Wireless Networks for Mobile Applications

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IEEE 802.11p Introduction

- Designed to provide connectivity to vehicles
  - Since 4G tecnology available not so crucial anymore
  - Still useful for safety/public applications
- Parts are taken from 802.11a and 802.11p
- Improves on the range and speed of the dedicated 5.9GHz licensed band (same in EU and USA)
  - Up to 1000m of transmission range
  - Up to 26Mbps of data rate
  - Capable of transmitting at 6Mbps at 300m of distance even if the node travels at 200Km/h
- Related previous terms/technology: Wave or DSRC

Safe Driving: Problem Statement

- Alert Messages has to be delivered very quickly to all cars following the AV
- Problems arise from multiple transmissions in case of accidents
  - multiple Abnormal Vehicles (AVs)
  - chain reactions
- Various proposals to reduce multiple (and redundant) transmissions.

PAPER:
A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning

X. Yang, J. Liu, F. Zhao, N. H. Vaidya

Introduction

- Vehicle safety applications require fast delivery of alert messages

- Problems arise from multiple transmissions in case of accidents
  - multiple Abnormal Vehicles (AVs)
  - chain reactions

- Propose Vehicular Collision Warning Communication (VCWC) protocol to reduce multiple (and redundant) transmissions.

Application Challenges

- Application challenges:
  - Stringent delay requirements immediately after the emergency
  - Support of multiple co-existing AVs over a longer period
    - transmissions from co-existing Avs interfere with each other
    - chain effect and persistent transmissions generate co-existence of AVs.
  - Differentiation of emergency events and elimination of redundant EWMs
    - busy tone on other frequencies to stop non-EWM transmissions
    - no need to further transmit the EWM after some time if following vehicles received it

Emergency Messages

- Inside the Emergency Warning Messages (EWMs):
  - geographical location
  - speed
  - acceleration
  - moving direction

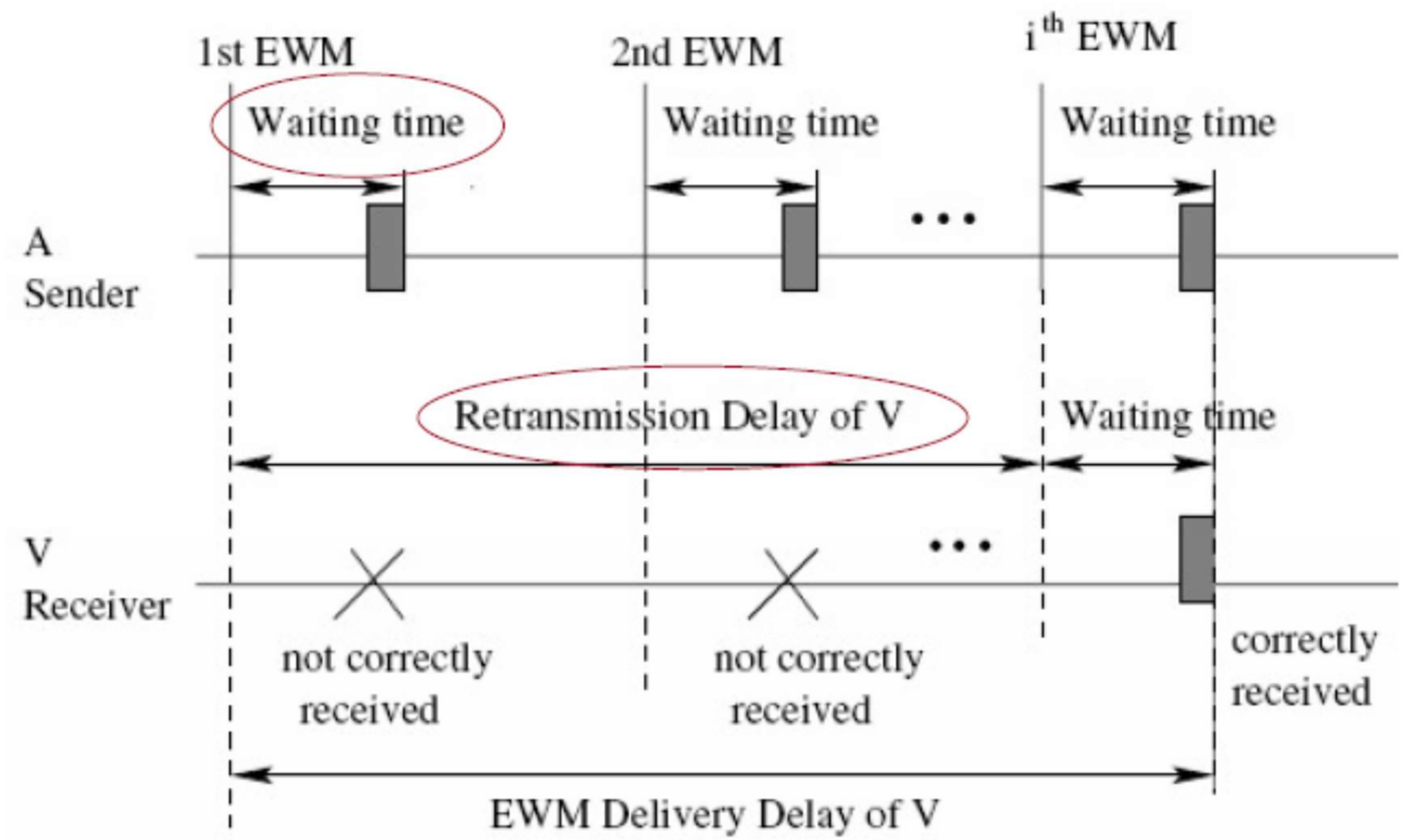
- Messages sent in broadcast

Other Assumptions

- each vehicle is able to obtain its own absolute and relative position
- each vehicle is equipped with at least one wireless transceiver
- DSRC and 802.11p (they used 802.11b for simulations) is used:
    - 6 Mbps
    - 300 m of range
    - transmissions possible even at 200Km/h

Delays

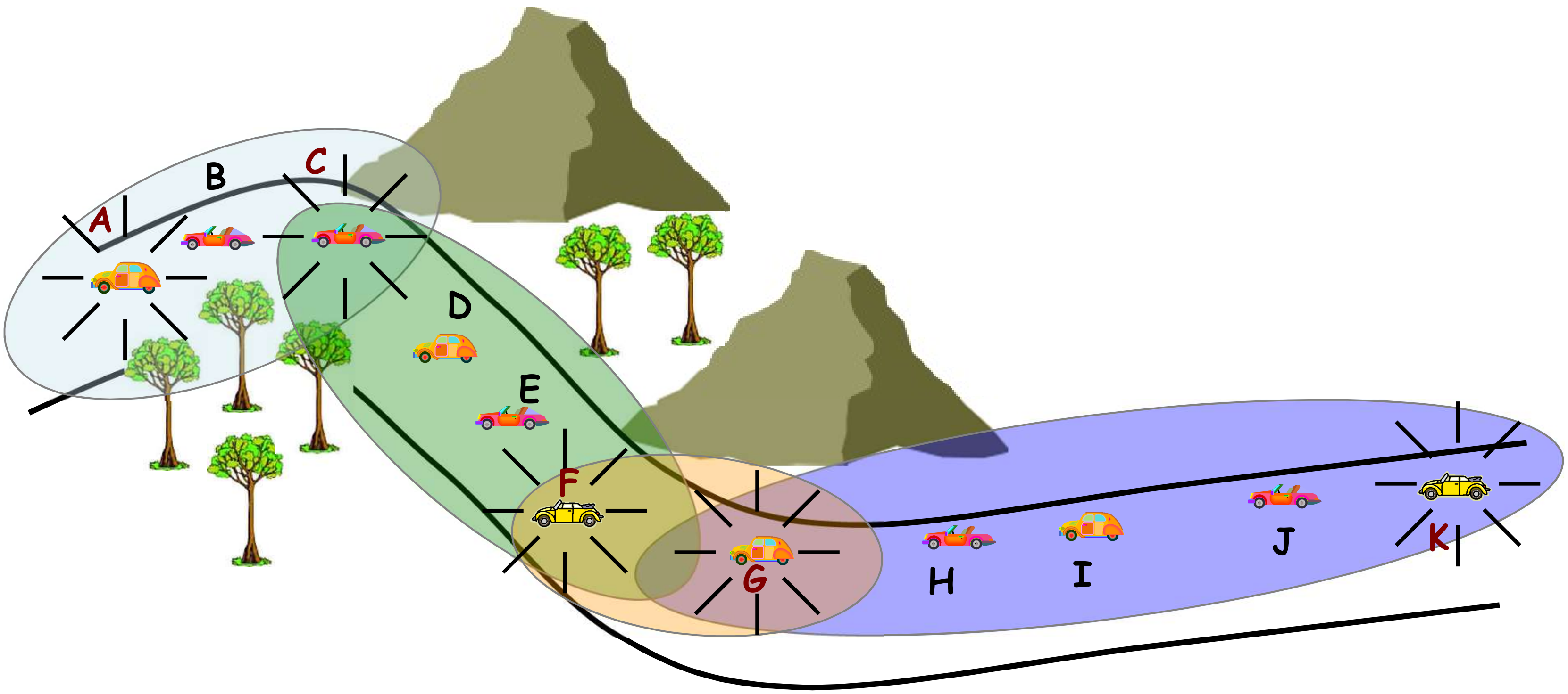
- Rate decreasing algorithm for EWMs



Vehicular Networks: System Model

- High mobility of nodes
- Variable transmission range
  - Erroneously ignored in most papers (simulations)
- A car cannot be sure to be the farthest car receiving that broadcast message
- Who has to forward the alert message?

Simple Example



- Optimal solution: A, C, F, G, and F broadcast the alert message (one message and 4 hops)

MCDS Approach

- Exploiting the notion of Minimum Connected Dominating Set* (MCDS)
  - Only node in the MCDS has to broadcast the message
  - Optimal but non feasible solution
  - Needs complete and updated knowledge of the network topology
  - A practical implementation with *n* nodes needs $O(n \log n)$ control messages.

* the minimum cardinality set of connected nodes, such that each other node in the network is connected to a node of the MCDS set.

Redundancy Avoidance Approach

- More practical approaches:
  - Backoff mechanism to reduce frequency of message transmission in case of collisions due to congestion
  - If the message has already been re-broadcast by a following vehicle do not forward it (it would be redundant)

- <u>None of these two schemes considers the number of hops that a message traverse</u>

Jamming Signal Approach

- Urban Multi-hop Broadcasting protocol utilizes jamming signals (or busy tone) to determine the next forwarder
  - Vehicles receiving an alert message emit a jamming signal for a time that is proportional to the distance from the sender
  - The last vehicle stopping the jamming signal knows it is the last one and forward the alert message
  - Jamming signal phase delays the transmission of the message: not suitable for alert messages

Contention Window Approach

- Vehicles could set their respective contention windows inversely proportional to the distance from the sender.
  - no control traffic generated
  - yet, unrealistically assumes that there is a unique, constant, and known a priori transmission range for all cars in every moment

Fast Broadcast: Basics

- **Fast Broadcast** solution is designed to have *Alert Messages* covering the area-of-interest in as less time as possible (as few hops as possible)

- Fast Broadcast works in two phases
  - *estimation phase*: vehicles exchange few *hello messages* to collect information in order to **estimate their own tx range**.
  - *broadcasting phase*: the tx range estimation is put to good use to reduce the number of hops that an *Alert Message* will experience in its trip to destination.

