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Optimizing Vehicular Communication Resources:
From Vehicular Connectivity To Infrastructure Deployment

Jérôme Härri - EURECOM

Workshop on Wireless Vehicular Communications
Halmstad University, Sweden, November 9th 2011

EURECOM: A Graduate School and a Research Center in Communication Systems

- **A network of prestigious academic partners:**
  - Telecom ParisTech, EPFL (Lausanne), EPFZ (Zurich), Politecnico di Torino, Aalto University Helsinki,Technische Universität München, Norwegian University of Science and Technology (NTNU)
- **Multinational industrial partners:**
  - Swisscom, CISCO, ST-Ericsson, BMW, Symantec …
- **A multilingual environment:**
  - 100 % classes in English
  - 70 % foreign professors
  - 60 % foreign students
- **Organization:**
  - Students:
    - 160 Masters
    - 75 PhDs
  - Around 150 staff members
    - Faculty: 23
    - Research staff: 26
    - PhD students: 75
    - Teaching support staff: 8
    - Administration: 10
  - 24 visiting scientists
  - A 10,2 M€ budget in 2010

Academia

Industry

THE MOBILE COMMUNICATIONS DEPARTMENT

- **Scope**
  - Mobile Networks (radio access and infrastructure)
  - Local and cellular networks
  - Phy and Protocols
- **Themes**
  - Signal processing
  - Information theory
  - Wireless protocols
  - Wireless vehicular networks and ITS
  - Software radio platforms (including RF)
- **People:**
  - 10 Faculty
  - 15 Engineers and Postdocs
  - > 30 Doctoral Students (on site)

ITS Activities in EURECOM

- **EURECOM is involved in two ‘religions’ for Intelligent Transportation Networks (but we are not exclusive)**
  - LTE-A
  - DSRC
- **Tools (Open-source):**
  - Large scale simulation platforms with iTETRIS
  - FOT and Emulation with OpenAir Interface
- **Involved in National and European Projects for ITS**
  - National:
    - SCORE@F / VELCRI / CORRIDOR / SYSTUF
  - European:
    - LOLA/EVITA/iTETRIS
- **Intelligent Transport Networks in EURECOM**
  - LTE-A for vehicular communications
  - DSRC-802.11p: 1-hop Broadcast/Multicast / congestion management
  - Infrastructure deployment Optimizations
  - Machine-2-Machine communications
  - IPv6 Mobility - Proxi-MIPv6
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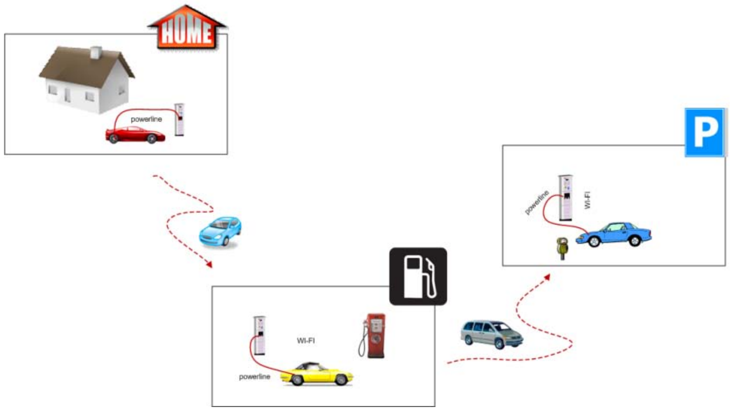
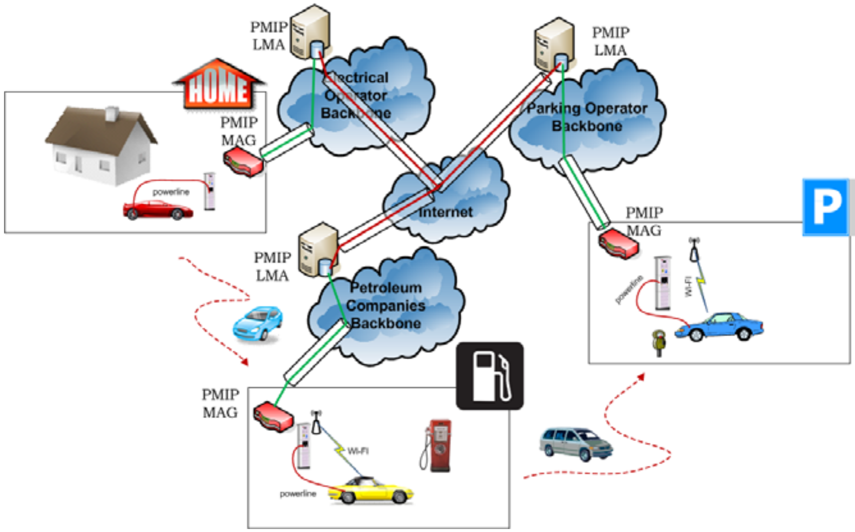
- **ITS Team**:
  - **Cross-department team**
- **MM Department**:
  - Prof. Benoît Huet
- **RS Department**:
  - Prof. Yves Roudier
- **CM Department**:
  - Prof. Bonnet
  - Prof. Knopp
  - Prof. Härri
  - Prof. Nikaein
  - Prof, Kaltenberger
  - Prof. Spyropoulos
  - M. Wetterwald

Electro-Mobility and Smart Grids

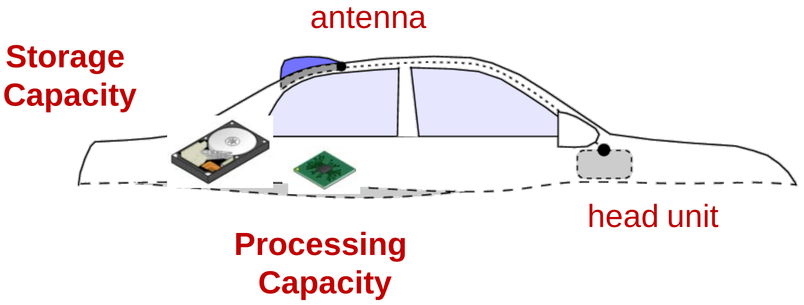
- **Distributing the Charging station**
  - In Points of Interests
  - As function of mobility
- **Designing the communication networks**
  - At the charging stations
    - Multiple interfaces
  - Between charging stations
- **Objective Function of electro-mobility**
  - Optimization of Energy
    - quick- load vs. long charge
    - Shortest path vs. least energy demanding path
    - Selling energy vs. using it



