WiFi-Based Passive Radar for Short Range Surveillance: Detecting and Locating Air Targets, Surface Vehicles and Human Beings

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Outline

- Potentialities and challenges of WiFi-based passive radar for short range surveillance applications

- Examples of applications
  - Air targets
  - Surface vehicles
  - Human beings

- Concluding remarks

Potentialities and challenges of the PCL short range applications

- Surveillance of small areas with possibly dense traffic → higher **resolution** required
- Increased measures **accuracy** to enable high precision applications (e.g. automated guided vehicles) → the use of a network of PCL Rxs is a viable solution
- **Availability** of the selected transmission of opportunity (e.g. indoor applications) and its **control**.
- Possibly high power level direct signal and **severe multipath** → efficient management of the Rx dynamic range and effective signal processing techniques
- Detection of very small targets in specific areas → role of **gap-filler** for long-range applications
- **Advanced capabilities** → cross-range profiling, classification

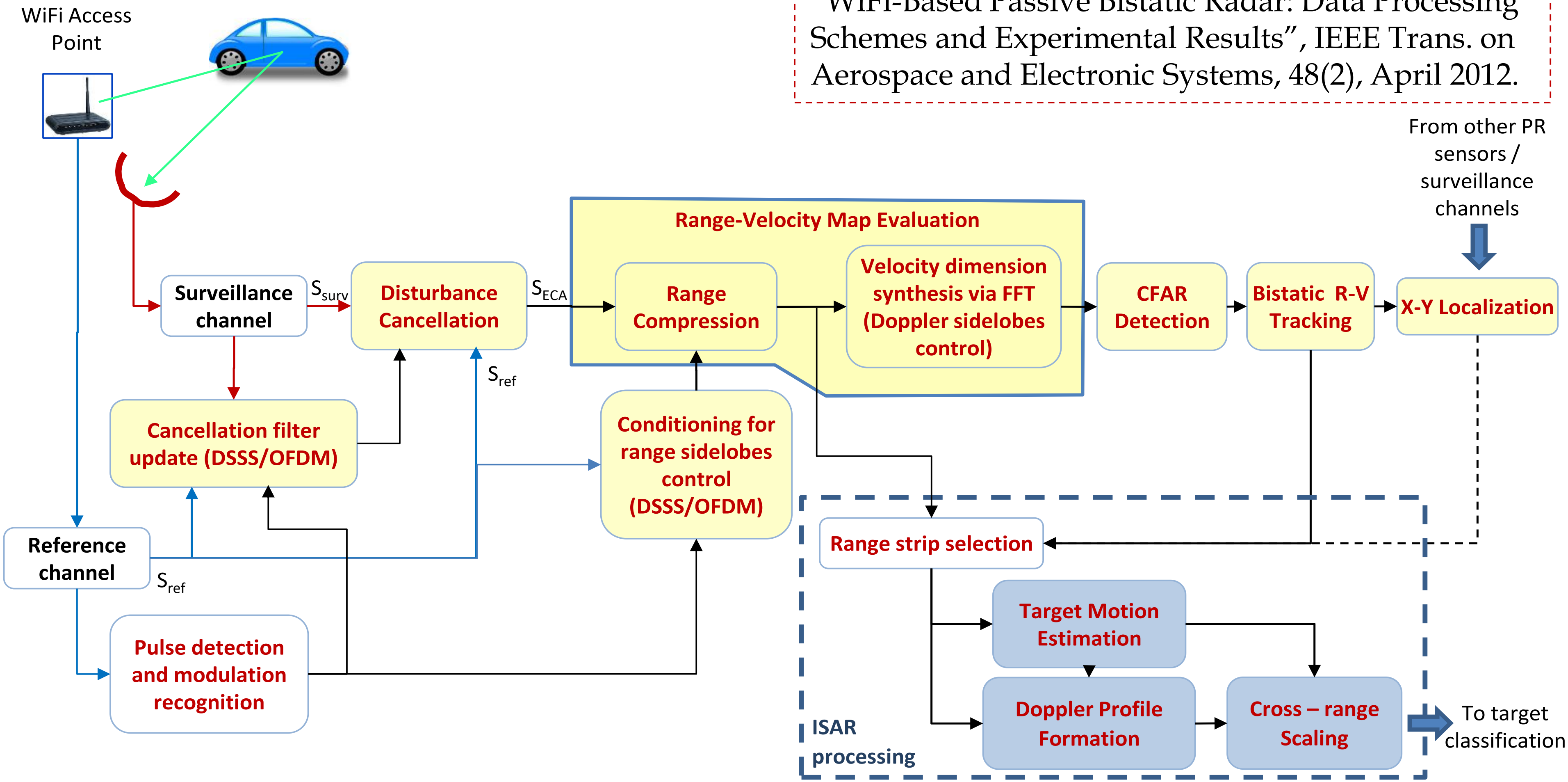
Passive surveillance using transmissions for communications and networking

Standard	Carrier frequency	Bandwidth	Modulation	Coverage (Base Station)
WiFi	2.4 (EU) / 5 (USA) GHz	11 / 20 MHz	DSSS / OFDM	Local Area
WiMAX	2.3 / 2.5 / 3.6 GHz	Variable [1.25 – 20] MHz	Scalable OFDMA	Metropolitan Area
GSM	900 / 1800 MHz	200 kHz	GMSK, FDM/TDMA/FDD	Metropolitan Area
UMTS	2100 MHz	5 MHz	CDMA	Metropolitan Area
LTE	800 / 3500 MHz	Variable [1.4 – 20] MHz	OFDM	Metropolitan Area