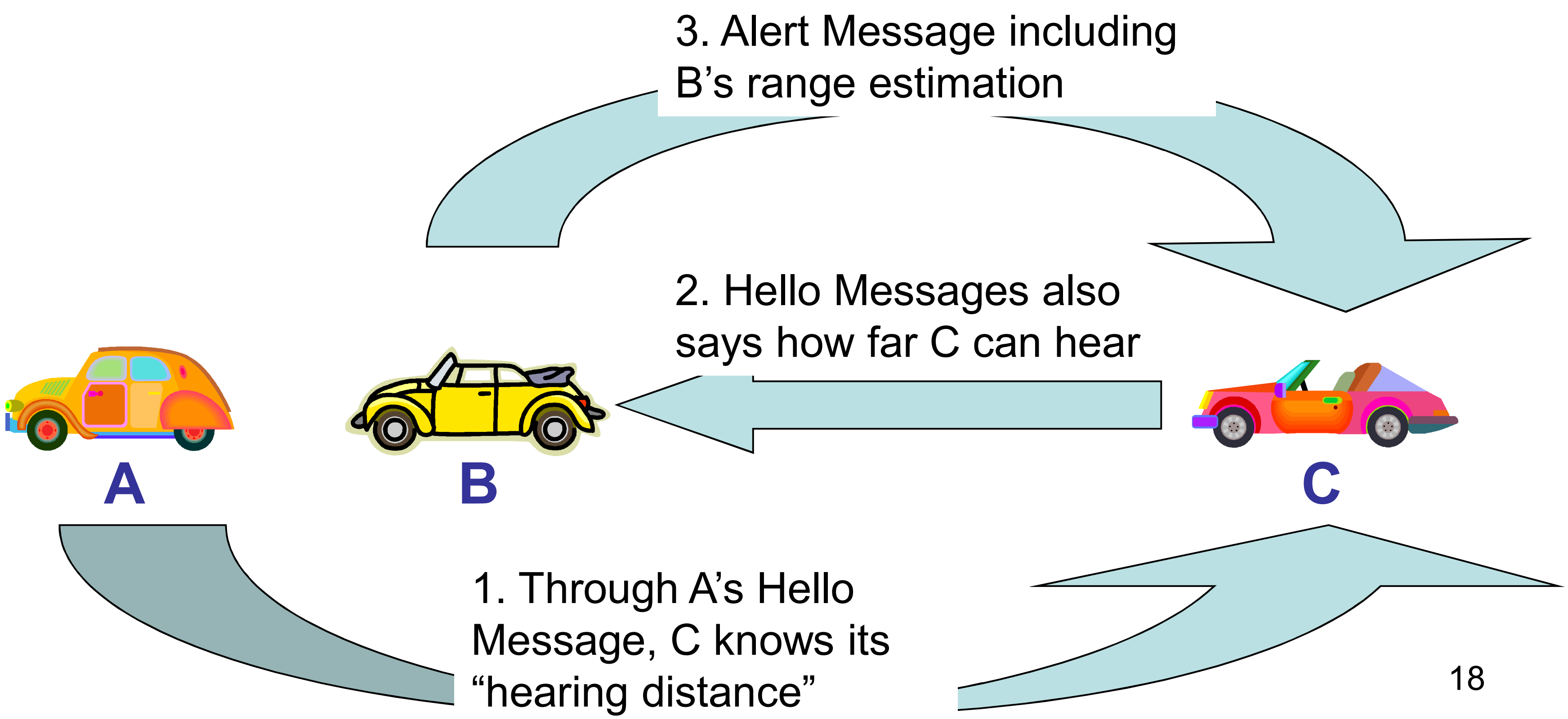
Fast Broadcast Mechanism: Phase 1

Estimation Phase:

- Continuously run
- Time is divided into rounds
- **ONE** *Hello Messages* randomly sent every time round
- *Hello Messages* contain the sender's position and the maximum frontward distance from which another vehicle has been heard transmitting an *Hello Message*

Fast Broadcast: Two Kinds of Messages

- In *Hello Messages:* information to estimate tx range
- In *Alert Messages:* sender's transmission range



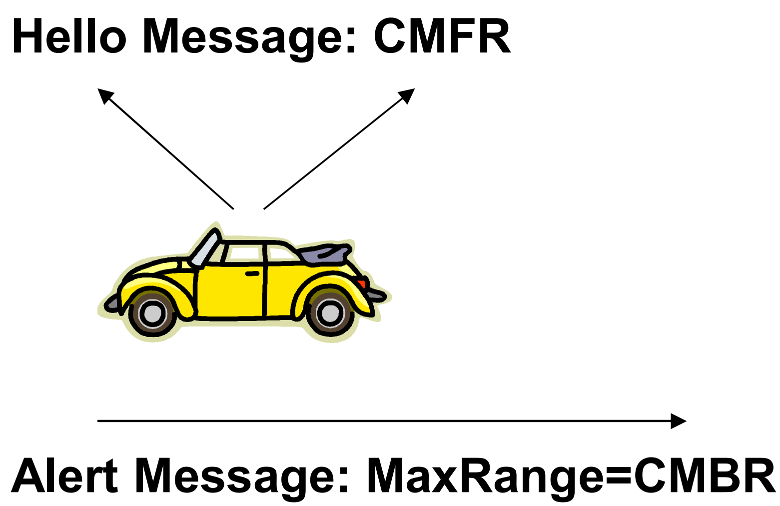
Hello Messages: Variables

CMBR: Current Maximum Backward Range

CMFR: Current Maximum Frontward Range

~~LMBR: Last Maximum Backward Range~~

~~LMFR: Last Maximum Frontward Range~~



Messages’ Different Purposes

- Distance from the sender and included CMFR are utilized for:
  - Hello messages received from the front used to compute the CMFR
  - Hello Messages received from the back used to compute the CMBR

***HM**: “This CMFR value is the maximum distance from which I have been able to hear another car in front of me”*

***AM**: “This CMBR value is the maximum backward distance at which some car would be able to hear me”*

Fast Broadcast Mechanism: Phase 2

Broadcast Phase:

- *Alert Messages* are generated by an AV
  - Alert sent in broadcast to warn following vehicles
- The *Alert Message* includes also the estimated tx range for that hop
- A node receiving the *Alert Message* waits a time that is proportional to the node's position with respect to the estimated maximum tx range

Contention Window Computation

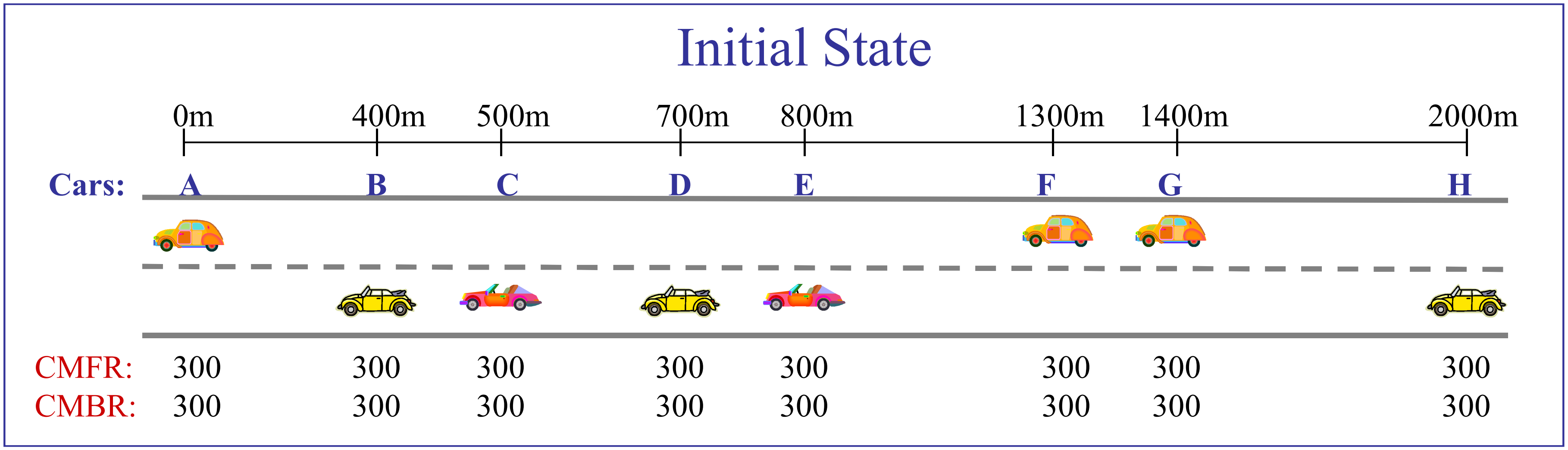
• AV broadcasts an *Alert Message* containing the Estimated Maximum Transmission Range (*MaxRange* = *CMBR*) and position

• Cars forward the Alert Message after a contention window calculated as follows:

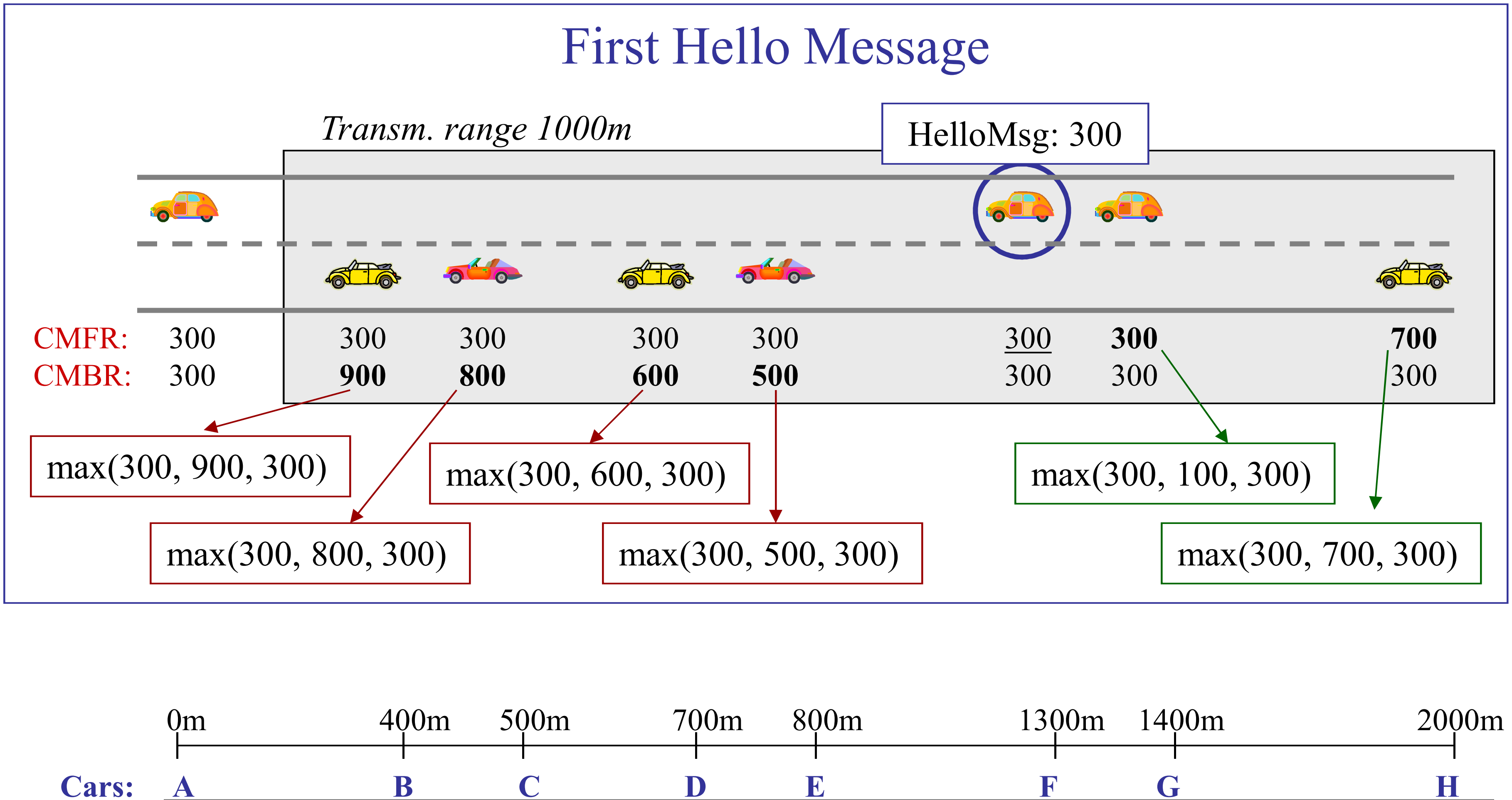
$$\left\lfloor \left(\frac{MaxRange - Distance}{MaxRange} \times (CWMax - CWMin) \right) + CWMin \right\rfloor$$

• If another car that is farther from the source than the considered one already forwarded the Alert Message, then the considered car abort its sending procedure (the message has already propagated)