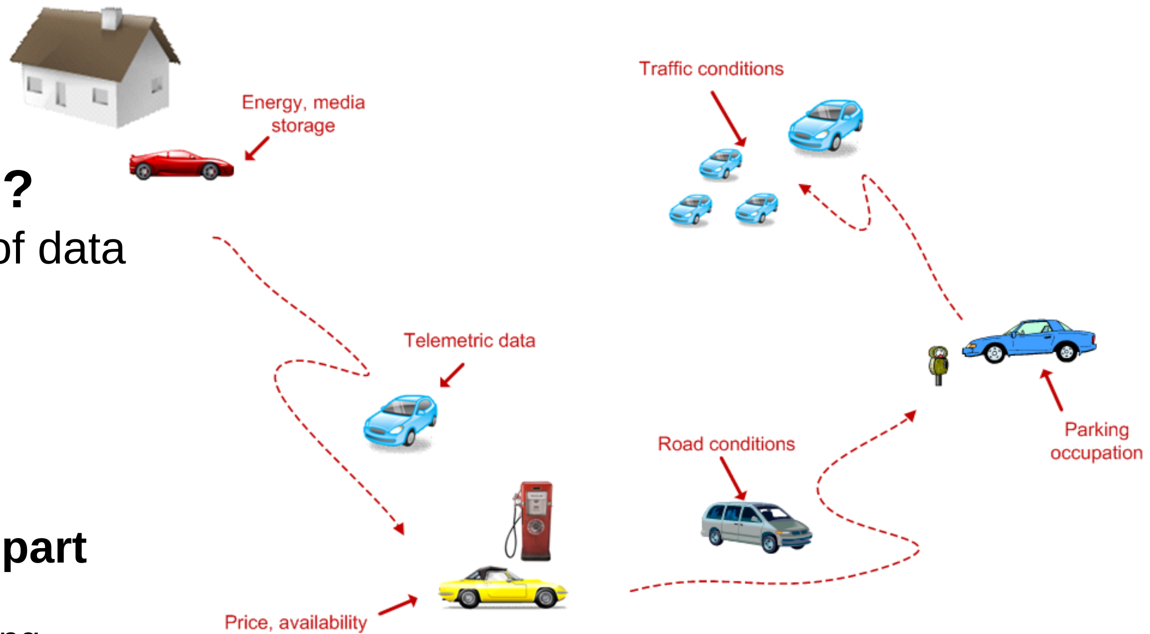


Urban Sensing and Vehicular Clouds

- **What does a vehicle contain?**
  - Antennas, head unit,…
  - Also: storage and processing capabilities
    - Could be used !!

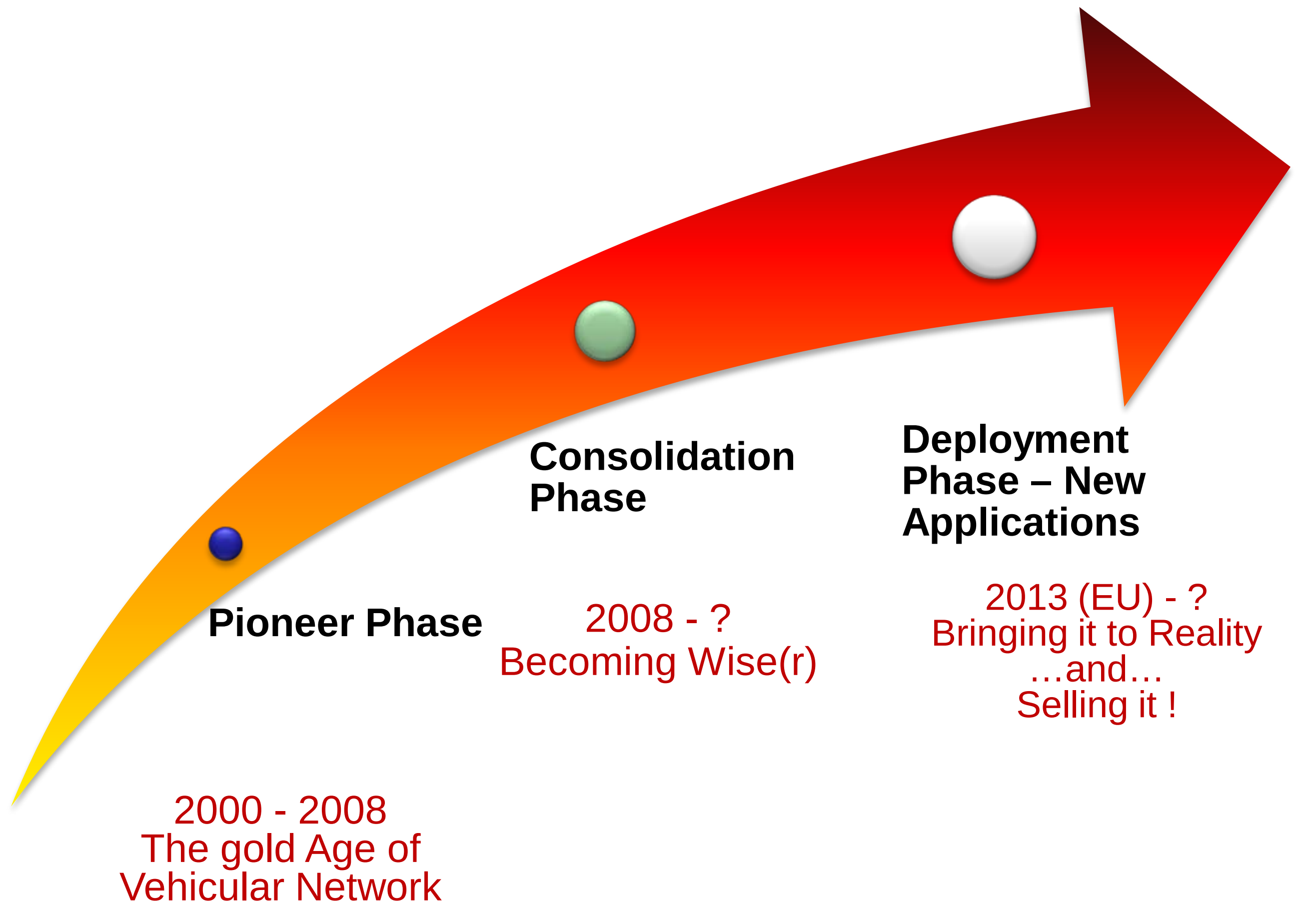


- **What does a vehicle do?**
  - Gathers a large amount of data
    - What to do with it?
    - Where to store it?
    - Where to process it?



- **Vehicles are connected and part of a vehicular cloud**
  - Mobile storage, mobile processing…

Evolution Phases in Vehicular Communications for ITS



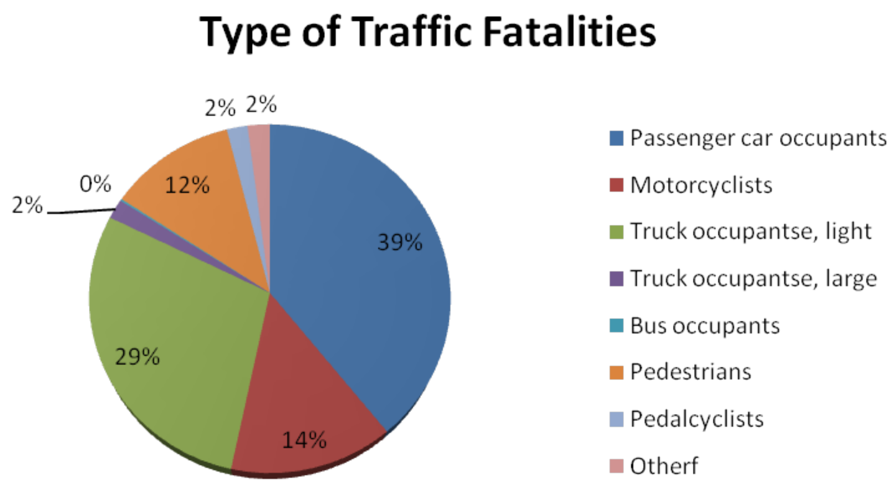
Safe Traffic

- **According to the American Automotive Association study [1], the cost for the US economy of traffic accident is 160 billion $ yearly**
  - Approx $1000 per citizen per year

[1] Car Accidents In The US Cost $164.2 billion, 2008]

- **Traffic Fatalities in the US between 1996-2006**
  - Approx 40,000 human beings per year, the size of a city like Grasse !