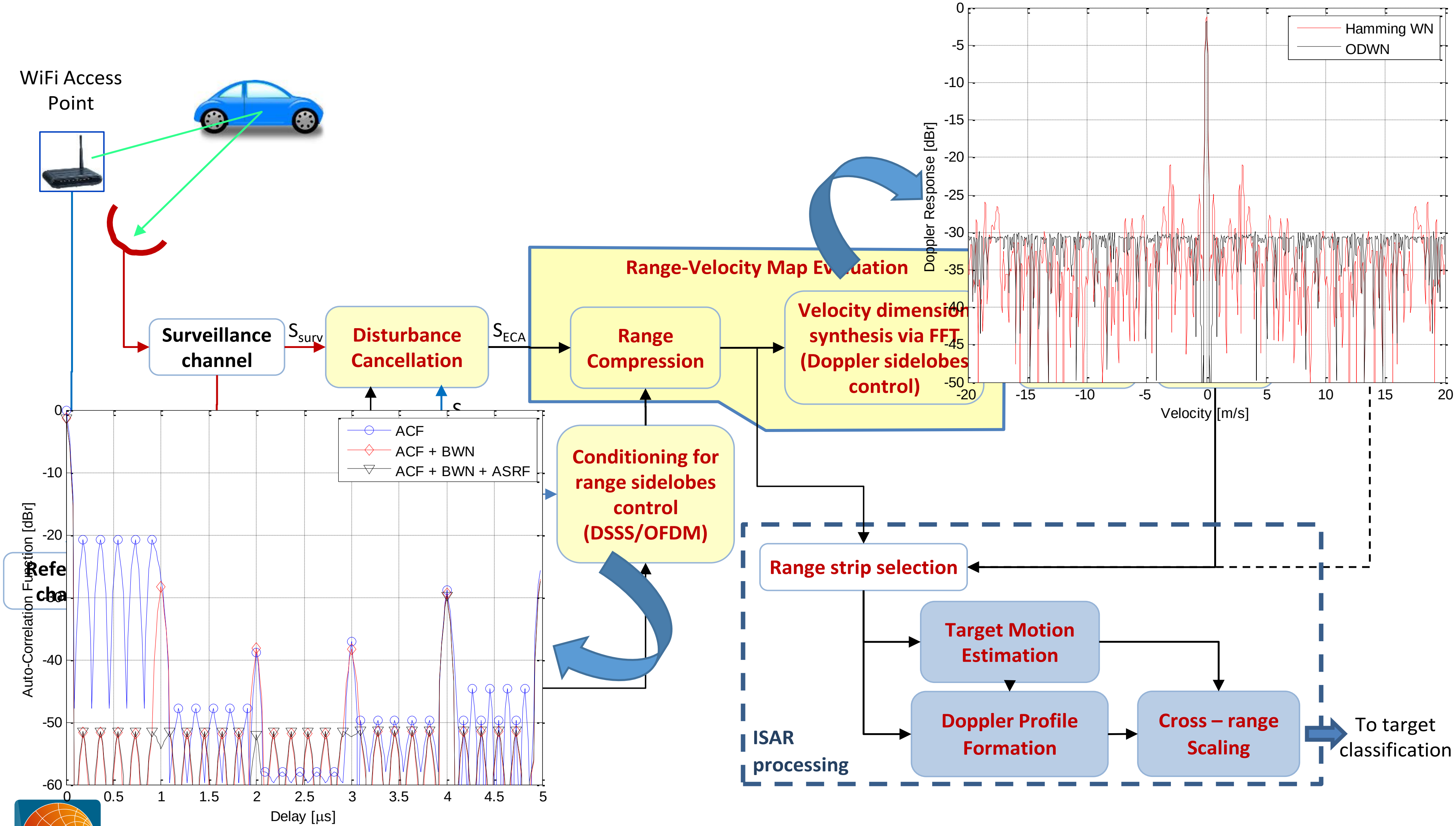
F. Colone, K. Woodbridge, H. Guo, D. Mason and C. J. Baker "Ambiguity Function Analysis of Wireless LAN transmissions for passive radar", IEEE Transactions on Aerospace and Electronic Systems, Vol. 47 , Issue 1, January 2011, pp. 240-264

Signal processing scheme for a WiFi based PCL (I)

F. Colone, P. Falcone, C. Bongioanni, P. Lombardo, "WiFi-Based Passive Bistatic Radar: Data Processing Schemes and Experimental Results", IEEE Trans. on Aerospace and Electronic Systems, 48(2), April 2012.