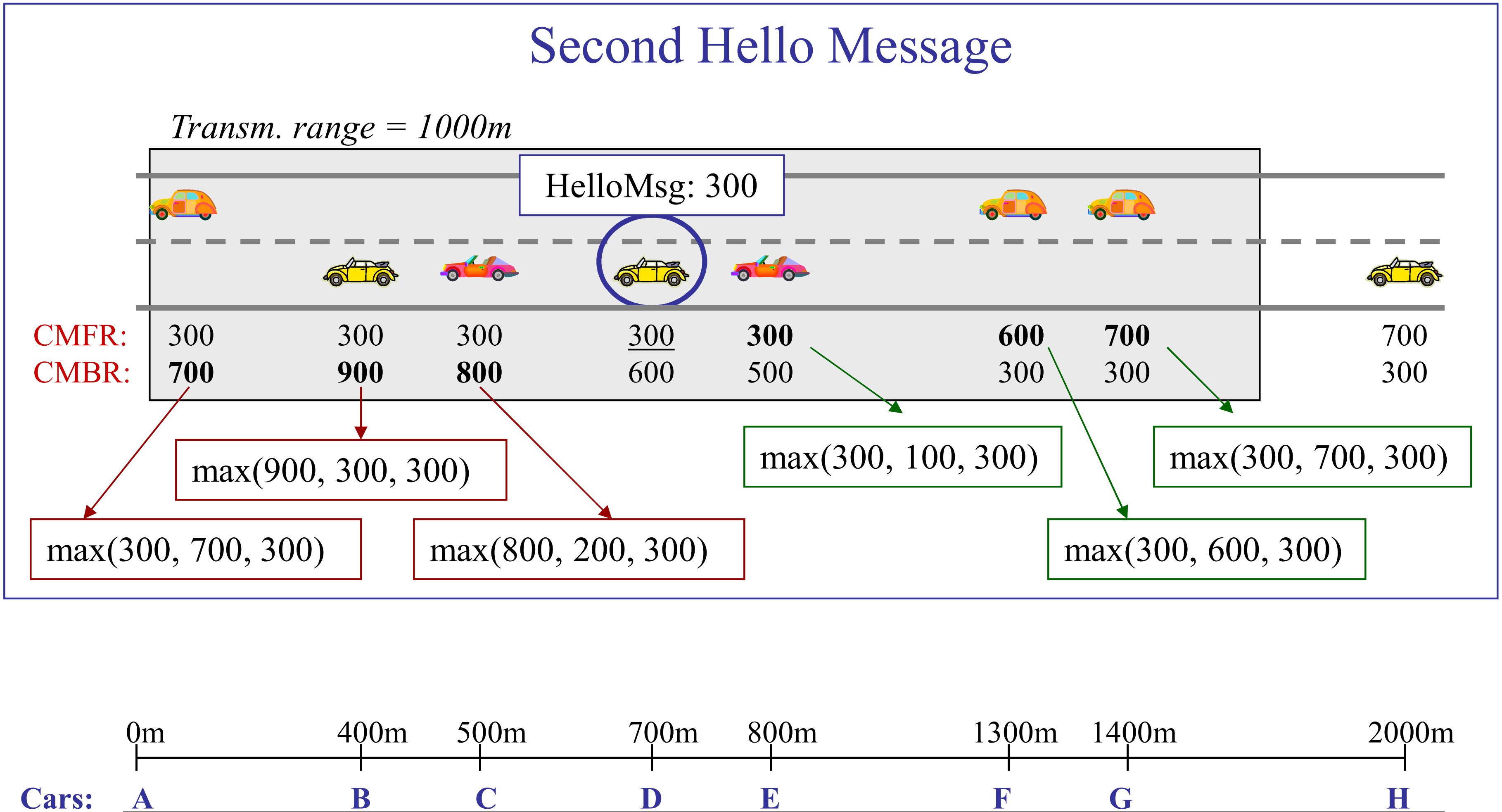
Example (1/5)


Initial State
0m 400m 500m 700m 800m 1300m 1400m 2000m
Cars: A B C D E F G H
CMFR: 300 300 300 300 300 300 300 300
CMBR: 300 300 300 300 300 300 300 300

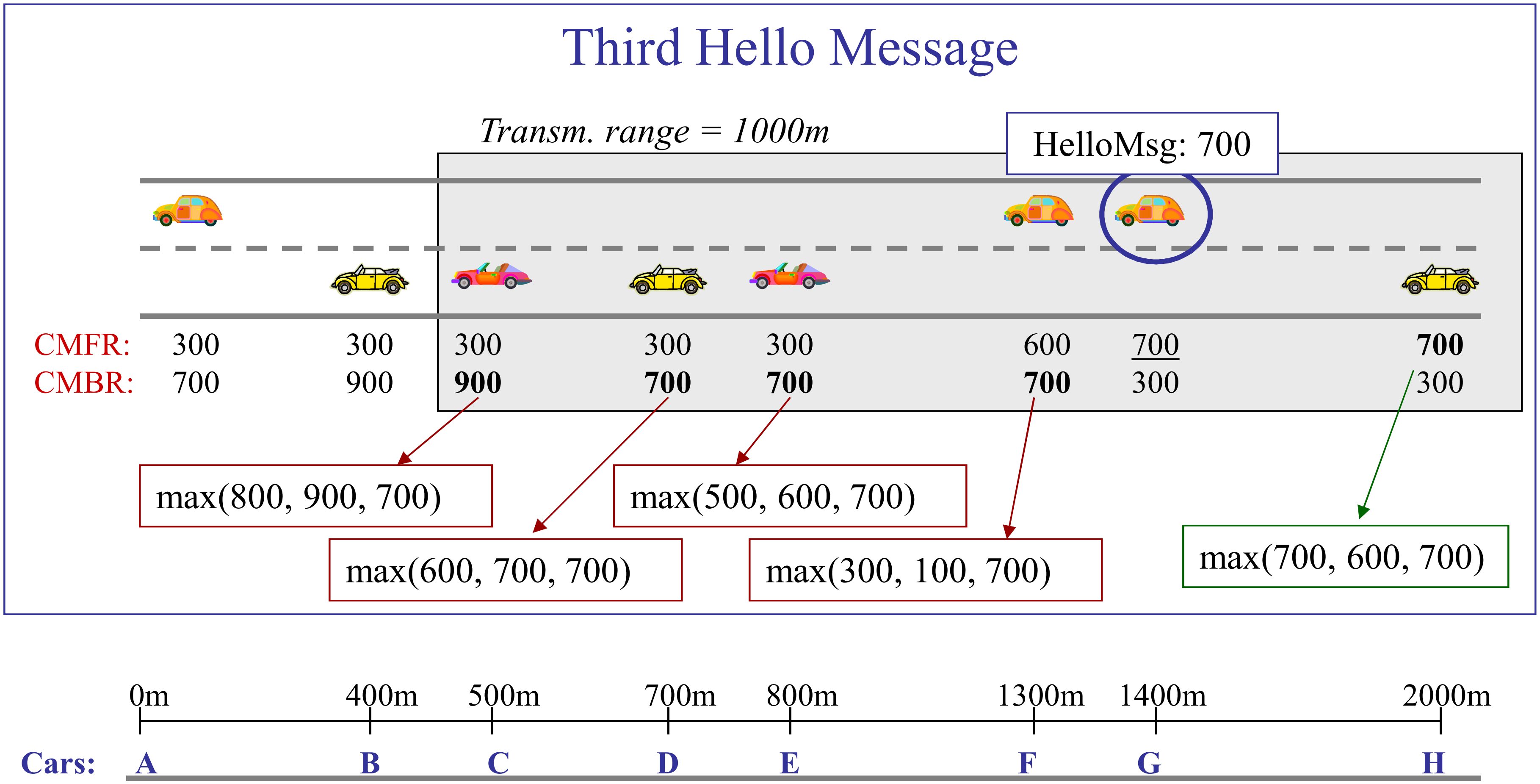
Example (2/5)


First Hello Message
Transm. range 1000m
HelloMsg: 300
CMFR: 300 300 300 300 300 300 300 700
CMBR: 300 900 800 600 500 300 300 300
max(300, 900, 300)
max(300, 800, 300)
max(300, 600, 300)
max(300, 500, 300)
max(300, 100, 300)
max(300, 700, 300)
0m 400m 500m 700m 800m 1300m 1400m 2000m
Cars: A B C D E F G H

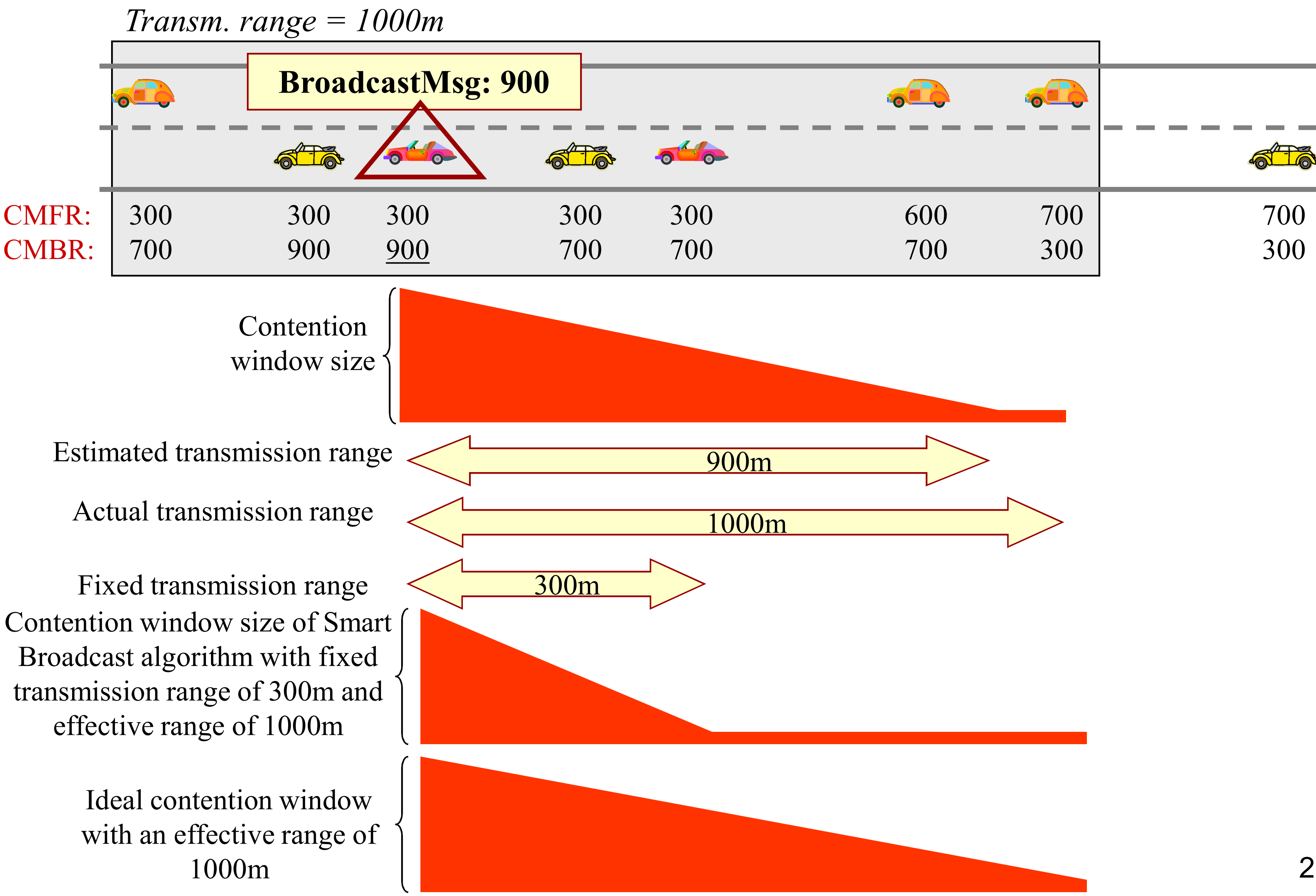
Example (3/5)


Second Hello Message
Transm. range = 1000m
HelloMsg: 300
CMFR: 300 300 300 300 300 600 700 700
CMBR: 700 900 800 600 500 300 300 300
max(900, 300, 300)
max(300, 700, 300)
max(800, 200, 300)
max(300, 100, 300)
max(300, 700, 300)
max(300, 600, 300)
0m 400m 500m 700m 800m 1300m 1400m 2000m
Cars: A B C D E F G H

Example (4/5)


Third Hello Message
Transm. range = 1000m
HelloMsg: 700
CMFR:
CMBR:
300
700
300
900
300
900
300
700
300
700
600
700
700
300
700
300
max(800, 900, 700)
max(600, 700, 700)
max(500, 600, 700)
max(300, 100, 700)
max(700, 600, 700)
0m
400m
500m
700m
800m
1300m
1400m
2000m
Cars:
A
B
C
D
E
F
G
H