	Cars
Population	250,851,833
Crashes	5,973,000
Fatalities	42,642
Injuries	2,575,000
Cost	160 billion



[Source: National Transportation Statistics, Bureau of Transportation Statistics]

Sustainable Traffic

- **Traffic Congestion is estimated to cost approximately the UK economy 15 billion € [1] yearly**
- **UK department of Transportation estimates an increase in congestion in 2010 of 25% over the value of 2000[1].**
- **Reducing traffic congestion could also reduce CO_2 emissions by up to 10% over 10 years[1].**

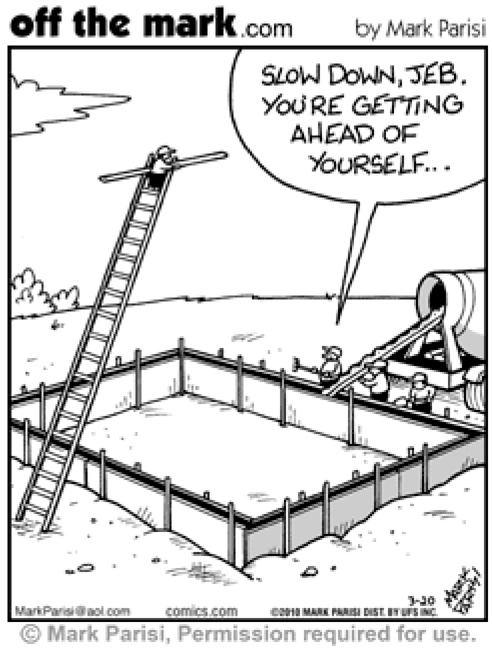
[1] Feasibility Study of road pricing in the UK, UK department of transportation, 2004]

- **Example of successful regulation of Traffic Congestion: London[2]**
  - 15% reduction in traffic
  - 30% reduction in congestion
  - 12% average speed increase

[2] London's Congestion Charge, Institute for Fiscal Studies , 2003]

- **Traffic Efficiency is therefore also a promising application !**

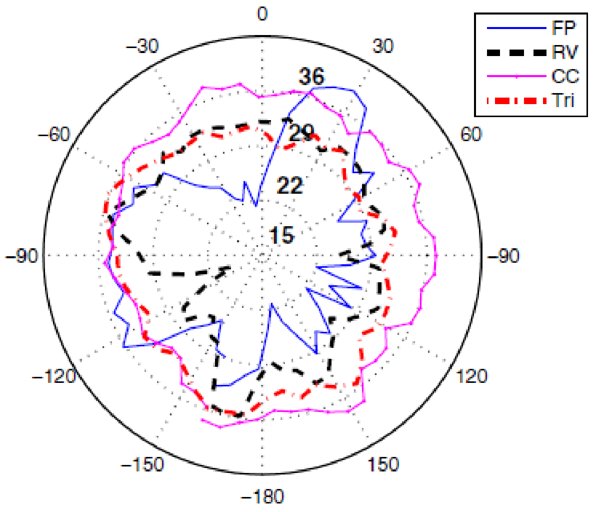
The world of Vehicular Wireless Networks



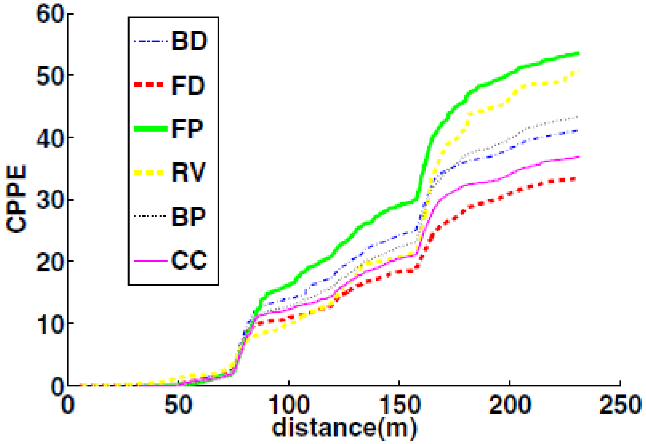
- **Not sounding too dramatic:**
  - Have we asked ourselves the right questions?
  - What will come next ?

Multiple Antenna Techniques and Testing

- **Impact of Antenna Placement on vehicles:**
  - Unidirectional Radiation:



  - *Cumulative percentage packet error:*

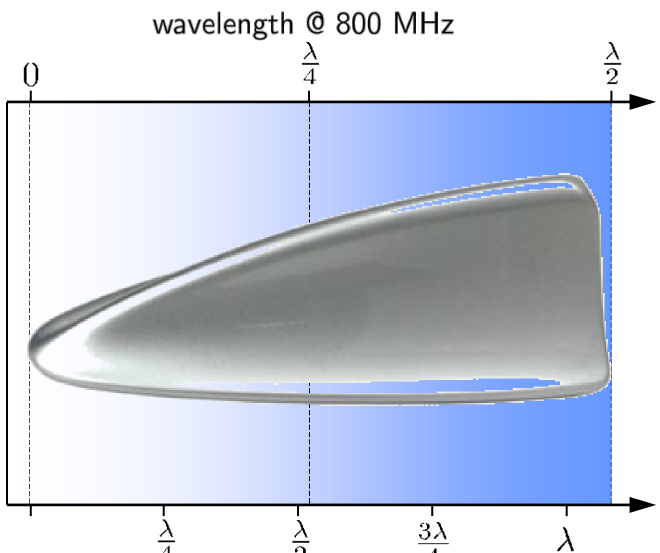


Legend:
- FP: Front Passenger
- FD: Front Driver
- BD: Behind Passenger
- CC: Car root center
- RV: Rear-view Mirror
- CC: Car-roof Center

Source: S. Kaul et al., "Effect of Antenna Placement and Diversity on Vehicular Network Communications", ICC 2010

Multiple Antenna Techniques and Testing

- **The antenna challenge**
  - Multi-standard & multi-mode functionality
  - Integration of multiple antennas with **limited form factors**
  - Integrated into a dielectric housing