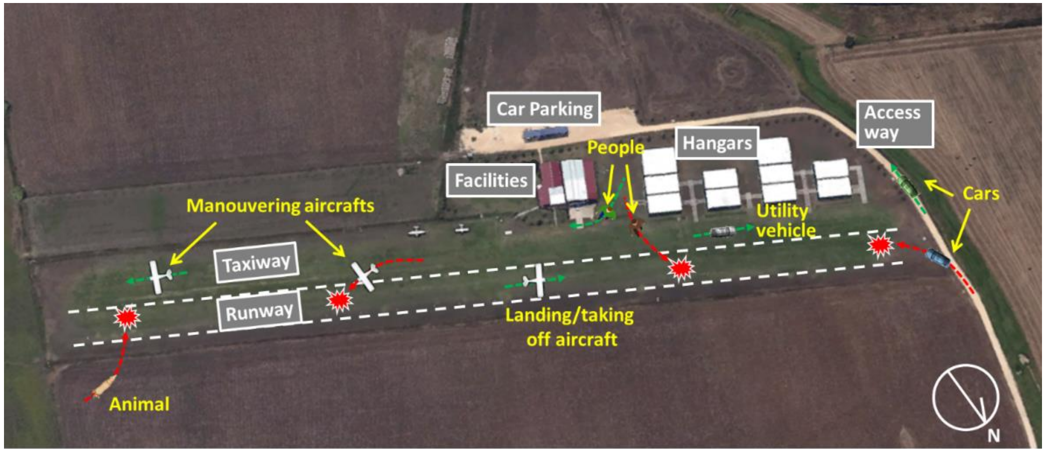


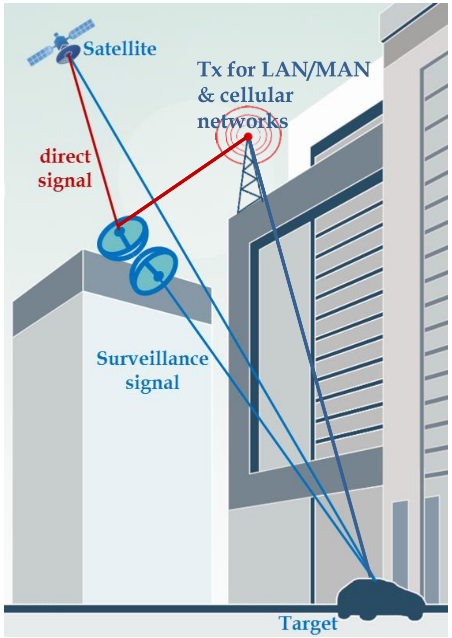
Signal processing scheme for a WiFi based PCL (II)



Possible surveillance applications

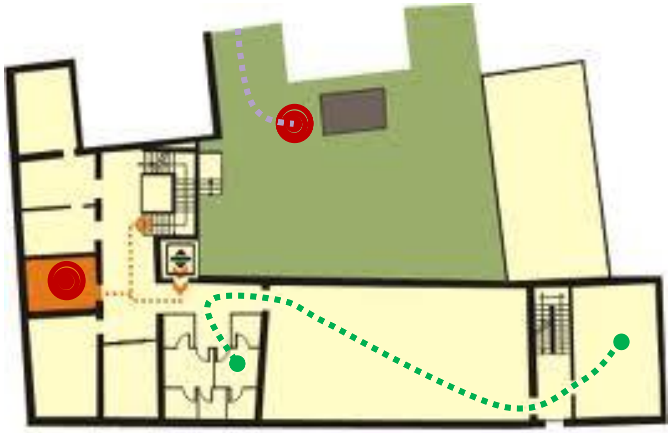
- **Aerial surveillance** (e.g. against small UAV/UAS/drones or in specific areas of airports/airfields)





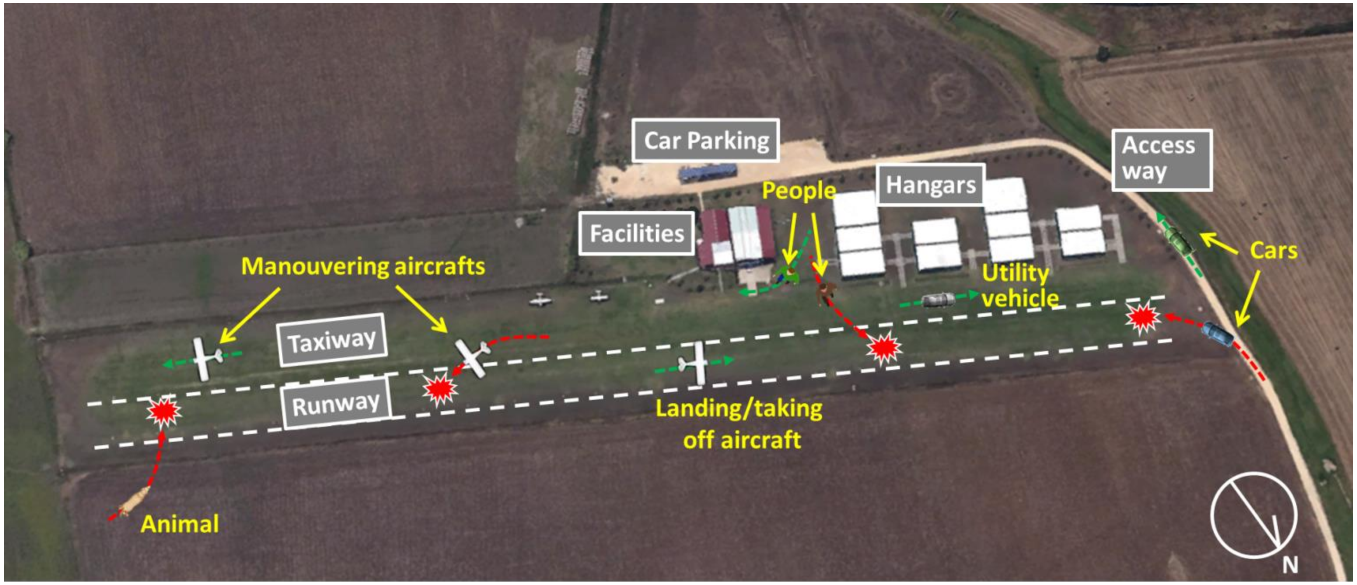
- **Surface Vehicular Traffic Monitoring** (e.g. vehicular traffic both on roads and on railways, UGV)

- **Indoor or local area surveillance** (e.g. detection of intruders, unauthorized people in forbidden areas etc.)



Continuous/ubiquitous monitoring using a dense network of sensors.

Airfield surveillance with WiFi-based PCL (I)

