IEEE/IFIP 15<sup>th</sup> Wireless On-demand Network systems and Services Conference (WONS 2019) 23 January 2019, Wengen, Switzerland

## The Role of Moving Things in Beyond 5G Networks

Susana Sargento, susana@ua.pt University of Aveiro, Instituto de Telecomunicações – Aveiro Co-Founder Veniam

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creating and sharing knowledge for telecommunications

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Moving Things: When did it started?

## Patented Dec. 28, 1926. UNITED STATES PATENT OFFICE.

HARRY FLURSCHEIM, OF PARIS, FRANCE.

RADIO WARNING SYSTEM FOR USE ON VEHICLES.

Application filed November 13, 1923, Serial No. 674,439, and in France December 5, 1922.

The present invention relates to radio warning systems for use on vehicles intended to permit a vehicle to signal its presence by means of electric waves to all other vehicles in its more or less immediate vicinity, equipped with similar or equivalent apparatus and devices, particularly to such vehicles located in front or on the side of the vehicle signalling its presence and facing in the approximate direction of said signalling vehicle.



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### **Connecting Vehicles**

Why communication in the roads?

#### mobile data

WiFi offloading solutions to cope with traffic growth continuous connectivity Connectivity anywhere, everytime connected cars **All Internet-based** services in the cars Self-driving



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### **Connected Vehicles Applications (ITS.DOT Source)**



### **ITS Applications with Real Vehicular Communication**

#### Virtual Traffic Lights



#### **Overtaking Manouver**

#### Michel Ferreira et al

Revisiting in EU 5GinFire with Video Transcoding as VNF

João Pereira, Miguel Diaz-Cacho, Susana Sargento, André Zúguete, Lucas Guardalben, Miguel Luís, "Vehicle-to-Vehicle Real-time Video Transmission through IEEE 802.110 for Assisted-Driving", IEEE 2018 IEEE 87th Vehicular Technology Conference VTC2018-Spring, Porto, Portugal, May, 2018 de aveiro

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#### **Connected Vehicles Applications: Self-Driving**





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### **Network Mechanisms**

- GPS + IEEE 802.11p + WiFi + GPRS + 3G/4G
- Smart connection manager for heterogeneous networks
- Seamless handovers, multihoming
- Multi-hop vehicular mesh networking
- M2M Delay tolerant data management
- Security mechanisms for connected vehicles.



# **Real Platform for Vehicular Networks**

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Total vehicles displayed (online in the last 2 minutes): 18

#### **Harbor Pilot Results**

- Latency in the IEEE 802.11p network ≤ 10 msec
- Latency in congestion ≤ 100 msec
- Handover time ≤ 100 msec
- Coverage  $\geq$  600m in LoS



Carlos Ameixieira, André Cardote, Filipe Neves, Rui Meireles, Susana Sargento, Luís Coelho, João Afonso, Bruno Areias, Eduardo Mota, Rui Costa, Ricardo Matos, João Barros, "HarborNet: A Real-World Testbed for Vehicular Networks", **IEEE Communications Magazine**, ISSN: 0163-6804, Vol. 52, Issue 9, September 2014, pp: 108 - 114.



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### **City Pilot Results**

- Bandwidth ≈ 8 Mb/sec
- Latency in the IEEE 802.11p network ≤ 10 msec
- Congestion latency  $\leq$  100 msec
- Handover time  $\leq$  100 msec
- Density of vehicles in rush hour (in the map, 1Km<sup>2</sup>): >90 buses
- Coverage  $\geq$  600m in LoS
- Up to 6 videos in the bus, simultaneously
- Many internet access users
- Offload > 50%



Pedro Santos, João Rodrigues, Susana Cruz, Tiago Lourenço, Pedro M. d'Orey, Yunior Luis, Susana Sargento, Ana Aguiar, João Barros, "PortoLivingLab: an IoT-based Sensing Platform for Smart Cities", IEEE Internet of Things Journal, ISSN: 2327-4662, January 2018.

# How to make it work?

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# Multi-Network Connection Manager: AHP and Optimization



Susana Sargento, André Cardote, Carlos Ameixieira, Filipe Neves, Jorge Dias, "Method and apparatus for Multi-Network Communication in Vehicular Networks", US Patent US9439121 B2, 6 September 2016.