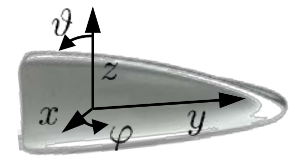


Fig. 3: Dielectric housing

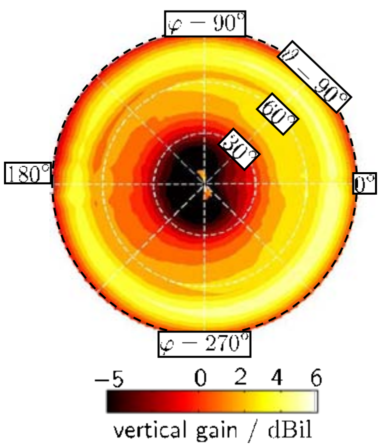


Fig. 1: Standalone Antenna

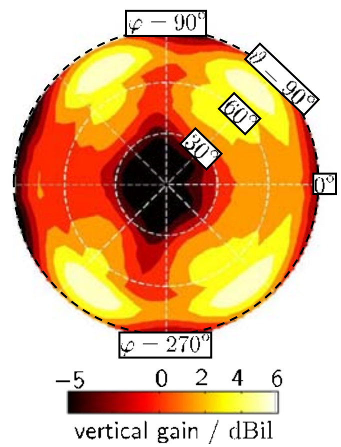
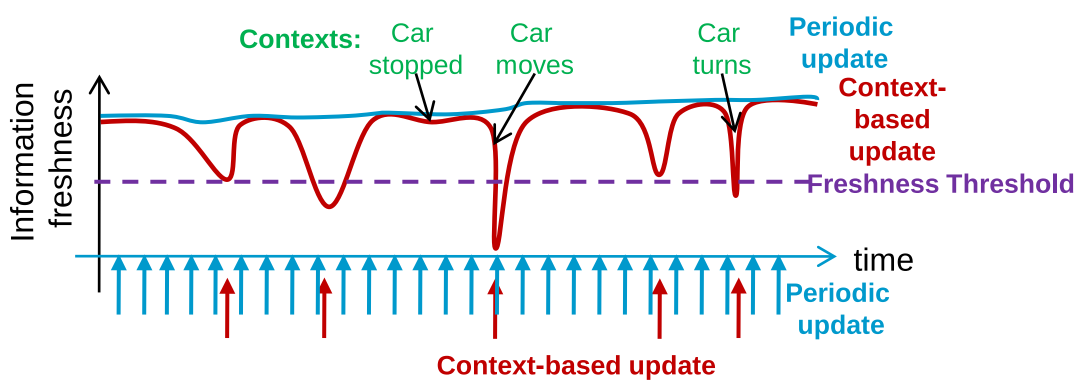


Fig. 2: Antenna with dielectric housing

Source: Oliver Klemp, BMW R&D, Munich, Germany, Oliver.Klemp@bmw.de

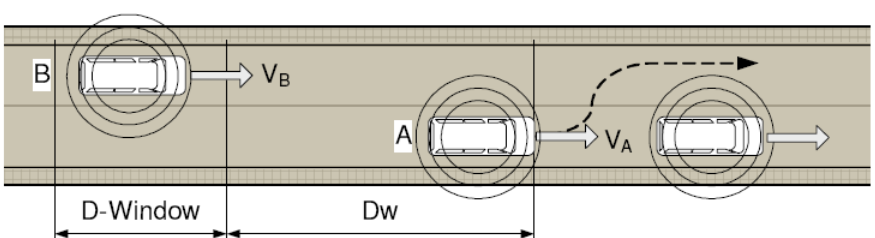
Application(s)-centric: Information Relevance

- **Information relevance communication**
  - Information does not have the same worth/relevance in space or time
  - Not adapted to application requirements
  - <u>Channel Congestion</u>: cannot provide maximal freshness and coverage everywhere
    - But could adjust transmit profiles to provide it where and when needed
- **<u>Example</u>: Cooperative Application-based TX Rate control**



[Source: Fatma Hrizi, Jérôme Härri, Christian Bonnet, " **Every Bit Counts: Tracking and Predicting Awareness**"]

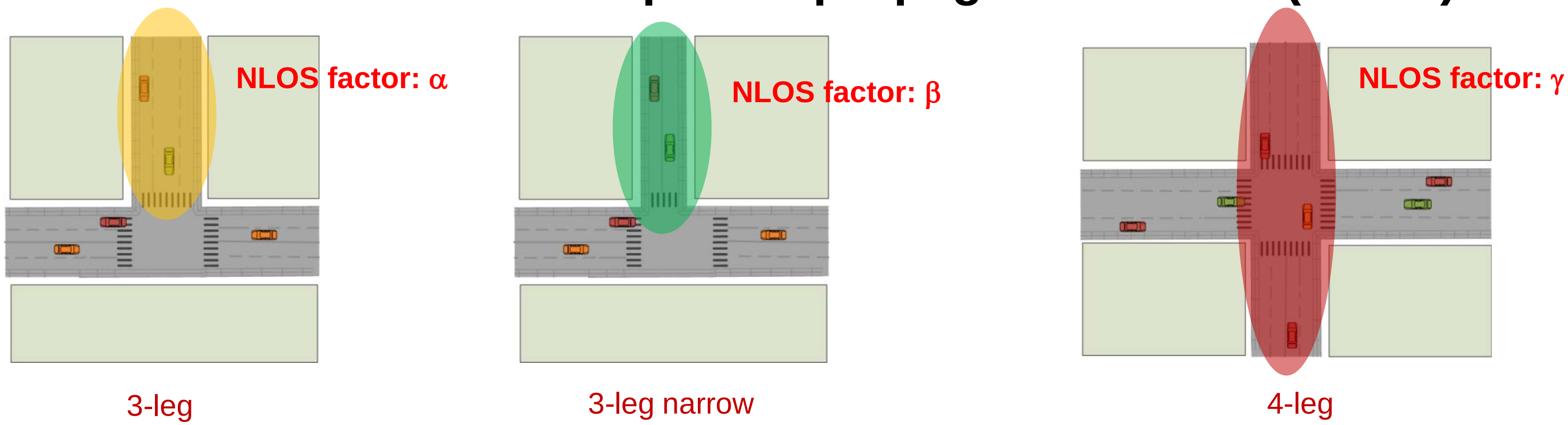
- **Example: Cooperative Application-based TX Power control**



[Source: Miguel Sepulcre, Javier Gozalvez, Jérôme Härri and Hannes Hartenstein, " **Application-based Congestion Control Policy for the Communication Channel in VANETs**"]

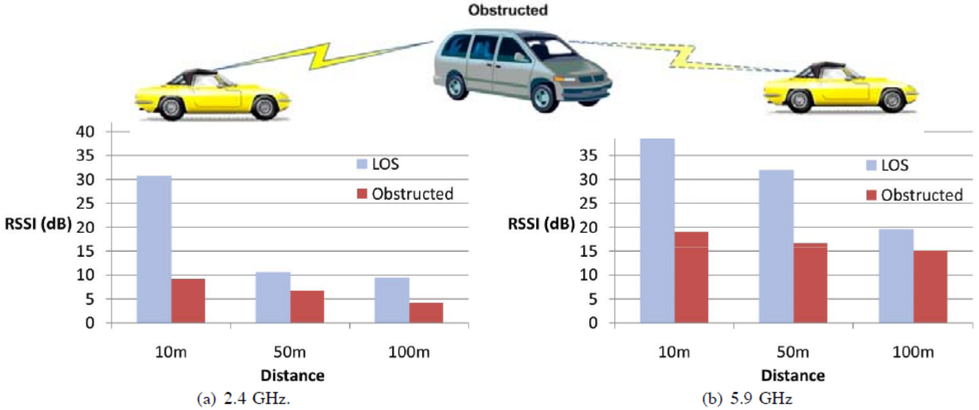
Static and Mobile Radio Obstacles

- **Urban areas have location-specific propagation values (NLOS)**



Source: T. Mangel et al., "**Vehicular Safety Communication at Intersections: Buildings, Non-Line-Of-Sight and Representative Scenarios**", IEEE WONS 20