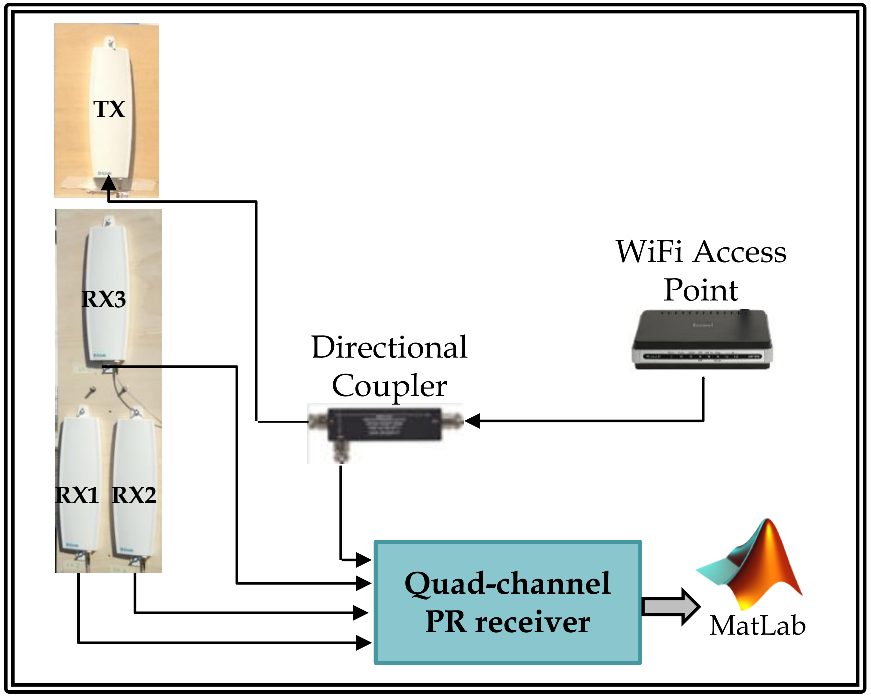


Tests at the airfield of Santa Severa using the experimental equipment developed at Sapienza.

http://www.sos-project.eu

- F. Colone, T. Martelli, C. Bongioanni, D. Pastina, P. Lombardo, "WiFi-based PCL for monitoring private airfields", IEEE Aerospace and Electronic Systems Magazine, vol. 32, no. 2, pp. 22-29, February 2017.

Airfield surveillance with WiFi-based PCL (II)



- A WiFi Access Point used as transmitter of opportunity
- 4-channels receiving system developed at Sapienza University of Rome
- Fully coherent BB down-conversion stage
- Signals sampled and stored for off-line processing

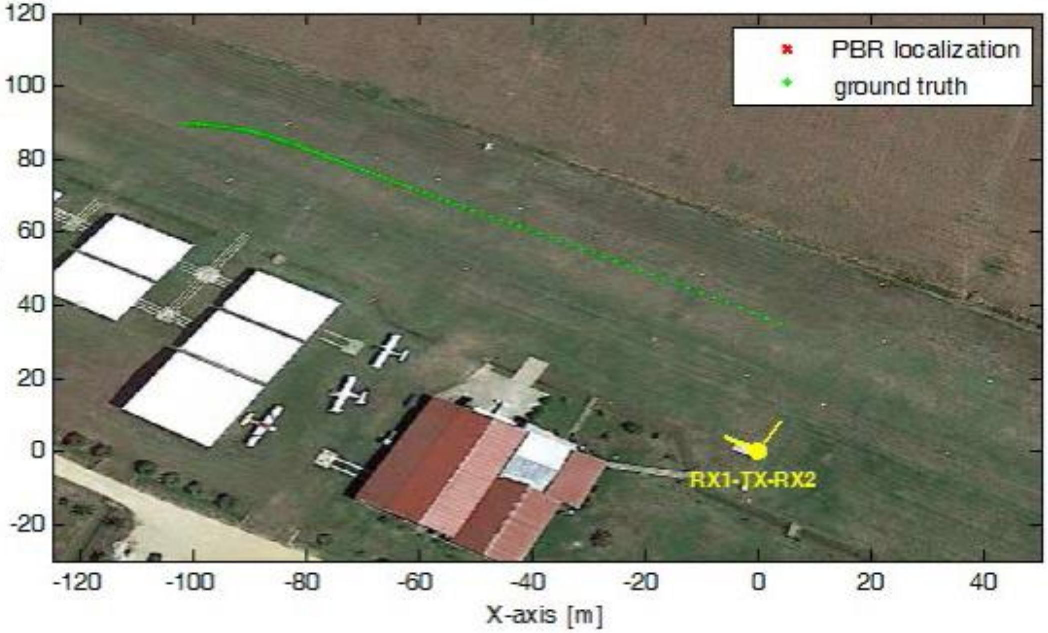
- Quasi-monostatic configuration
- 3 surveillance antennas:
  - $h_{RX1} = h_{RX2} = 1.43$ m
  - $h_{RX3} = 1.82$ m
  - $h_{TX} = 2.20$ m
- Tests of about 20 s

Experimental Set-up

Airfield surveillance with WiFi-based PCL (III)

TEST #1

A small aircraft moved on the runway just after landing

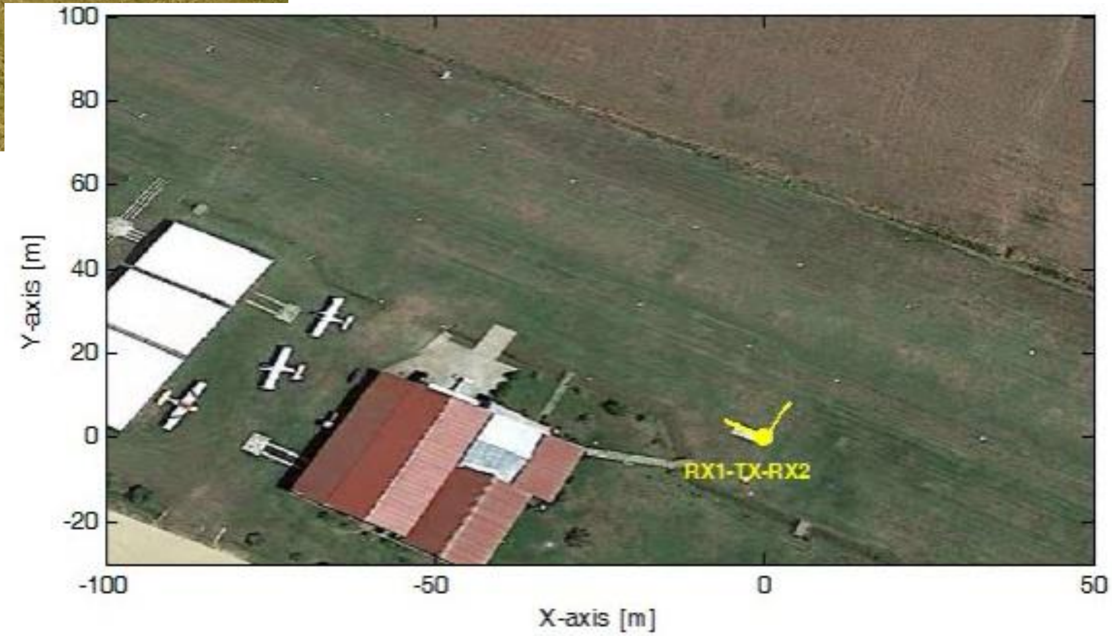


- The small aircraft is continuously detected along its trajectory
- A good agreement is observed between PBR results and available ground-truth