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#### **Mobility and Handovers**

	Handover Latency IEEE 802.11p (msec)
N-PMIP	[20 , 60]
LISP	[40 , 60]
DMIPA	[60 , 80]



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INSTITUIÇÕES ASSOCIADAS: Diogo Lopes, Susana Sargento, Ricardo Matos, "Improving Mobility Management over Vehicular Networks", US Patent US9717104 B2, 25 July 2017.





### **Multihoming and Mobility**

- Vehicles can send/receive traffic through more than interface one simultaneously
- Example
  - 802.11p IEEE and Cellular for real-time communications
  - IEEE 802.11g/n for delay tolerant communications
- Make use of Network Coding



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Christian Gomes, Miguel Luís, Susana Sargento, André Zúquete, Rui Lopes, "Multi-technology Vs Single-technology Architecture for Network Coding in VANETs", IEEE International Symposium on Computer and Communications (ISCC), Natal, Brasil, June 2018.

Delivery ratio (%)

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45-67, N

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## **UrbanSense**





### Sensors

#### Meteorological

- . Temperature
- . Humidity
- Luminosity
- Rain
- Wind
- Solar radiation

#### Air Pollution

- . Ozone (O3)
- Particles
- Noise

## WiFi connectivity

- Fixed hotspots
  - Porto Digital

Mobile hotspots

Vehicular Network

Cellular hotspots

INS Pedro M. Santos, Tania Calcada, Diogo Guimarães, Tiago Condeixa, Susana Sargento, Ana Aguiar, João Barros, Platform for Collecting Data From Urban Sensors Using Vehicular Networking", ACM MobiCom Workshop on Challenged Networks - CHANTS, Paris, France, September 2015.



Sensor 1

Sensor 2

Sensor N

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### **Sensors Data (4th December 2018)**

	and the second se			
MAIN NAVIGATION	Dashboard General information			🍪 Dashboard
🚯 Dashboard	Filter			
🖗 Мар				
Metrics <		Air 🖻 Waste	All Noise Q Radiation	☆ People III None
Alerts	Temperature	C-	Air	
🖋 Rules	Average: 17.36°c	>75%:1		erage (CO2): 63.0 ppm
😪 Citizen area	Maximum/Minimum: 17.36 * <sup>c</sup> / 17.36 * <sup>c</sup>	50 to 75%: 0	Maximi	um/Minimum: 63.0/63.0
OTHER INFO	Streams active/all: 2 / 2	Streams active/all: 1/1	Stream	ıs active/all: 3/3
🕑 Help	Last reading: Dec. 4, 2018, 7:01 p.m.	Last reading: April 10, 2018, 3:45 p.m.	Last rea	ding: Dec. 4, 2018, 7:01 p.m.
	More info 🛇	More	info 오	More info <b>O</b>
	Waste 👝	Noise	Radiation	People counter
	>75%: 0	Max: 70.0 <sup>dB</sup>	> 7 UV: 0	>75%: 0
	50 to 75%: 0	Average: 70.0	4 to 7 UV: 0	50 to 75%: 0
	Streams active/all: 5 / 5	Streams active/all: 1/1	Streams active/all: 1/4	Streams active/all: 1/1
	Last reading: Dec. 4, 2018, 6:19 p.m.	Last reading: Dec. 4, 2018, 7:01 p.m.	Last reading: Dec. 4, 2018, 7:01 p.m.	Last reading: June 8, 2018, 6:06 p.m.
	More info 🛇	More info 🛇	More info <b>O</b>	More info 🛇

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# How do Build Protocols Using Vehicular Networks' Data ?

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#### Integrating Crosswalk Awareness in Safety-oriented Wireless Vehicular Networks (VRUs)

Backscatter modulation and piezoelectric sensors detect the presence of pedestrians Crosswalk awareness is disseminated to all the vehicles of interest using IEEE 802.11p/WAVE The information is displayed to the driver, alerting for possible pedestrians



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Integrating Crosswalk Awareness in Safety-oriented Wireless Vehicular Networks

#### VANET

OBUs receive the information from the RSU next to the crosswalk Geographical information and heading can be used to filter and control the dissemination process





#### O Notification

 If the vehicle is in a Zone of Interest for that crosswalk, the driver is notified about its status





#### Integrating Crosswalk Awareness in Safety-oriented Wireless Vehicular Networks

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#### Data Gathering through Mobile Vehicles

Sensing the City – collecting and disseminating a large amount of data through vehicular net.

Opportunistic Communications – delay tolerant transmission

Heterogeneity – An infrastructure capable of serving as a testbed for a wide range of applications and services.