- **Not all vehicles are to be considered similar**



Source: M. Boban et al., "**Impact of Vehicles as Obstacles in Vehicular Ad Hoc Networks**", IEEE JSAC 2010

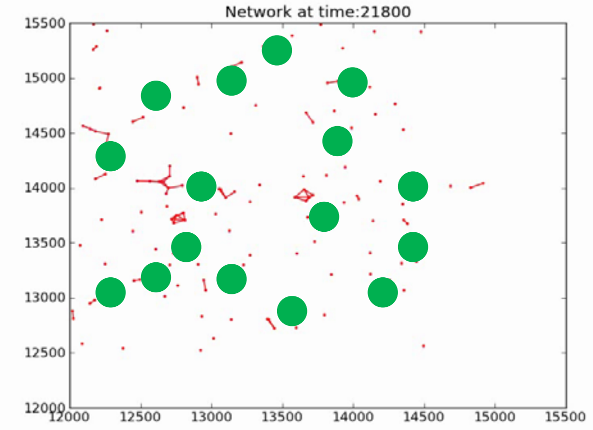
Connectivity Characteristics in Vehicular Networks – Different Worlds

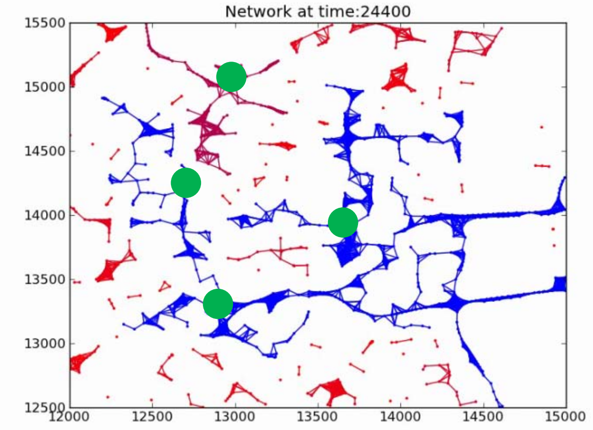
- **Vehicular Communications have different Connectivity characteristics**

Traffic Efficiency / Infotainement	Traffic Safety
Mostly Unicast	Mostly Broadcast
Link Connectivity	P-Connectivity
Bursty Traffic	Mostly Periodic Traffic
Throughput Oriented	Message Oriented
Delay ‘tolerant’	Delay Centric
Large-scale	Local Scale
Infrastructure Required	Limited Infrastructure Requirements

Connectivity Analysis

- **Sparse Initial Vehicular Network:**
  - Network strongly disconnected
    - Requires infrastructure assistance
- **Mature Vehicular Network:**
  - Network is clustered
    - Requires partial infrastructure assistance
- **Common Aspect:**
  - Deployment not based on coverage
    - Rather on connectivity context
      - Mobility, degree, NLOS..
- **Trade-off**
  - Optimizing connectivity: customer satisfied
  - Minimizing infrastructure size: provider satisfied





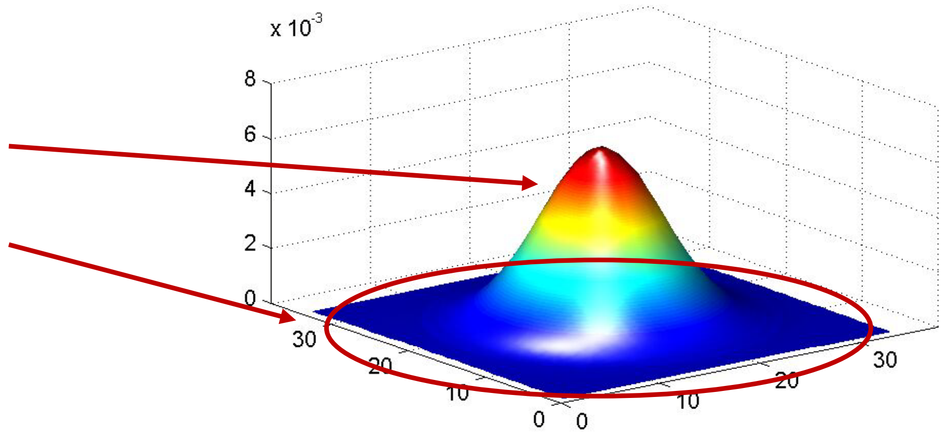
M. Fiore, J. Härri, The Networking Shape of Vehicular Mobility, ACM Mobihoc 2008, Hong Kong, 2008
P. Cataldi, J. Härri, User/Operator Utility-Based Infrastructure Deployment Strategies for Vehicular Networks, IEEE WiVEC 2011, San Francisco, 2011

CONNECTIVITY-BASED INFRASTRUCTURE DEPLOYMENT

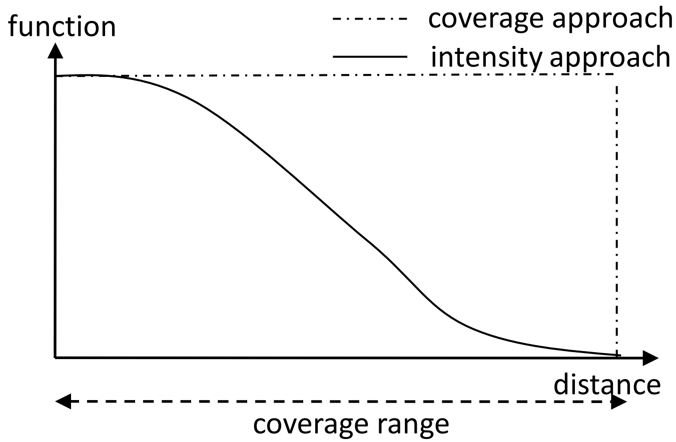
P. Cataldi, J. Härri, User/Operator Utility-Based Infrastructure Deployment Strategies for Vehicular Networks, IEEE WiVEC 2011, San Francisco, 2011

Infrastructure Connectivity vs- Coverage

- **Coverage does not reflect connectivity**
  - Intensity of the connectivity
  - Pure Coverage



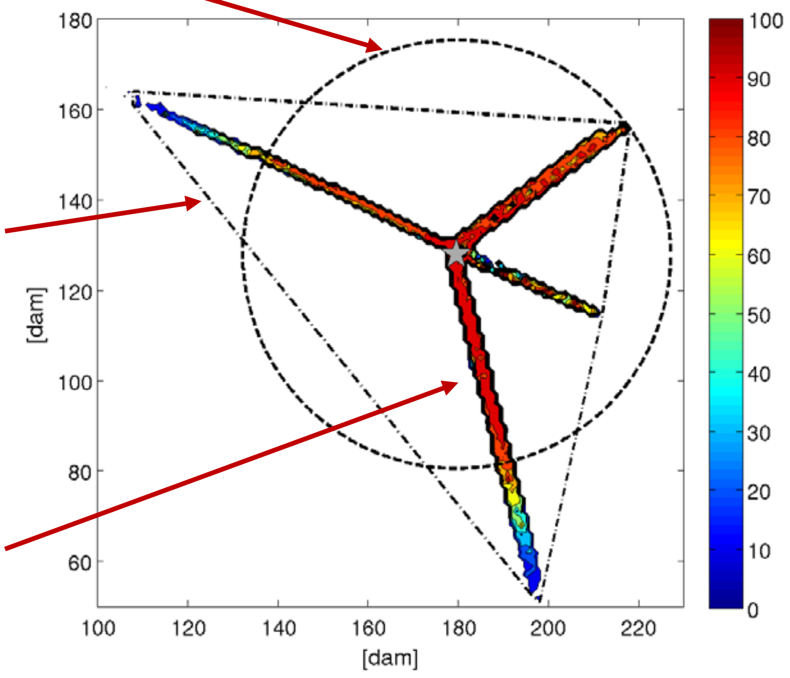
- **Coverage Intensity Function**
  - Generic Function
  - In this work:
    - WINNER B1
    - Path loss + Shadow Fading + Fast Fading
    - Considering LOS/NLOS



