets thermodynamic temperature
Planck mass m_p	2.176 51[13] e-8	kg		$m_p{}^2$ = (h/2π) c / G
Planck time t_p	5.391 06[32] e-44	s		= (h/2π) / (m_pc^2)
Planck length l_p	1.616 199[97] e-35	m		= ct_p
Planck temperature	1.416 833[85] e+32	K		= m_pc^2 / k

Figure: Universal Constants

Assumptions II

- Some vehicles are equipped with IEEE 802.11p communication On Board Unit (OBU) and localization resources : vehicle agents
- Some traffic light are equipped with IEEE 802.11p communication Road Side Unit (RSU) and localization resources : intersection agents

In the simulation scenario, we varied the number of vehicle and intersection agents.

Dynamic maps

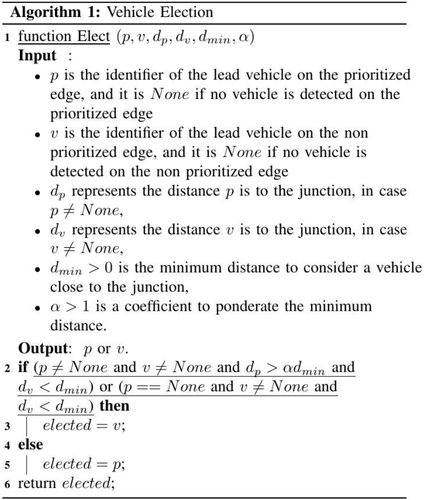
We defined and developed a map module. This same module is used for

- the vehicle agent to build a map of the TLS approaching or leaving
- the intersection agent to build a map of the equipped vehicles approaching or leaving

Election

Periodically the TLS elect a vehicle among the lead vehicles approaching the junction. In our case, there are maximum two lead vehicles.

Election algorithm



Algorithm 1: Vehicle Election

```
function Elect $(p, v, d_p, d_v, d_{min}, \alpha)$
    Input :
        • $p$ is the identifier of the lead vehicle on the prioritized edge, and it is $None$ if no vehicle is detected on the prioritized edge
        • $v$ is the identifier of the lead vehicle on the non prioritized edge, and it is $None$ if no vehicle is detected on the non prioritized edge
        • $d_p$ represents the distance $p$ is to the junction, in case $p \neq None$,
        • $d_v$ represents the distance $v$ is to the junction, in case $v \neq None$,
        • $d_{min} > 0$ is the minimum distance to consider a vehicle close to the junction,
        • $\alpha > 1$ is a coefficient to ponderate the minimum distance.
    Output: $p$ or $v$.
if ($p \neq None$ and $v \neq None$ and $d_p > \alpha d_{min}$ and $d_v < d_{min}$) or ($p == None$ and $v \neq None$ and $d_v < d_{min}$) then
    $elected = v$;
else
    $elected = p$;
return $elected$;
```

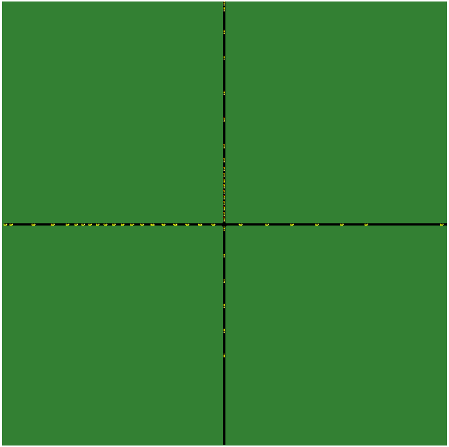
Action

- The elected vehicle can send a message with its open TCP connection to set the TLS in a desired state.

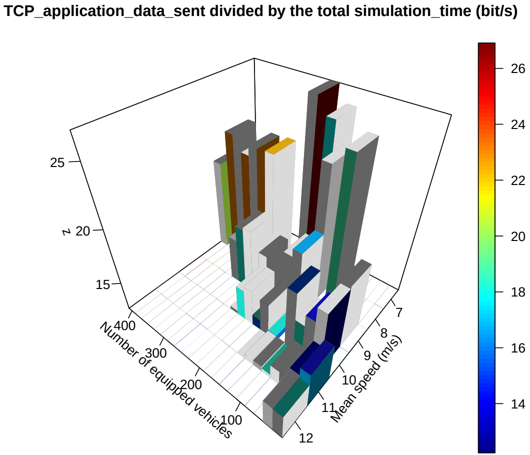
Properties

- max duration for a given state ensures dynamics of the TLS
- min duration for a given state ensures stability of the TLS
- if no vehicle is equipped, max duration makes the TLS program a cyclic one
- the control tends **to favour equipped vehicles** although every vehicle can pass the junction
- the junction is controlled by TLS that ensures **safety** by avoiding giving green light to antagonistic phases