Broadcast Message



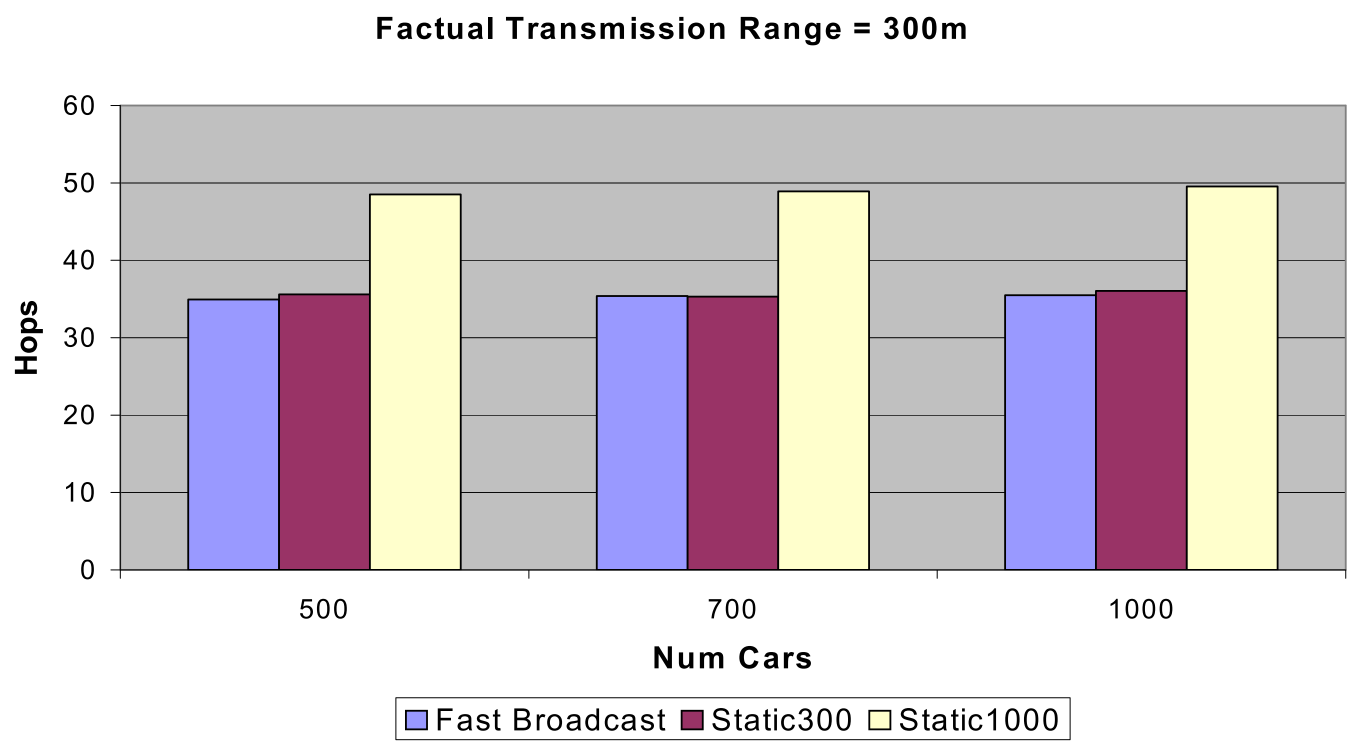
Simulation Assessment

- Strip-shaped road
- Area-of-interest of 8km.
- 20 simulations for each scenario
  - outcomes averaged
- Different numbers (densities) of cars
  - 500, 700, and 1000
- Within the same simulation, cars have various speeds
  - uniformly distributed in the range 72-144Km/h.
- CWMin and CWMax equal to 32 and 1024 slots
  - as the real IEEE 802.11 protocol
- **Two possible cases for the actual transmission range**
  - **300m and 1000m.**

Compared Schemes

- Fast Broadcasting
  - Exploits our tx range estimator
- Static300
  - considers 300m as a fixed parameter for the tx range
  - Ideal iff the actual transmission range is indeed 300m
- Static1000
  - considers 1000m as a fixed parameter for the tx range
  - Ideal iff the actual transmission range is indeed 1000m

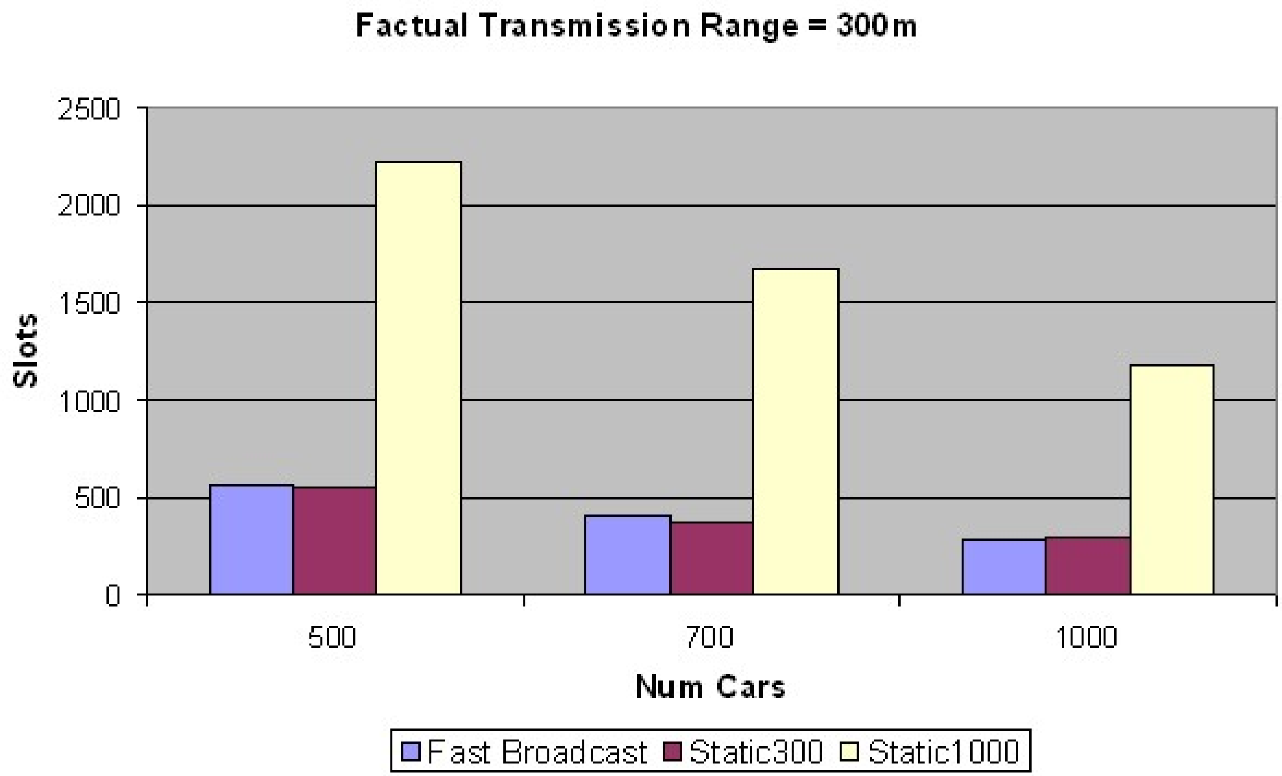
Summarizing Results (1/4): 300m of Actual Transmission Range



Number of hops required to propagate the broadcast message.

Static300 considers 300m as a fixed parameter for the transmission range
Static1000 considers 1000m as a fixed parameter for the transmission range

Summarizing Results (2/4): 300m of Actual Transmission Range

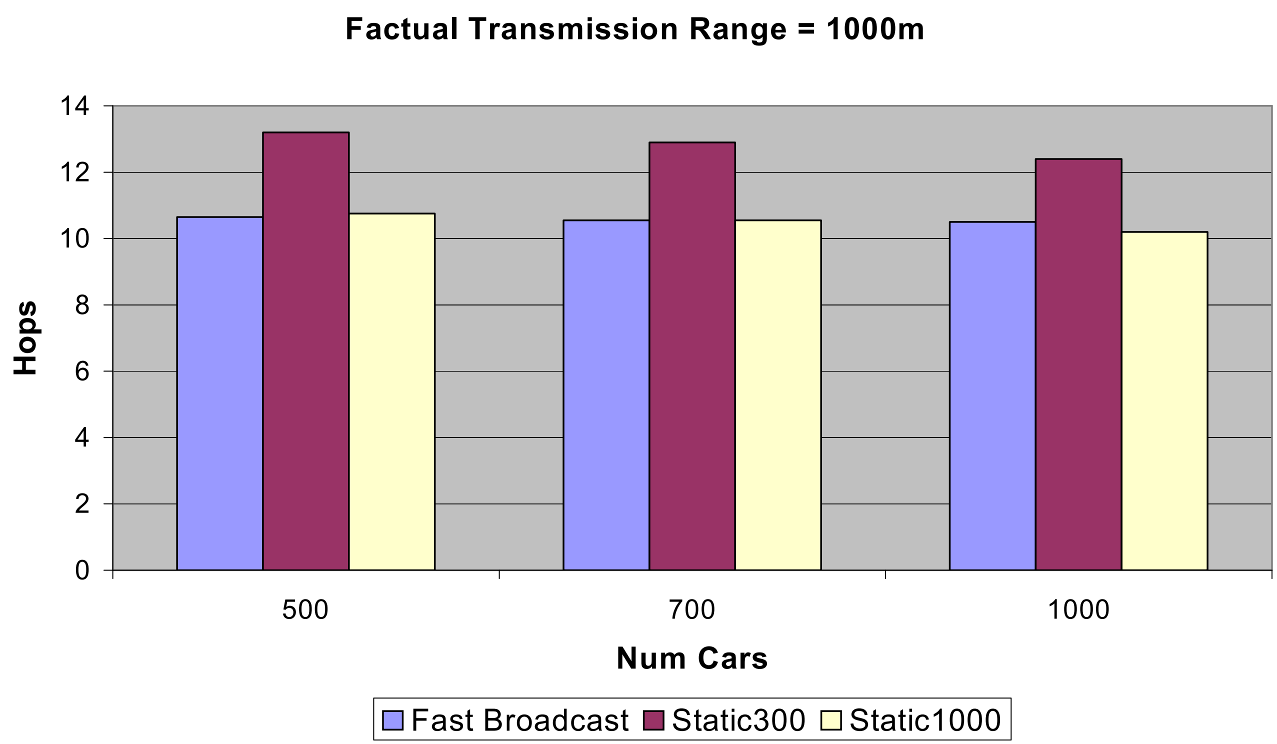


Tot number of slots waited to propagate the broadcast message.

Static300 considers 300m as a fixed parameter for the transmission range

Static1000 considers 1000m as a fixed parameter for the transmission range

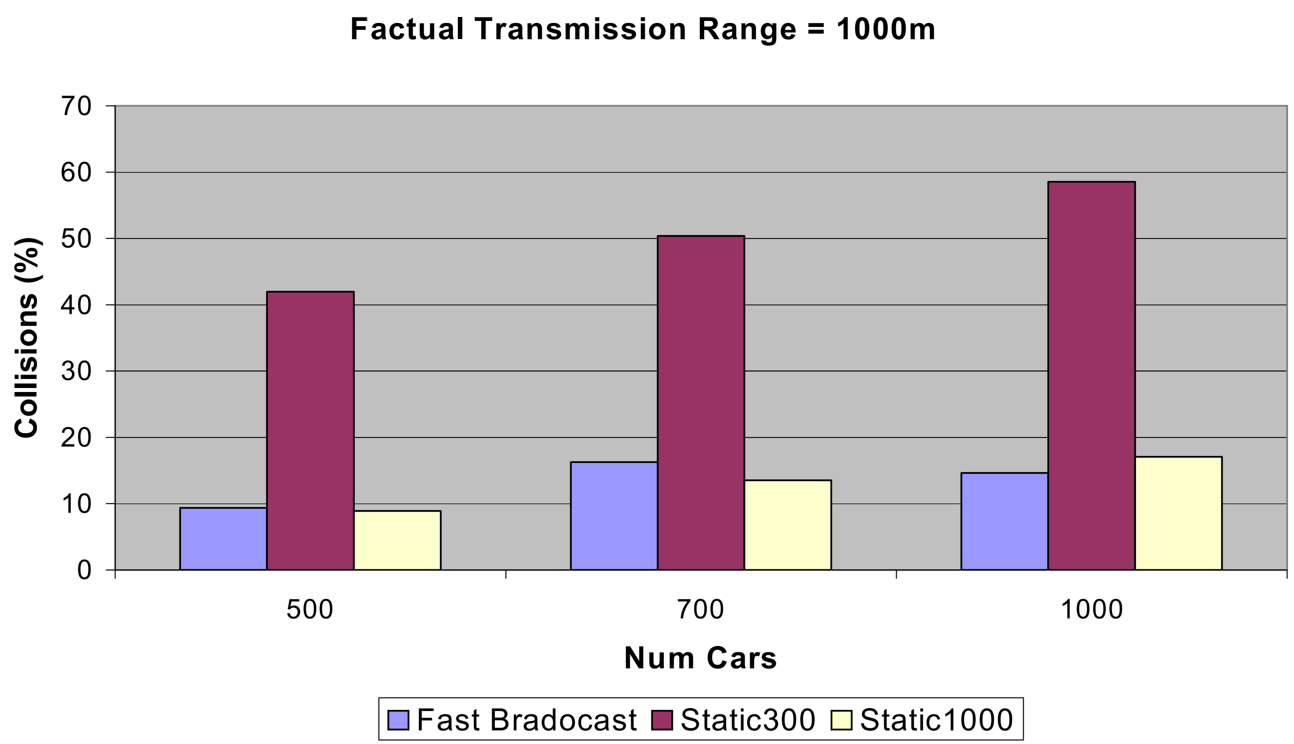
Summarizing Results (3/4): 1000m of Actual Transmission Range



Number of hops required to propagate the broadcast message.