Using vehicles data to predict the

bestvehiclestoforward&disseminatethetraffic to the infrastructure

- Connectivity do RSU
- Location and mobility

- Aging Social-aware (contacts INSTITUIÇÕES ASSOCIADAS: with neighbors and RSUs)



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### **Data Dissemination through Mobile Vehicles**

#### Videos, software updates, touristic information

#### Advertisement packets are used to know the required content in each vehicle

High delivery ratio, but/

Excessive number and size of advertisement packets: control overhead

#### Data is transmitted between vehicles

Only some vehicles shall disseminate information, or

Vehicles send redundant information: data overhead

Use vehicular network data to predict the best vehicles to disseminate the content to other vehicles – connectivity, neighboring, mobility



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### **Data Dissemination through Mobile Vehicles**

Content distribution approach through the vehicular network

Encode information about which data to send (the one Most useful in the vicinity)

- . Bloom filters
- Bit arrays

#### Tests in real scenarios

90% reduction of control overhead>50% reduction of data overhead



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Joana Conde, Carlos Senna, Susana Sargento, "Content Distribution Optimization Algorithms in Vehicular Networks", IEEE International Symposium on Computer and Communications



#### Mobility Prediction-Assisted Over-The-Top Edge Prefetching



#### Hybrid Markov chain: 1<sup>st</sup> and 2<sup>nd</sup> order



# What can we learn for ITS?

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Jorge Pereira, Susana Sargento, José M. Fernandes, "Decision Support Dashboard for Traffic and Environment Analysis of a Smart City", 4th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2018), Funchal, Portugal, 16-18 March 2018.

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#### **Predicting Buses Time**

Buzzer CityHub

#### **Profile from the line 300 CIRC.HOSPITAL DE S.JOÃO-ALIADOS** The following chart belongs to the line 300 with direction 0, which makes the route CIRCULAR HOSPITAL DE S.JOÃO-ALIADOS.

📥 Bus Line Performance

✓ Live Map



Stop Order	Stop Code	Time
0	HSJ6	15:00:09
1	ESED2	15:07:39
2	FEUP2	15:08:39
3	FEP1	15:09:24
4	MLAR2	15:10:09
E		15-10-54

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Leandro Ricardo, Susana Sargento, Ilídio Oliveira, "An Information System for Bus Travelling and Performance Evaluation", 4th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2018), Funchal, Portugal, 16-18 March 2018.

. . .



#### **Can we improve public transportation?**





#### Online Dashboard – Bus Stats

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### Fog Computing for Smart Mobility Applications in **VANETs**



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# Can we use the Knowledge to other Types of Networks?



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# Data Gathering through Mobile Vehicles: cars, boats and bicycles

# Seamless integration of any object with the Internet

Sensing the City – collecting and disseminating a large amount of data through heterogeneous elements.

**Multi-technology** 

#### Fig.1: Architecture Overview





### **Aquatic Monitoring**





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### Aquatic Monitoring

Path Planning Communications

#### Sensing

Network

Epidemic PAmuLQE - U-E2E
PAmuLQE - B-E2E PAmuLQE - NACK



600 800 1000 1200 1400 Elapsed time (sec)





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D. Sousa, M. Luís, S. Sargento, ACP Pereira, An Aquatic Mobile Sensing USV Swarm with a Link Quality-Based Delay Tolerant Network, MDPI Sensing S, Vol. 18, No. 10, pp. 3440 - 3440, October, 2018.

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#### Arial drones: control and communication







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### **Experiments: collaborative sensing**



Nuno Paula, Bruno Areias, André Reis, Susana Sargento, "Multi-drone Control with Autonomous Mission Support", Workshop on UNmanned aerial vehicle Applications in the Smart City: from Guidance technology to enhanced system Interaction (UNAGI'19), IEEE International Conference on Pervasive Computing and Communications (IEEE PERCOM), Kyoto, Japan, March 105/17/10/05/25/2019.

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#### The need for moving networks in ITS and beyond

Vehicular networks have a great potential for ITS, but also beyond...

Vehicular networks can go much beyond cars: boats, drones (aerial and aquatic), trains, bicycles, and others.

Enormous types of use cases with connected moving vehicles

From self-driving and autonomous cars, to environmental monitoring in aquaculture;

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From rescue scenarios in remote areas to smart cities; Many more...

Vehicular communications with endless possibilities for a near-term future!

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### The Role of Moving Things in Beyond 5G Networks

#### Thanks!

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