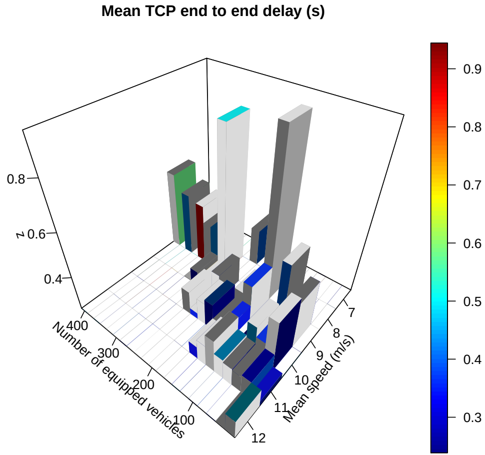
Scenario on one junction



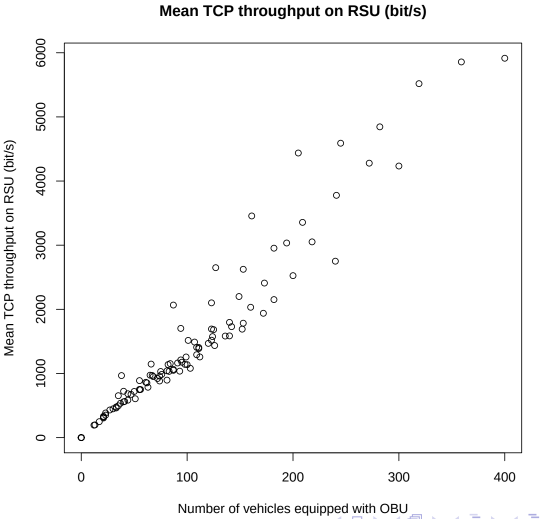
Simulation results on one junction for the communication performance (1/3)



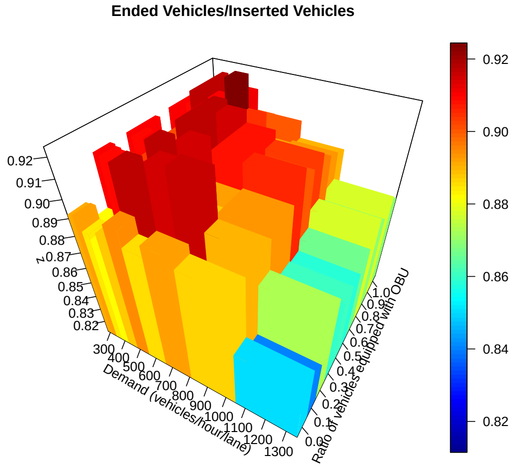
Simulation results on one junction for the communication performance (2/3)



Simulation results on one junction for the communication performance (3/3)

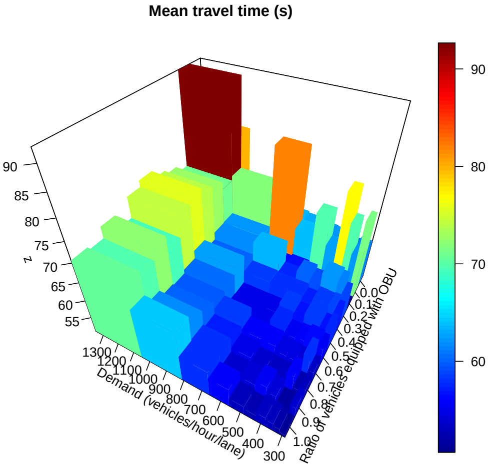


Simulation results on one junction for the road traffic performance (1/3)

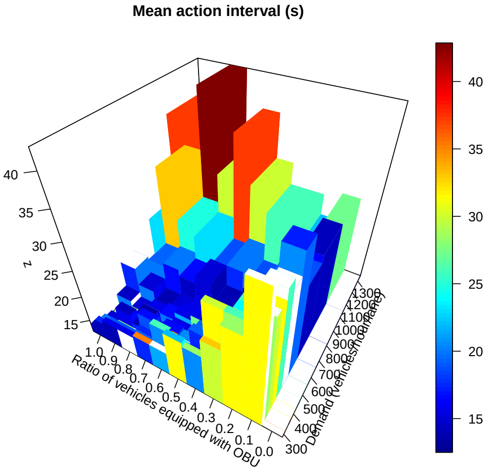


Ended Vehicles/Inserted Vehicles

Simulation results on one junction for the road traffic performance (2/3)



Simulation results on one junction for the road traffic performance (3/3)



Mean action interval (s)

Scenario on one american like urban network

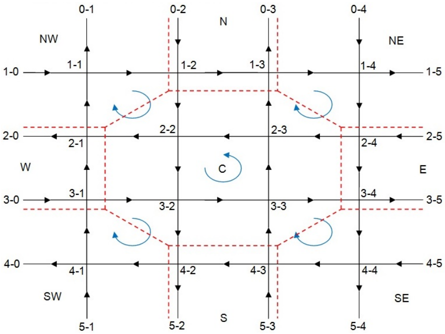


Figure: Regular network example.