Static300 considers 300m as a fixed parameter for the transmission range
Static1000 considers 1000m as a fixed parameter for the transmission range

Summarizing Results (4/4): 1000m of Actual Transmission Range



Percentage of Collisions to propagate the broadcast message.

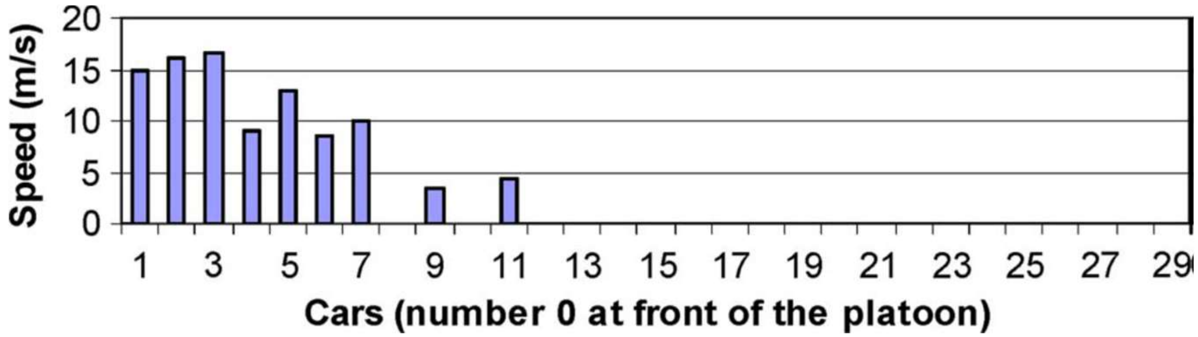
Static300 considers 300m as a fixed parameter for the transmission range

Static1000 considers 1000m as a fixed parameter for the transmission range

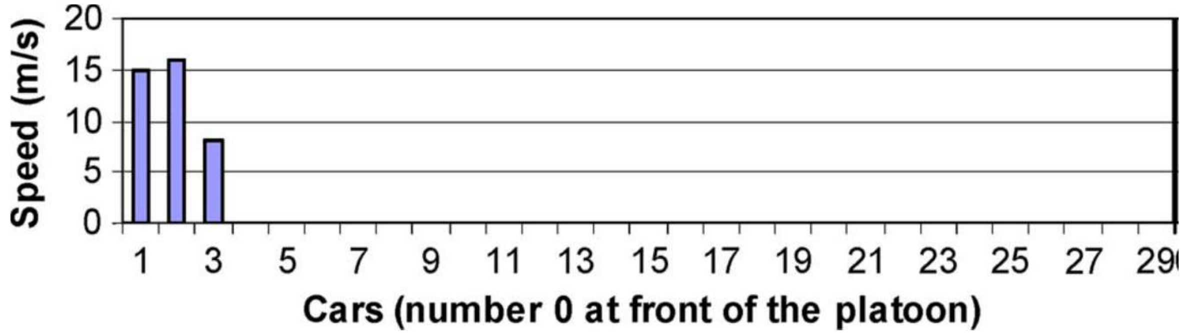
Avoiding crash accidents

Speed after stop
If speed > 0 then accident at that speed

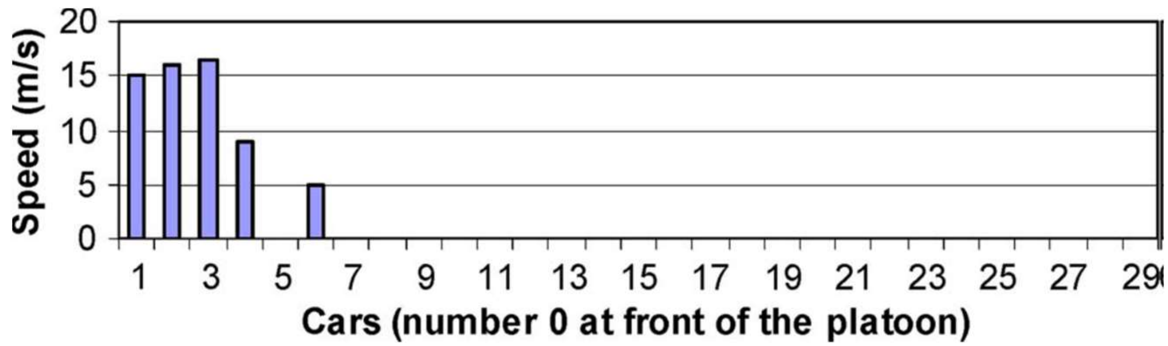
ALERT



none



all



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In Summary…

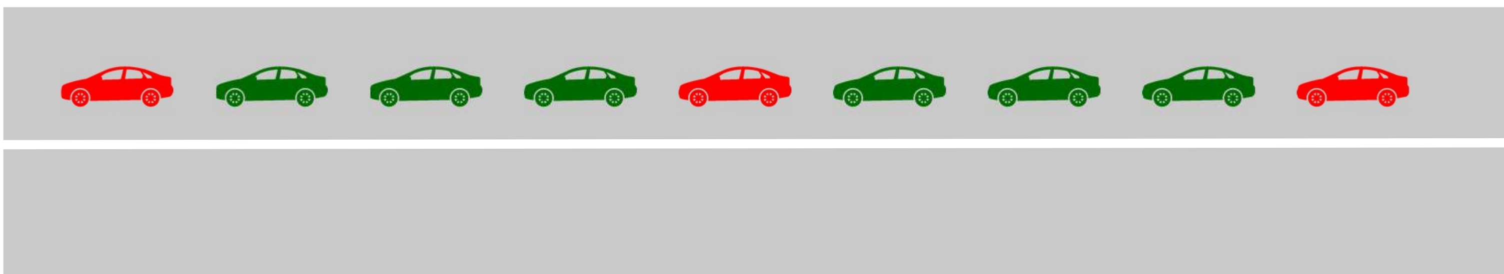
- Interferences caused by environmental conditions and cars' mobility modify transmission ranges.
  - Impact on performance of broadcasting algorithms
- Fast Broadcast is a multi-hop broadcast protocol for vehicular networks
  - Estimates the max transmission range with few hello messages
  - minimizes the number of hops to be traversed and message retransmissions, during the broadcast activity
  - reduces the delivery time

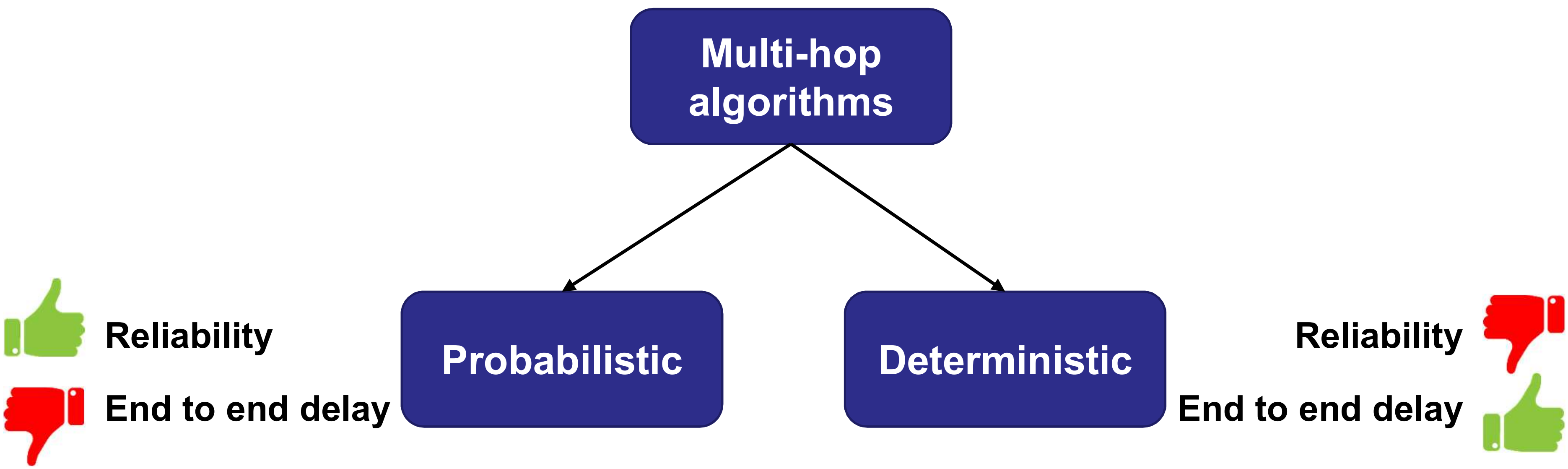
C. E. Palazzi, S. Ferretti, M. Roccetti, G. Pau, M. Gerla, "How Do You Quickly Choreograph Inter-Vehicular Communications? A Fast Vehicle-to-Vehicle Multi-Hop Broadcast Algorithm, Explained", in Proc. CCNC 2007, Las Vegas, NV, USA, Jan 2007.

C. E. Palazzi, M. Roccetti, S. Ferretti, "An Inter-Vehicular Communication Architecture for Safety and Entertainment", IEEE Transactions on Intelligent Transportation Systems, vol. 11, no. 1, Mar 2010, 90-99.

Algorithm Classification

- Multi-hop propagation
  - Farthest forwarder definition
  - Two main approaches





Probabilistic: Fast Broadcast

- Multi-hop **probabilistic** delay-based broadcasting protocol
- Dynamic transmission range estimation
  - No need to know it *a priori*, as often assumed in other protocols
- Estimation Phase:
  - Vehicles exchange small *Hello Messages* (beacons) to estimate their transmission range
  - **1 Hello Message** sent every *BeaconInterval* (e.g., 100ms) within each transmission range
- Broadcast Phase:

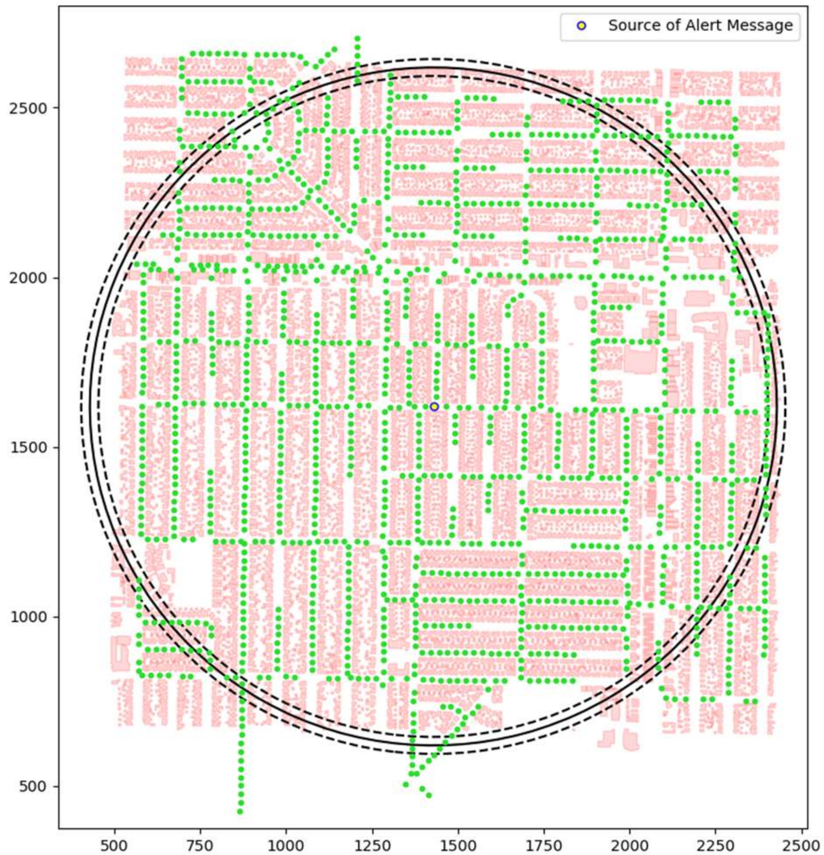
Waiting random slots within [0…X]	[0…1024]	[0…512]	[0…32]