Connectivity vs. Coverage

Over-estimation of Coverage

- **Circular homogeneous coverage-based approach**
  - Does not reflect directional coverage
  - Over-estimates coverage, also where not possible/necessary
- **Convex Polygon-based coverage-based approach**
  - Reflects directional coverage
  - Still over-estimates coverage, also where not possible/necessary
- **Non-convex polygon-based coverage-based approach**
  - Reflects directional coverage
  - Manages to estimate coverage with more granularity

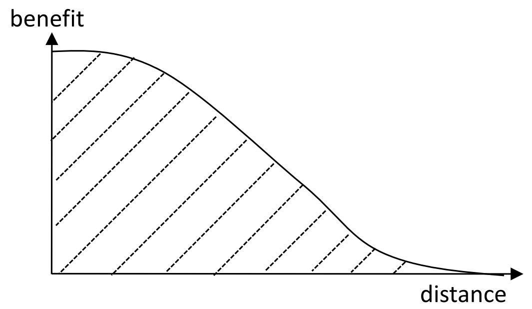


Infrastructure Optimization Algorithm

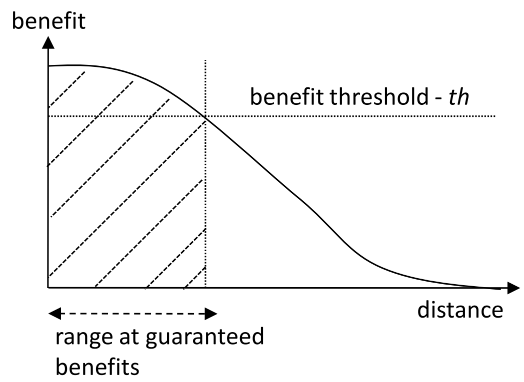
***Maximum Benefit Problem**: Given a collection* of N sets S = {s_1, s_2, ..., s_N}, where each set is a subset of a given set of ground elements E = {e1, e2, ..., eM}, each of those associated with a benefit value w(ej), select the k sets that maximize the benefit of the union set U.

- **Known NP-Hard Problem**
  - Solved using a Greedy Formulation
    - Iterates over E to find e_x maximizing the benefit of U

- **Two Benefit Functions:**



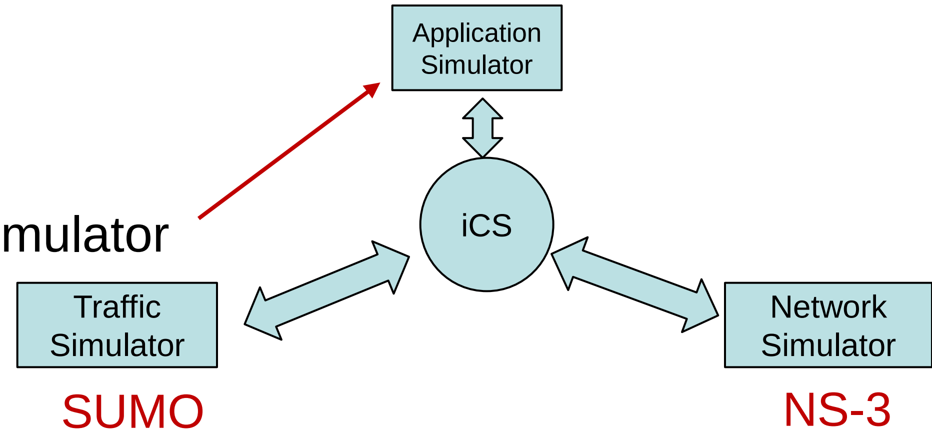
Connectivity



Connectivity-Threshold

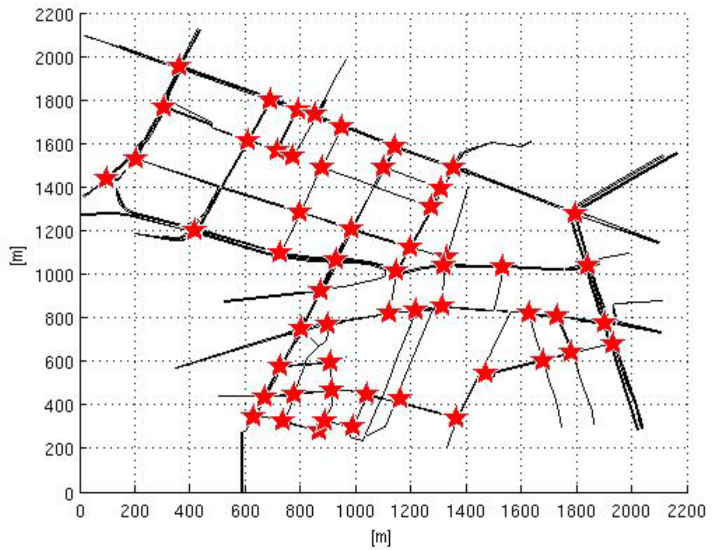
Simulation Scenario

- **iTETRIS Platform**
  - http://www.ict-itetris.eu/10-10-10-community/
  - Implemented in the Application Simulator

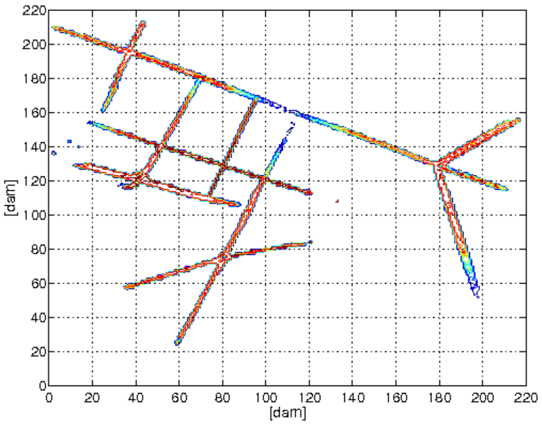


- **Scenario Parameters**

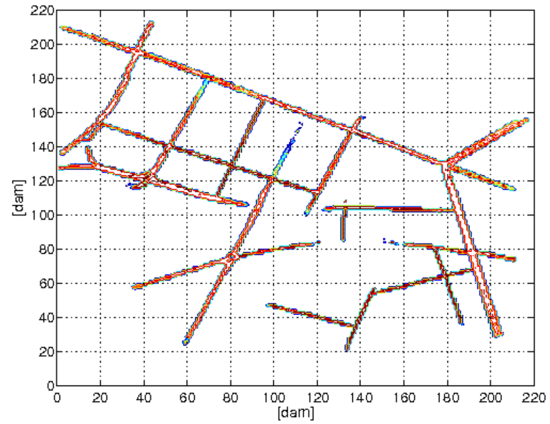
Parameters	Values
Map [in SUMO] Urban	Urban (Costa-Pasubio in Bologna)
Simulation Time	300 s (post initialization)
beacon frequency	2 Hz
beacon size	132 bytes
RSU transmission power	20 dBm
RSU height	6 m
Fading model [in ns3]	WINNER II B1
MAC [in ns3]	802.11p CCH