Airfield surveillance with WiFi-based PCL (IV)

TEST #2

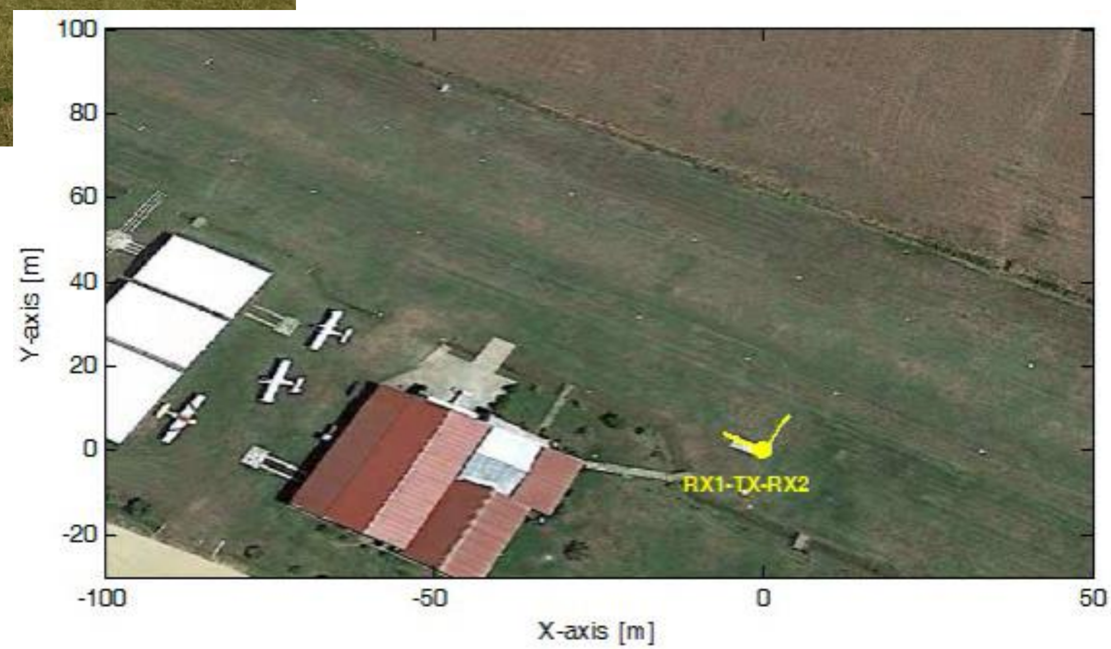
A small maneuvering aircraft in the proximities of the runway



Airfield surveillance with WiFi-based PCL (V)

TEST #3

A very small aircraft is moving in the proximities of the runway

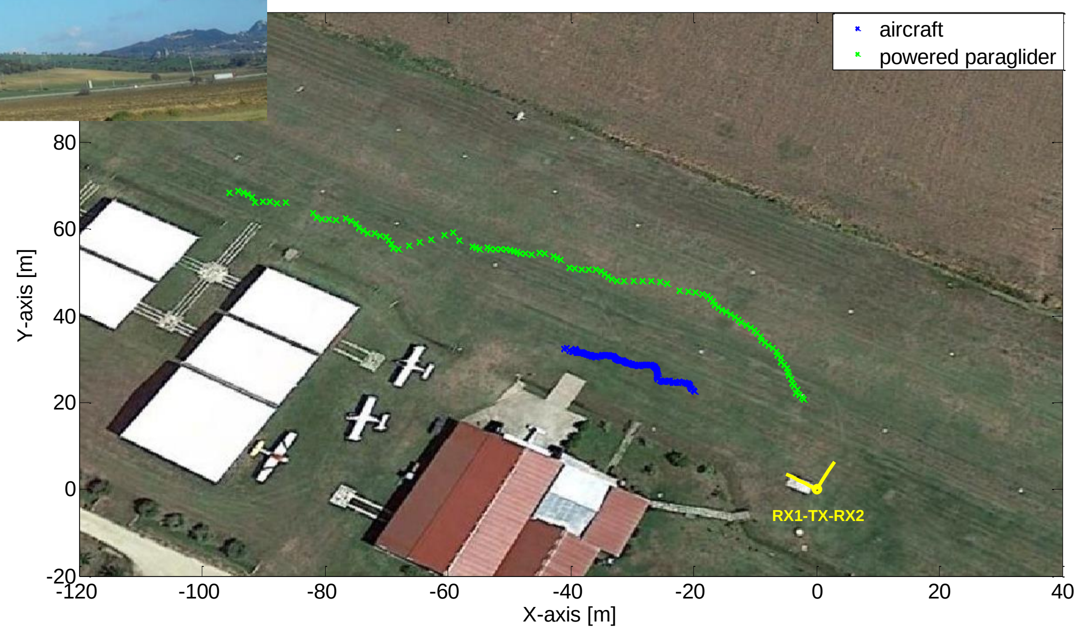


Airfield surveillance with WiFi-based PCL (VI)

TEST #4

A powered paraglider is flying over the runway involved in a 'touch and go' maneuver.
Contemporaneously, a small aircraft is moving toward the passive sensor.