Deterministic: ROFF

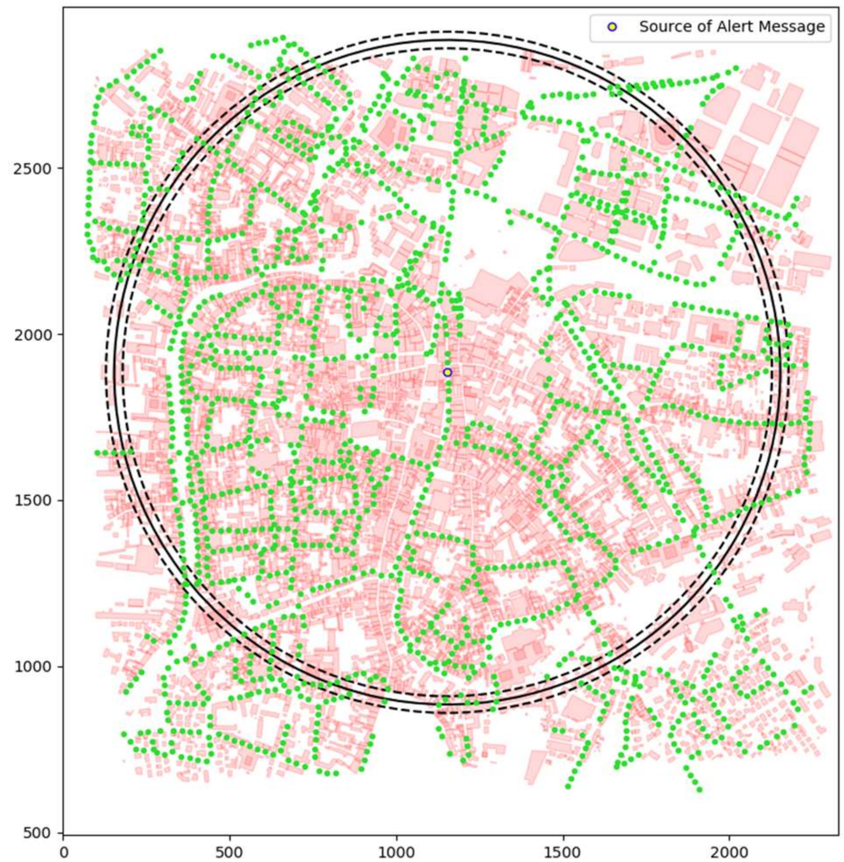
- ROFF – RObust Fast Forwarding
- Multi-hop **deterministic** delay-based broadcasting protocol
- Estimation Phase:
  - **Each vehicle** sends a Hello Message every *BeaconInterval* (e.g., 100ms)
  - Neighborhood discovery process
- Broadcast Phase:

Priority	*3*	*2*	*1*
Waiting time	2	1	0

Considered Urban Scearios



Los Angeles



Padua

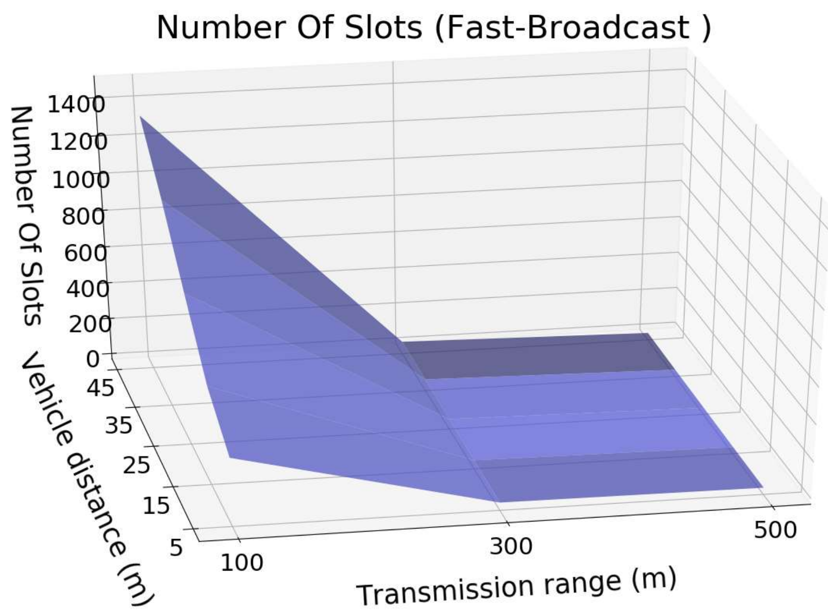
For conciseness we only show results for Padua here

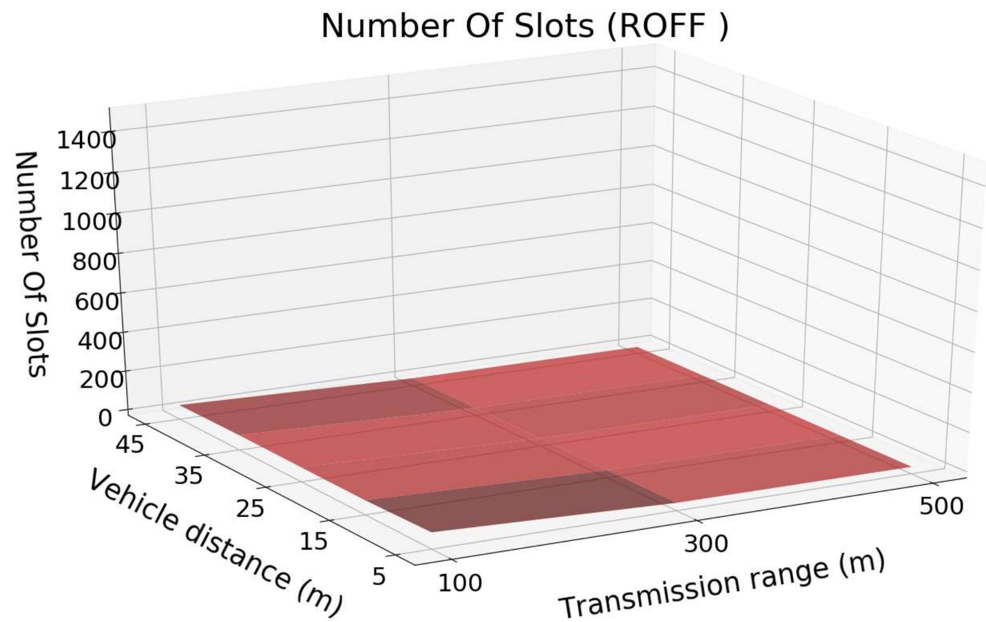
Test Configuration

Scenario configuration	
Scenario name	Padua
Latitude N [°]	45.4171
Latitude S [°]	45.3981
Longitude W [°]	11.8654
Longitude E [°]	11.8923
Circumference radius [m]	1000
Distance between vehicles [m]	5, 15, 25, 35, 45
Number of vehicles	4975, 2856, 1775, 1318, 1072
Number of simulations	4500

Simulator configuration	
Packet payload size	100 byte
Frequency [GHz]	2.4
Channel bandwidth [MHz]	22
Transmission speed [Mbps]	11
Transmission powers [dBm]	-7.0, 4.6, 13.4
Transmission ranges [m]	100, 300, 500
Modulation	DSSS
Propagation loss model	ns3::TwoRayGround
Propagation delay model	ns3::ConstantSpeed

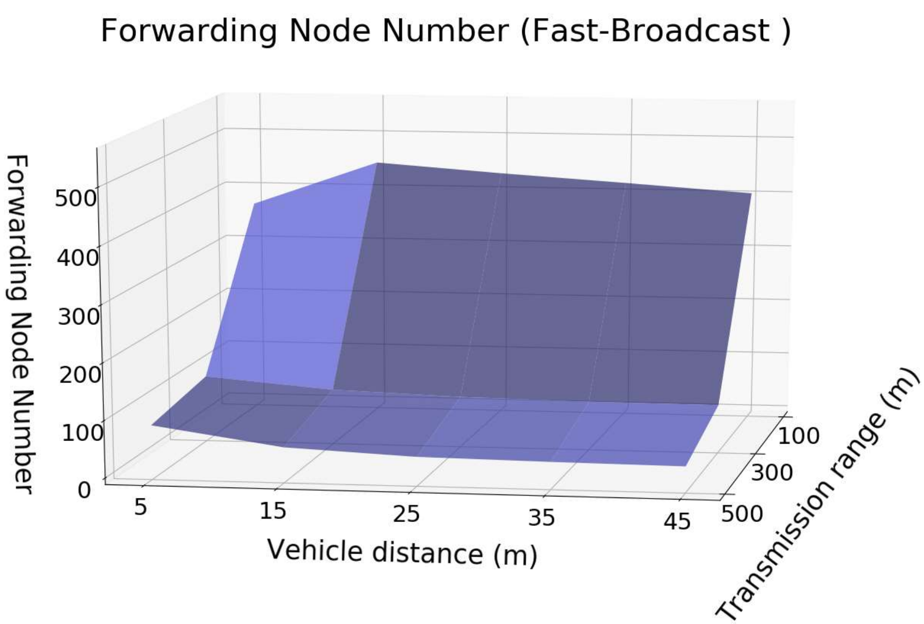
End-to-End Delay



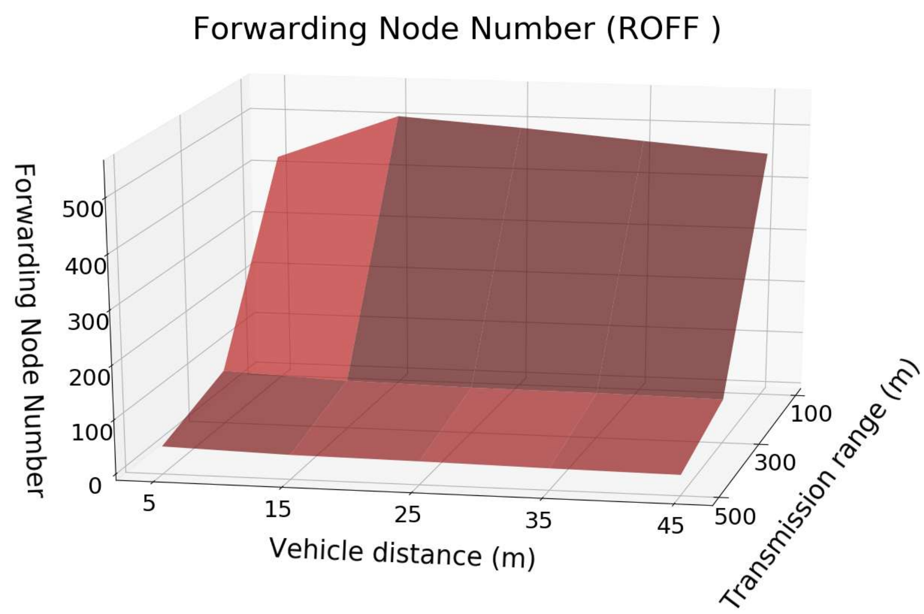


ROFF (deterministic) has less end-to-end delay in case of few vehicles

Redundancy



Forwarding Node Number (Fast-Broadcast)
Forwarding Node Number
0
100
200
300
400
500
5
15
25
35
45
Vehicle distance (m)
100
300
500
Transmission range (m)