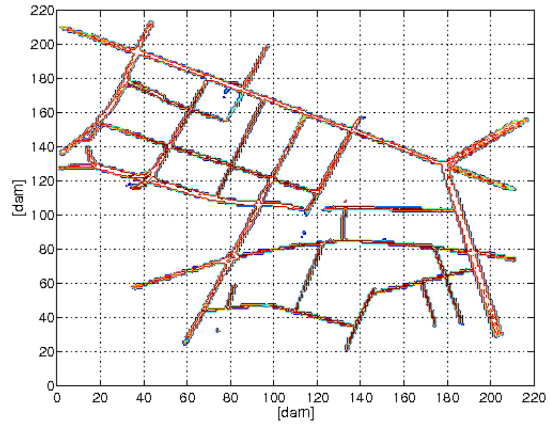
Impact of the optimal RSU selection



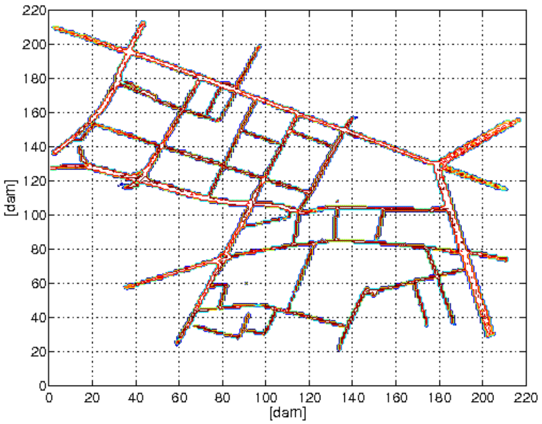
5 RSUs; 42% Benefit



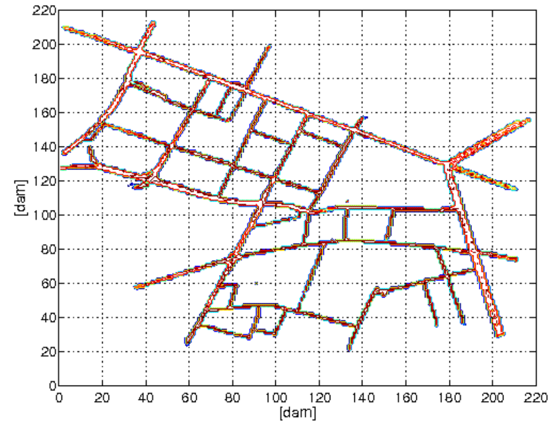
11 RSUs; 68% Benefit



17 RSU; 81% Benefit



31 RSUs; 95% Benefit

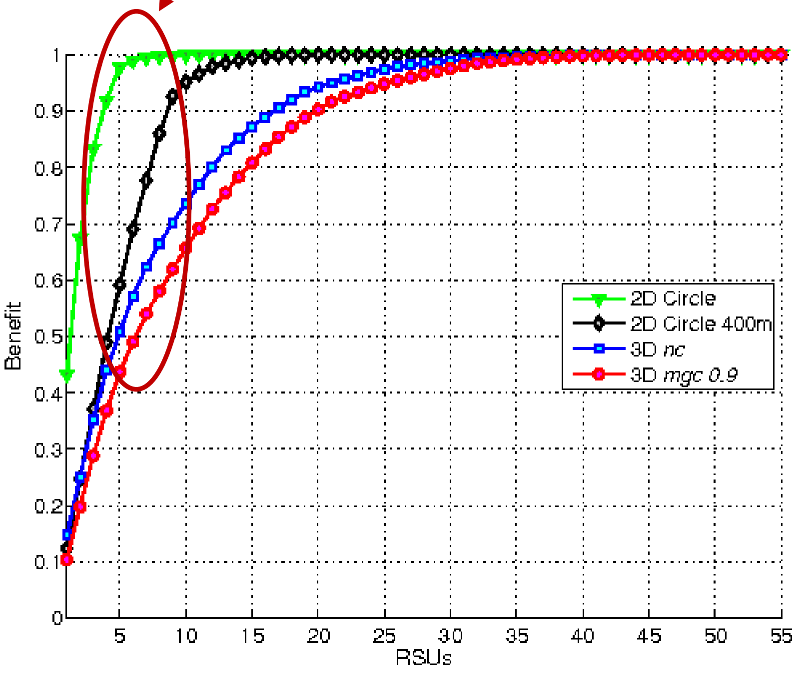


55 RSU; 100% Benefit

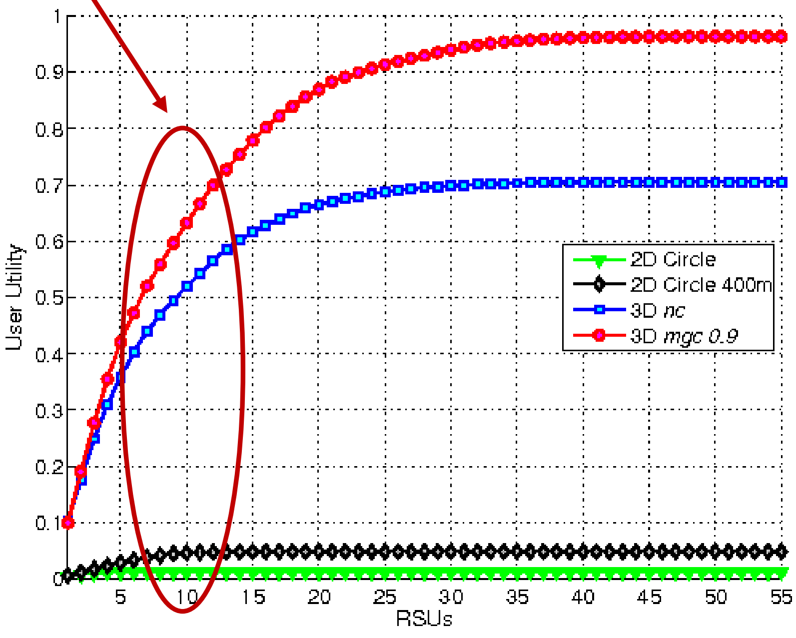
Optimized Coverage

Better benefit from a coverage approach

Coverage approach provides coverage where not necessary (no utility)