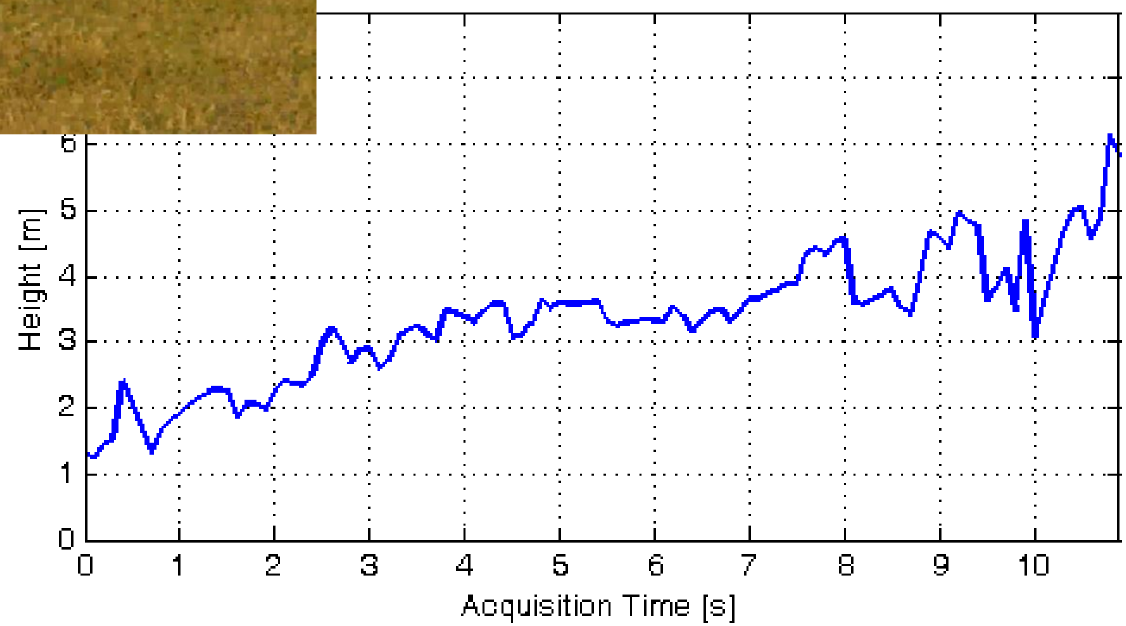
The two sequences of plots clearly reveal the presence of the observed targets



Airfield surveillance with WiFi-based PCL (VII)

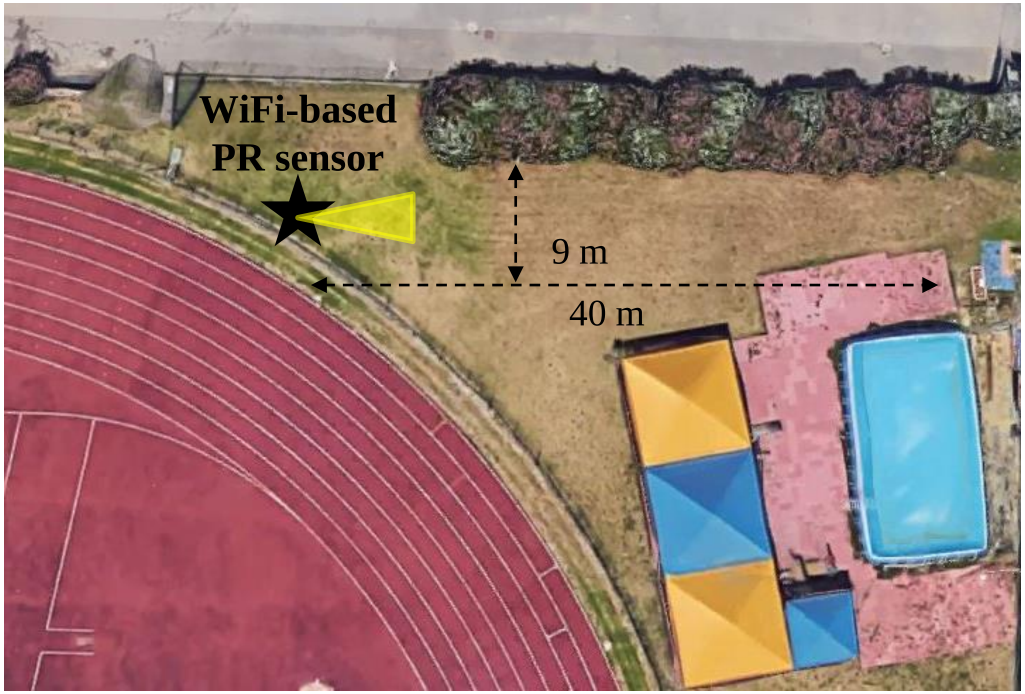
TEST #5

Ultralight aircraft take-off

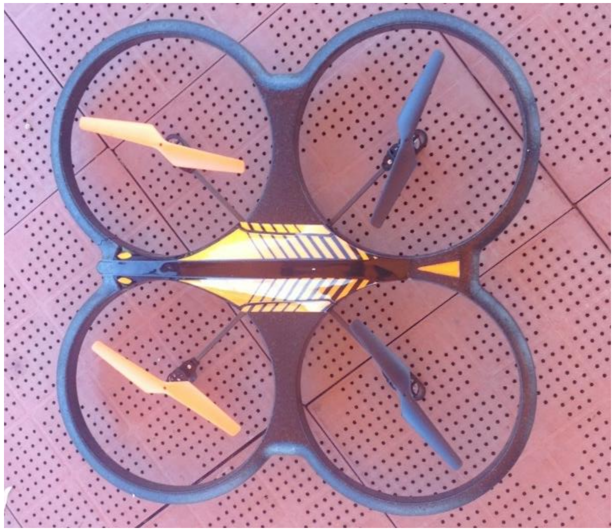


Drone detection and localization (I)

Test campaigns performed in the external area of the Sapienza University sport center in Rome