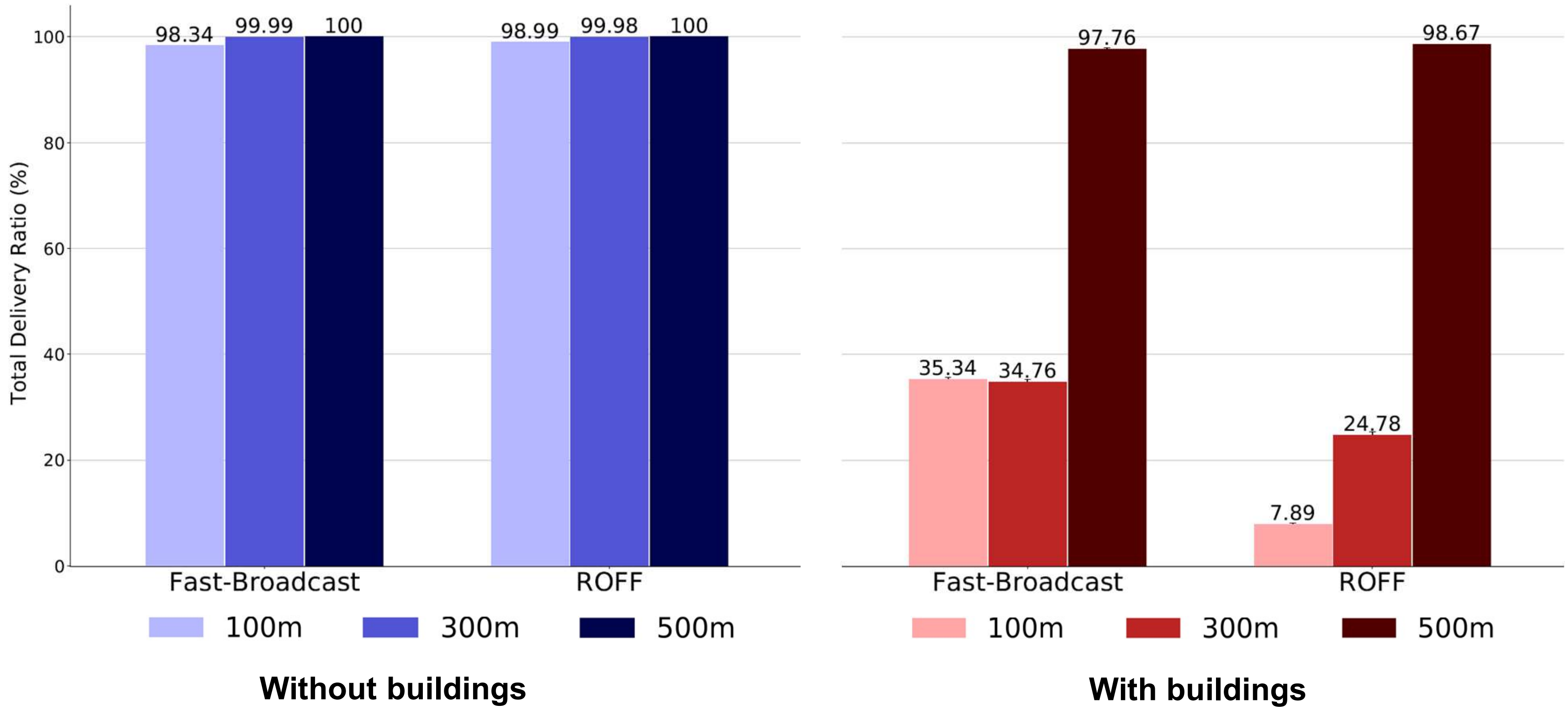
Forwarding Node Number (ROFF)
Forwarding Node Number
0
100
200
300
400
500
5
15
25
35
45
Vehicle distance (m)
100
300
500
Transmission range (m)

Padua with Buildings

Scenario configuration	
Scenario name	Padua
Latitude N [°]	45.4171
Latitude S [°]	45.3981
Longitude W [°]	11.8654
Longitude E [°]	11.8923
Circumference radius [m]	1000
Distance between vehicles [m]	25
Number of vehicles	1775
Number of buildings	**6322**
Number of simulations	4500

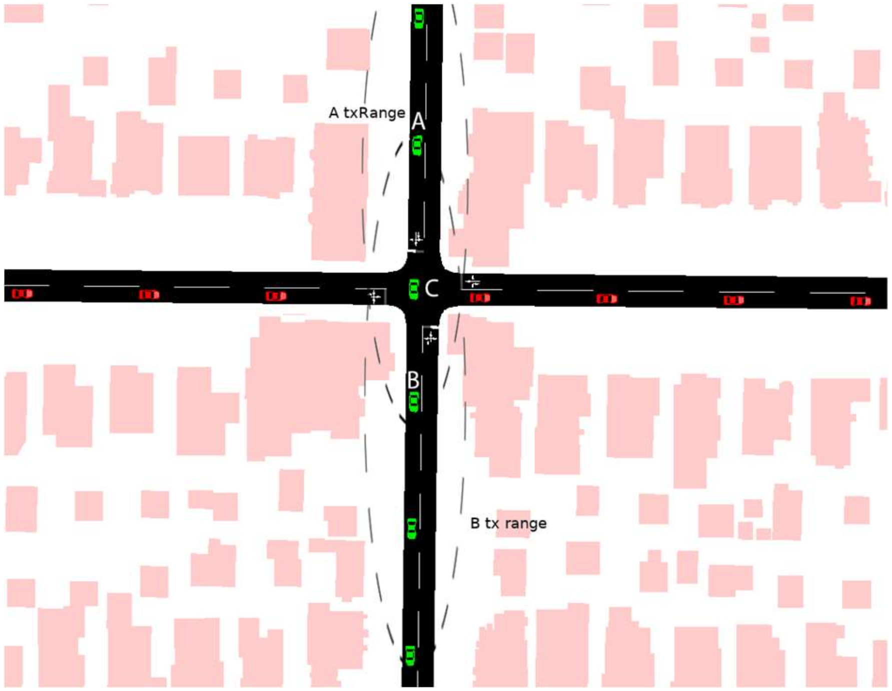
Simulator configuration	
Packet payload size	100 byte
Frequency [GHz]	2.4
Channel bandwidth [MHz]	22
Transmission speed [Mbps]	11
Transmission powers [dBm]	-7.0, 4.6, 13.4
Transmission ranges [m]	100, 300, 500
Modulation	DSSS
Propagation loss model	ns3::TwoRayGround
Propagation delay model	ns3::ConstantSpeed
Shadowing model	**ns3::ObstacleShadowing**

Padua with Buildings: Coverage

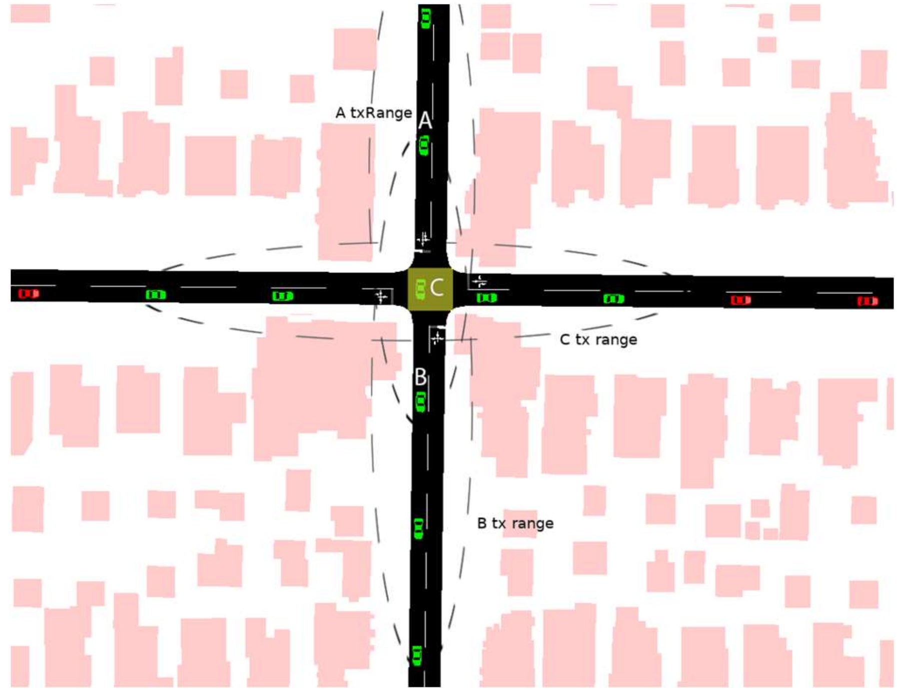


Fast-Broadcast (probabilistic) has better coverage with shorter tx range

Exploiting Junctions: Example



Without junction model



With junction model

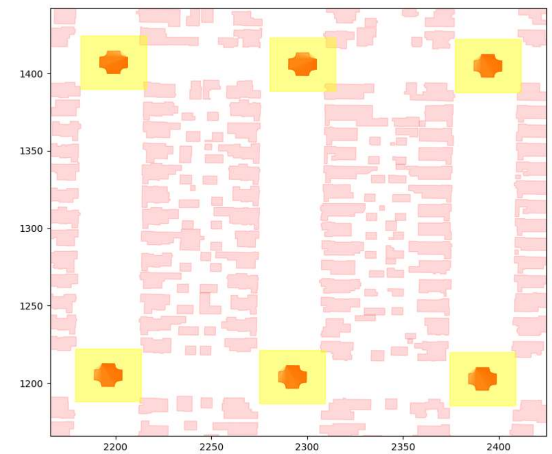
Using vehicles or repeaters at junctions as forwarders improves coverage

Junctions: Model

- Aim: exploit vehicles located within junctions to improve coverage
- Identification of junctions via OSM/SUMO tools

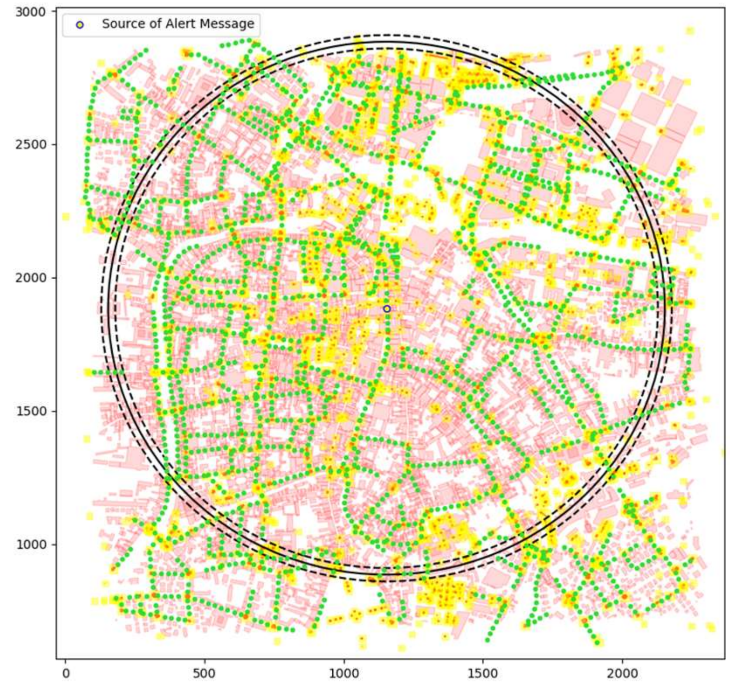
```
<junction id="1101896841" type="right_before_left" x="1261.31" y="2430.73"
incLanes="94925123#0_0 -94925123#1_0" intLanes=":1101896841_0_0 :1101896841_1_0
:1101896841_2_0 :1101896841_3_0 :1101896841_4_0 :1101896841_5_0"
shape="1262.20,2433.25 1263.07,2432.75 1262.80,2431.98 1262.85,2431.66 1263.03,
2431.39 1263.32,2431.17 1263.73,2430.99 1263.11,2429.09 1259.38,2430.19 1259.87,
2432.13 1260.78,2432.09 1261.18,2432.22 1261.56,2432.46 1261.90,2432.81">
```

- 20x20m bounding box to extend the polygon
- Vehicles within a junction participate in a **second contention**
- Extension applicable both to Fast-Broadcast and ROFF
  - SJ-Fast-Broadcast and SJ-ROFF