Scenario on one american like urban network

We used SUMO "origin and destination edges instead of a complete list of edges. In this case the simulation performs fastest-path routing based on the traffic conditions found in the network at the time of departure/flow begin." [5].

Table: The traffic demand for the first 900 s. (1/2)

Destinations Origins	Center zone	Each other zone
Center zone	0	10 (*veh*)
Each other zone	15 (*veh*)	15 (*veh*)

Scenario on one american like urban network (2/2)

Table: The traffic demand for the last 900 s.

Origins \ Destinations	Center zone	Each other zone
Center zone	0	10 (veh)
Each other zone	20 (veh)	20 (veh)

Simulation results on a network for the road traffic performance (1/3)

Table: Ended vehicles in a scenario with the traffic demand of tables III and IV. Simulated time = 1800 s. Mean and standard deviation for 20 simulation runs.

Ended Penetration rate Equipped junctions	0%	20%	50%	80%
25%	1373±19 (0±0)%	1470±33 **(+7.1±2.5)%**	1507±18 **(+9.8±2.4)%**	1484±19 **(+8.1±1.9)%**
50%	1373 ±19 (0±0) %	1499±49 **(+9.2±3.4)%**	1583±19 **(+15.3±1.9)%**	1571±20 **(+14.5±2.3)** %
100%	1373±19 (0±0)%	1281±151 (-6.7±11.2)%	1805±49 **(+31.5±4.1)%**	1877±29 (+36.7±2.8)%

Simulation results on a network for the road traffic performance (2/3)

Table: Running vehicles in a scenario with the traffic demand of tables III and IV. Simulated time = 1800 s. Mean and standard deviation for 20 simulation runs.

Running / Penetration rate / Equipped junctions	0%	20%	50%	80%
25%	954±16 (0±0%)	842±32 **(-11.8±3.5%)**	817±18 **(-14.4±2.7%)**	848±21 **(-11.2±2.4%)**
50%	954±16 (0±0%)	835±36 **(-12.4±3.8%)**	764±17 **(-19.9±2.1%)**	778±21 **(-18.4±2.5%)**
100%	954±16 (0±0%)	962±80 (+0.9±8.7%)	583±43 **(-38.9±4.7%)**	517±27 (-45.8±2.9%)

Simulation results on a network for the road traffic performance (3/3)

Table: Mean Travel Time (s) in a scenario with the traffic demand of tables III and IV. Simulated time = 1800 s. Mean and standard deviation for 20 simulation runs.

MTT(s) Penetration rate Equipped junctions	0%	20%	50%	80%
25%	413.9±1.8 (0±0%)	381.9±4.3 **(-7.7±1.1%)**	376.0±3.1 **(-9.2±0.8%)**	380.0±3.4 **(-8.2±0.9%)**
50%	413.9±1.8 (0±0%)	381.8±15.2 **(-7.8±3.8%)**	355.6±5.0 **(-14.1±1.5%)**	354.9±4.5 **(-14.2±1.2%)**
100%	413.9±1.8 (0±0%)	399.6±30.6 (-3.4±7.4%)	302.0±6.9 **(-27.0±1.7%)**	281.2±4.6 (-32.1±1.2%)

Conclusions

VEINS framework has been modified and extended to include TCP/IP support.

We presented a V2I algorithm for urban traffic light control.

Perspectives

Road traffic control could benefit to mix macroscopic and microscopic model scales.

Road network global optimization could improve the control performances.

Thank you

References I

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References II

- "Ieee guide for wireless access in vehicular environments (wave) - architecture," *IEEE Std 1609.0-2013*, pp. 1–78, March 2014.
- `http://sumo.dlr.de/wiki/Definition_of_Vehicles,_Vehicle_Types,_and_Routes#Incomplete_Routes_.28trips_and_flows.29`.

The IA and vehicle map module

unique vehicle identifier	
c	the IA_to_car_TCP_connection identifier
T	the trajectory which is an ordered map of couples (time, coordinates)
lst	the last time the vehicle data has been received by the IA
fst	the first time the vehicle data has been received by the IA
r	the radius is the distance the car is to the approaching junction
$\cos\theta$ $\sin\theta$	the car position is defined by its radius to the TLS and the angle this radius is from the (x) axis
s	the state of the car whether the car is coming or leaving the junction

Parameters

The total simulation time is 600 s for the junction scenario and 1800 s for the network scenario.

Table: Main parameters for the communication and road traffic control. Other parameters are VEINS defaults ones.

Parameter name	Parameter value
vehicle TCP *position_send_interval*	500 ms
UDP broadcasting interval	500 ms
IA *election_interval*	500 ms
cycle_duration	90 s
max_state_duration	45 s
min_state_duration	8 s
map_module_timeout	2 s
map_module_length	5 s
d_{min}	100 m
α	2
MAC 1609 use service channel	true
MAC 1609 bitrate	27 Mbps
MAC 1609 carrier frequency	5.890×10^9 Hz
transmit power	1 mW
application message payload	30 bytes
transceiver sensitivity	-89 dBm

Thank you