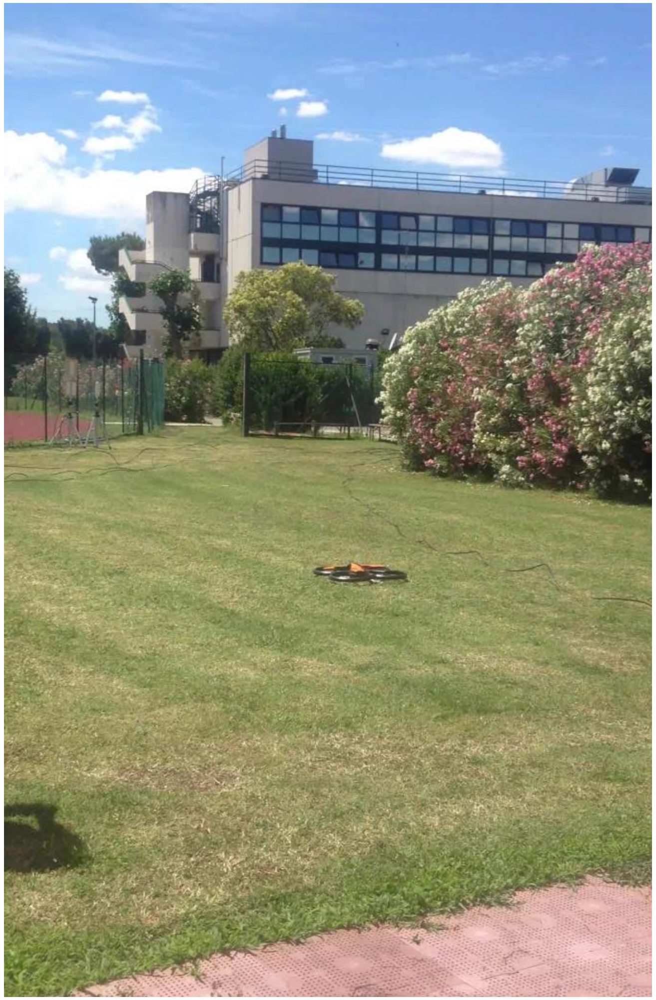
Drone used as target of opportunity



Size: 60 cm x 60 cm x 9 cm
Material: carbon fiber & expanded foam

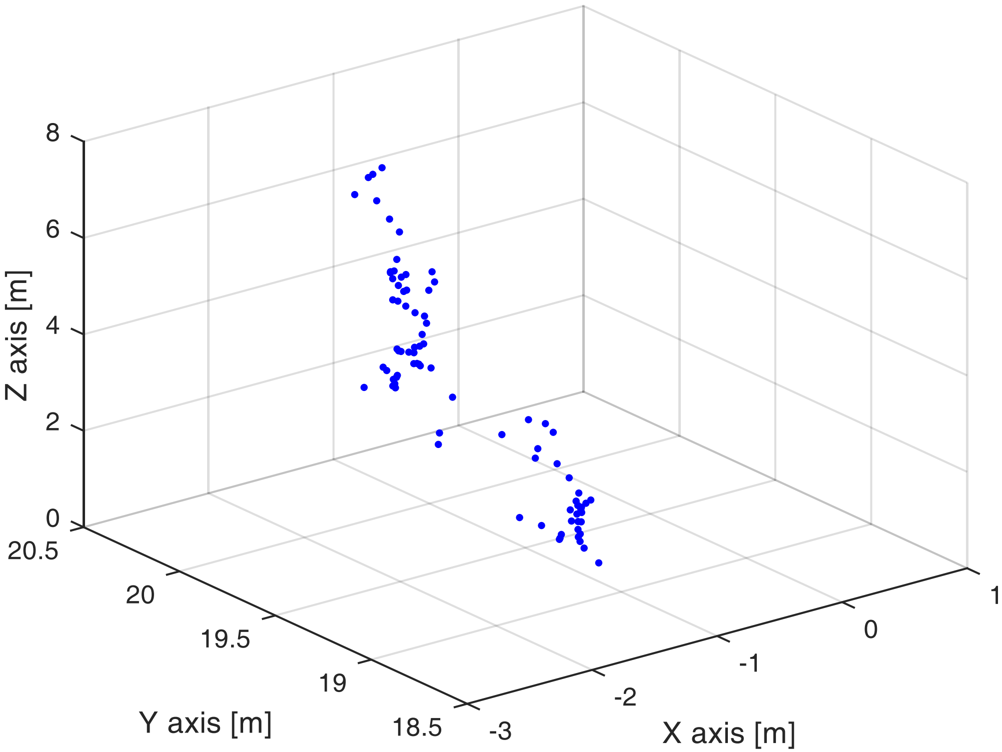
T. Martelli, F. Murgia, F. Colone, C. Bongioanni, P. Lombardo, "Detection and 3D localization of ultralight aircrafts and drones with a WiFi-based Passive Radar", to be presented at the International Conference on Radar Systems (RADAR 2017), Belfast (UK).

Drone detection and localization (II)