Junctions: Scenarios

Los Angeles



Padua

Padua with Junctions

Scenario configuration	
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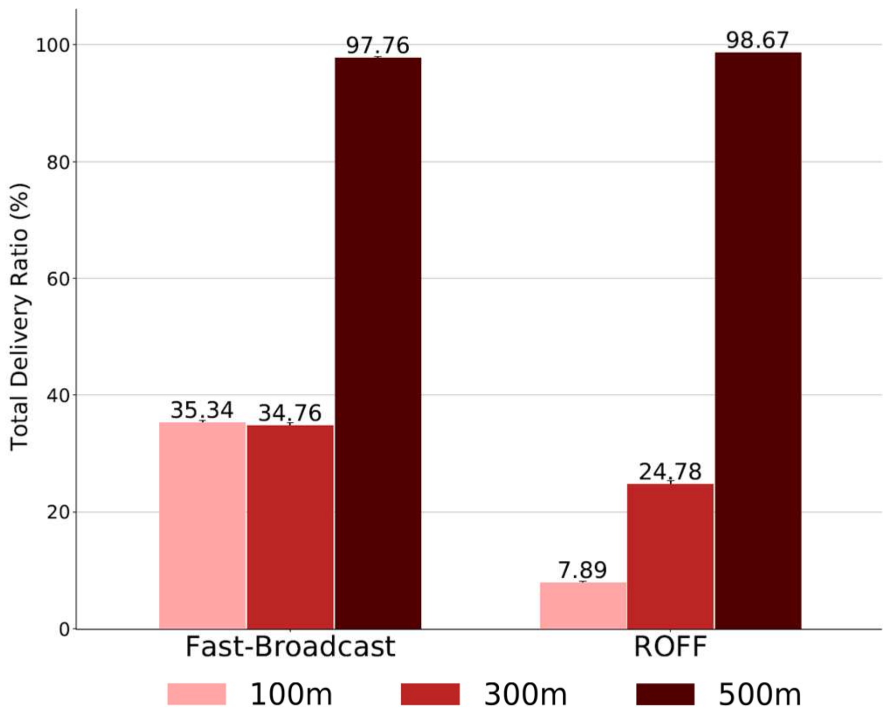
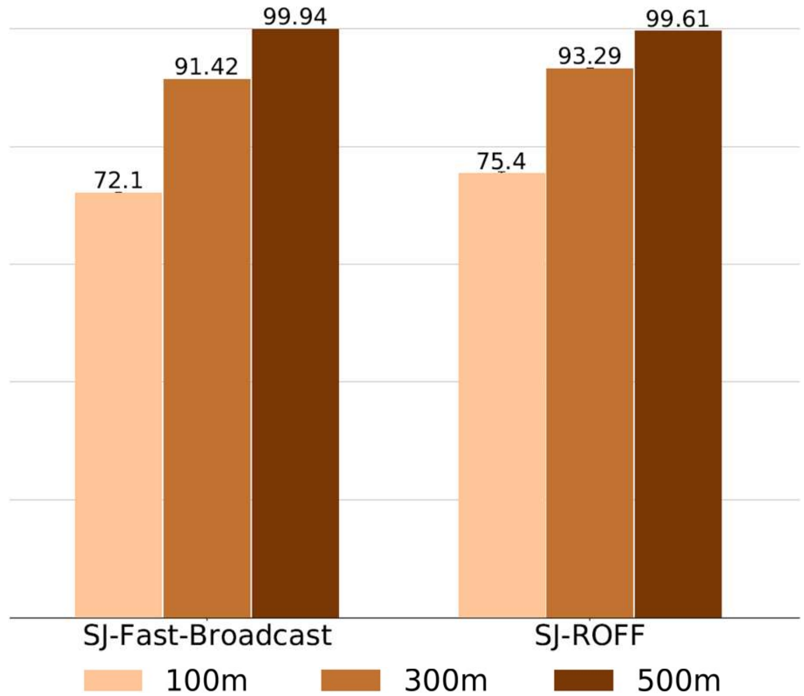
Latitude S [°]	45.3981
Longitude W [°]	11.8654
Longitude E [°]	11.8923
Circumference radius [m]	1000
Distance between vehicles [m]	25
Number of vehicles	1775
Number of buildings	6322
Number of junctions	**3231**
Number of simulations	4500

Simulator configuration	
Packet payload size	100 byte
Frequency [GHz]	2.4
Channel bandwidth [MHz]	22
Transmission speed [Mbps]	11
Transmission powers [dBm]	-7.0, 4.6, 13.4
Transmission ranges [m]	100, 300, 500
Modulation	DSSS
Propagation loss model	ns3::TwoRayGround
Propagation delay model	ns3::ConstantSpeed
Shadowing model	ns3::ObstacleShadowing

Padua with Junctions: Coverage



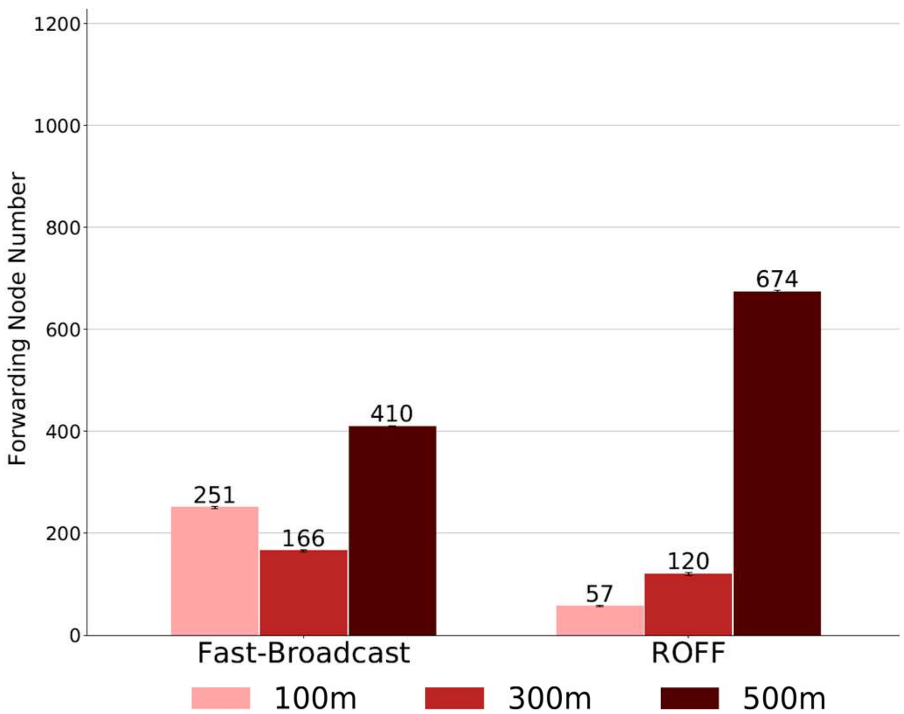
Without smart junction



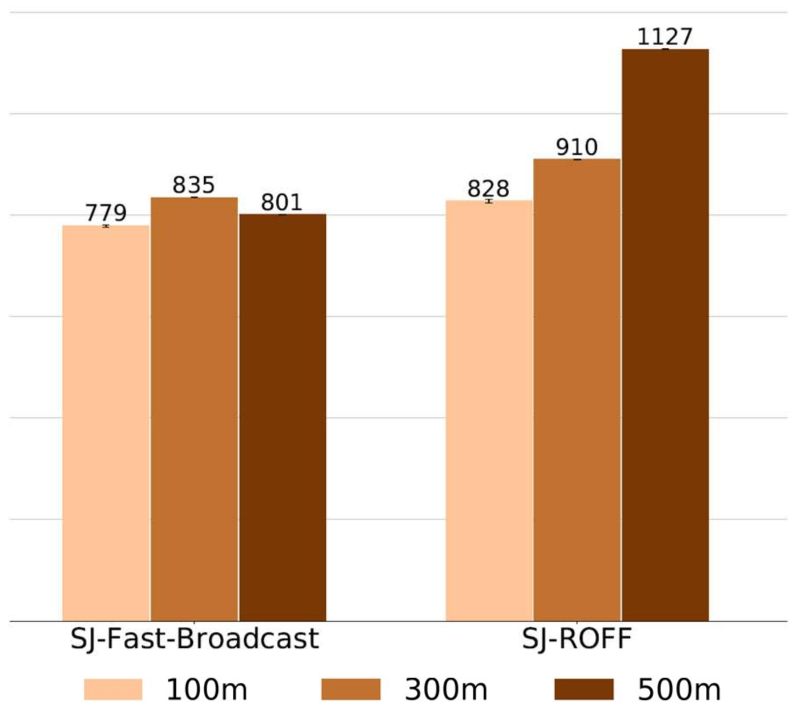
With smart junction

much better coverage

Padua with Junctions: Redundancy



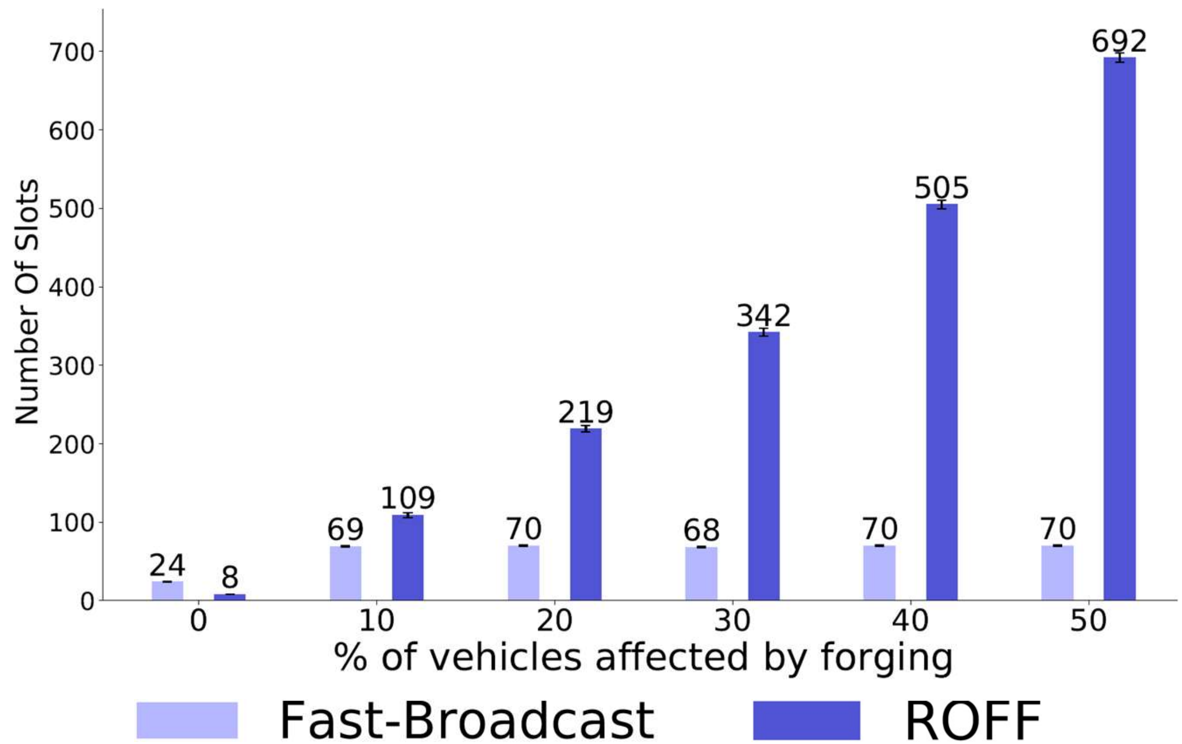
Without smart junction



With smart junction

Better coverage is paid with more messages transmitted (those at intersections are in addition to the regular ones

Forging Position Attack



Having malicious nodes declaring fals positions in their Hello Messages has a much greater impact on deterministc algorithms (ROFF) than probabilistic ones (Fast-Broadcast)

In Summary…

- Deterministic propagation algorithms such as ROFF ensure a smaller end-to-end delay than Fast-Broadcast
  - Greater redundancy
  - Determinism and collisions
  - Higher number of Hello Messages
- SJ-Fast-Broadcast and SJ-ROFF improve coverage greatly
  - At the cost of more retransmissions

C.E. Palazzi, J. Gottardo, A. Bujari, D. Ronzani, "Message Dissemination in Urban IoV", IEEE/ACM DS-RT 2019: 23rd International Symposium on Distributed Simulation and Real Time Applications , Cosenza, Italy, Oct 2019

Future Work, Projects, Thesis

Just a few examples

- Dynamic lower and upper bounds for Fast-Broadcast's waiting time calculation
  - Based on vehicle density

- Junction identification backup mode
  - Reliance on GPS
  - Compute angle between received messages to identify vehicles within junctions

- Study regarding FANETs (Flying Ad-Hoc Networks)

- Simulations or Real experiments in Antwerp
  - NS3, Omnet, etc.
  - Actual 5G+VANET highway