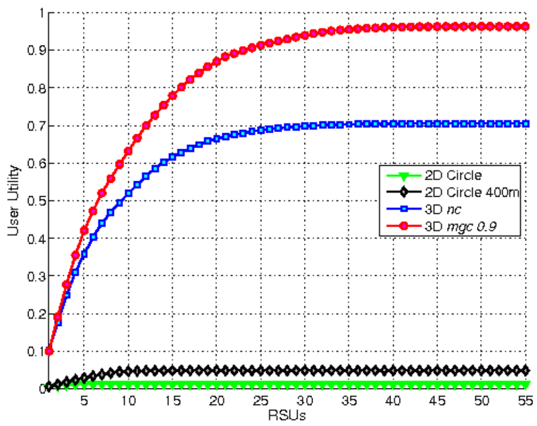


Coverage Optimization

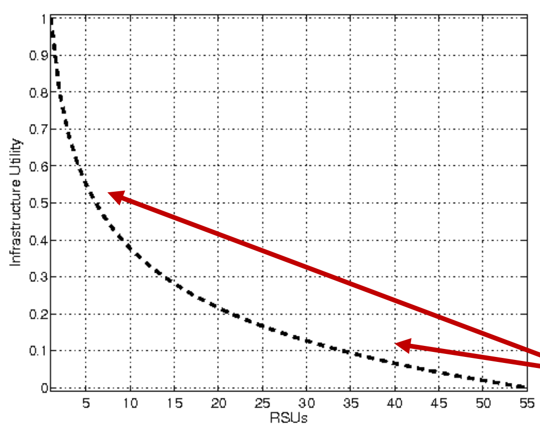


User Utility

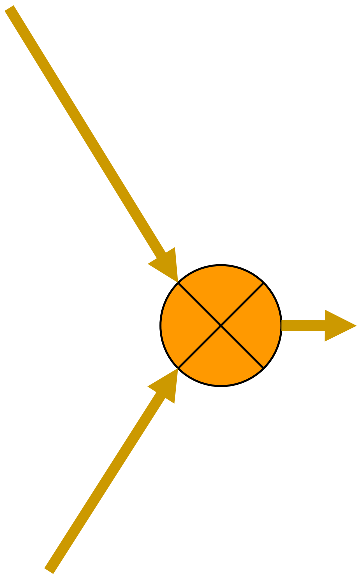
Provider Satisfaction and Joint Optimization



User Utility



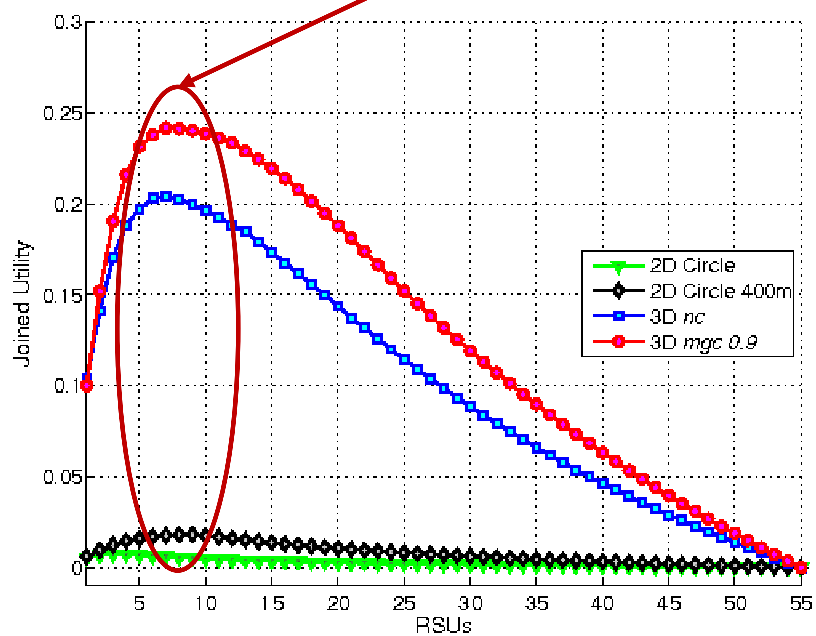
Operator Utility



Operator Utility decreases with # RSU

~8 RSU required in all approaches

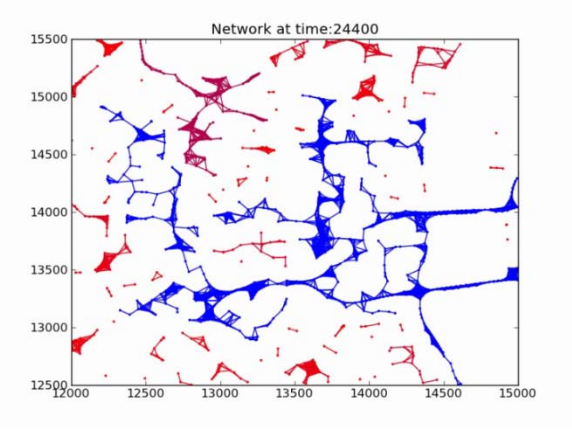
<u>Benefit</u>: not the same RSUs' locations !!



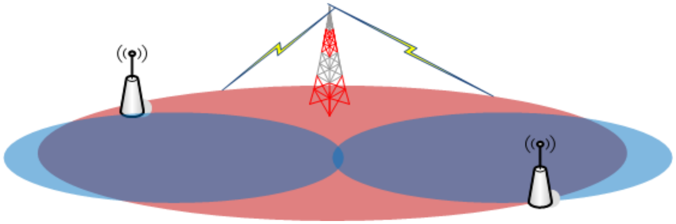
Joint User-Operator Satisfaction

Future (Current) Work

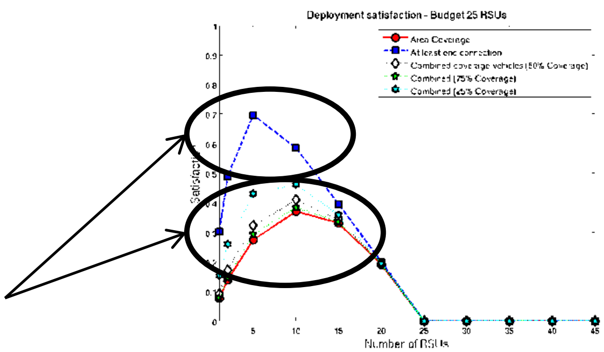
- **Multi-hop Connectivity**
  - Multi-hop connectivity creates giant clusters and allows data percolations
    - Changes the objective of RSUs
      - ☞ Connectivity vs. Capacity



- **Heterogeneous Infrastructures (RSU, LTE Micro/Femto)**
  - The benefit of one extra infrastructure depends on its capacity
  - Their order in the optimization



- **Application-driven Optimization**
  - The benefit depends on the requirements of the applications



Different Optima

Summary

- **Developed a framework for Infrastructure node deployment in vehicular networks**
  - Considers generic functions: extensible to heterogeneous networks and other metrics
  - Non-convex polygon coverage representation
  - Joint optimization of user and operator's satisfactions
- **In this talk:**
  - Considered deployment of RSU in calibrated urban area
  - Illustrated the trade-off to be considered from deployment costs and locations
  - Optimized satisfaction based on directional connectivity, rather circular constant coverage
- **Further Information:** P. Cataldi, J. Härri, User/Operator Utility-Based Infrastructure Deployment Strategies for Vehicular Networks, IEEE WiVEC 2011, San Francisco, 2011

Thank you for your attention…

But, do not leave…more to come…

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