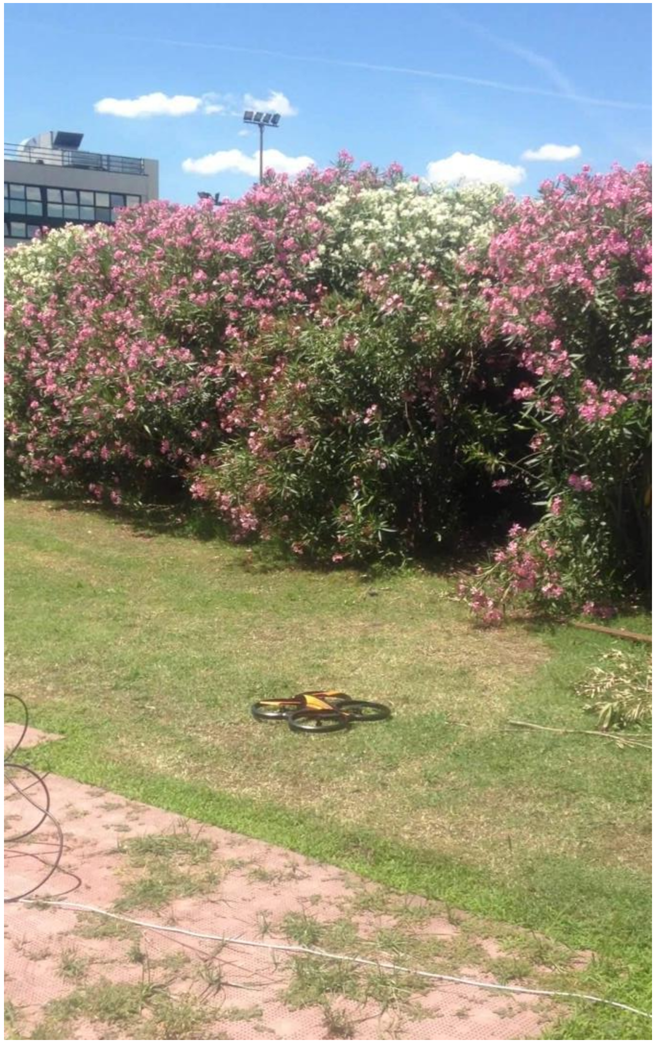


TEST #1

The drone soars from the ground at a distance of about 20 m from the PR sensor

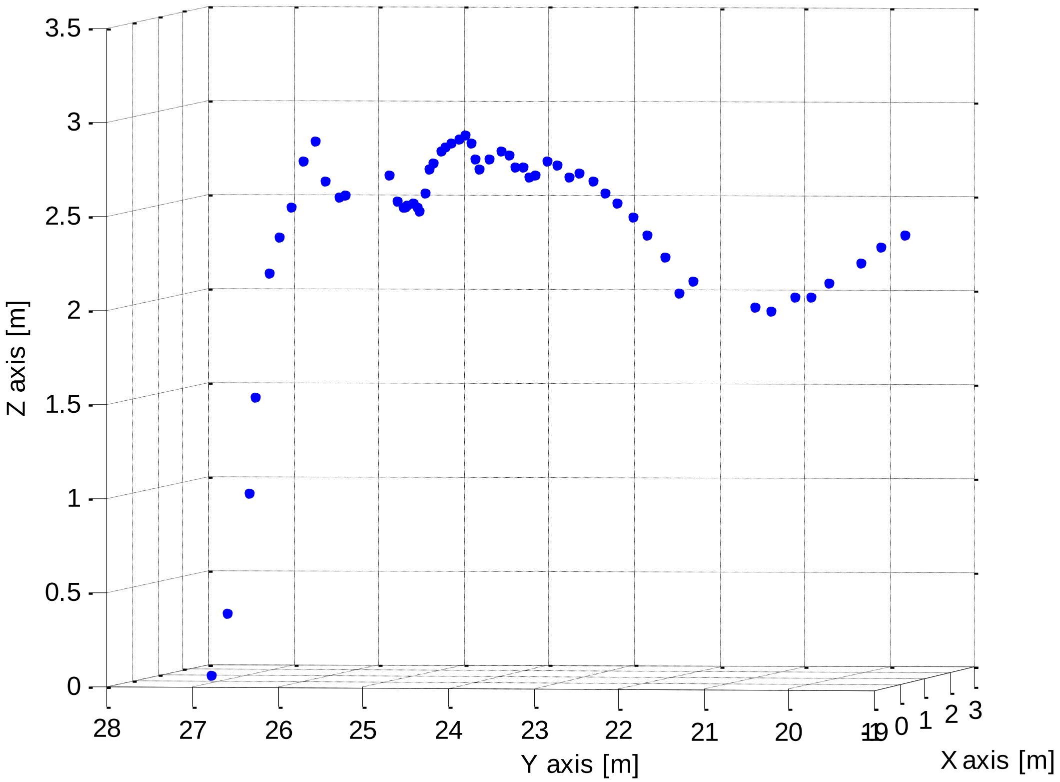


Drone detection and localization (III)



TEST #2

The drone moves at about 30 m from the PR sensor toward the receiver location

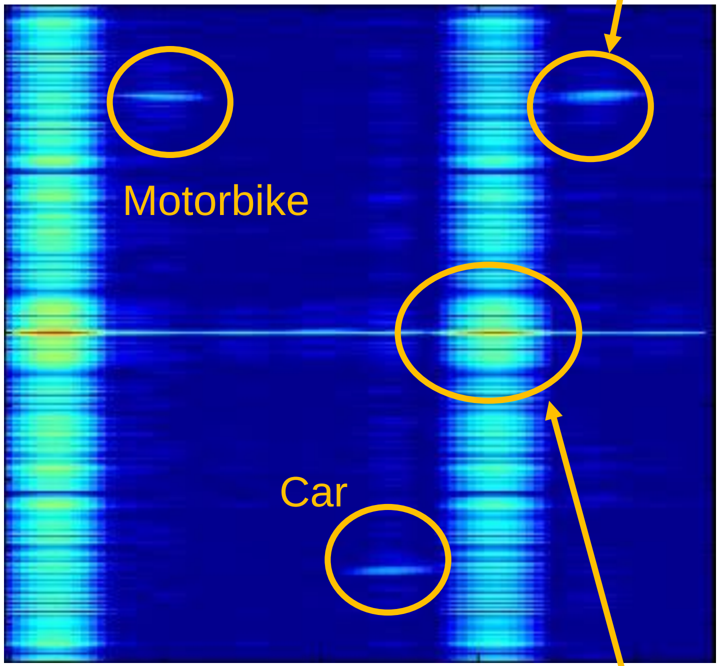


Surface vehicles monitoring with WiFi based PCL (I)

Experimental results for WiFi based PCL

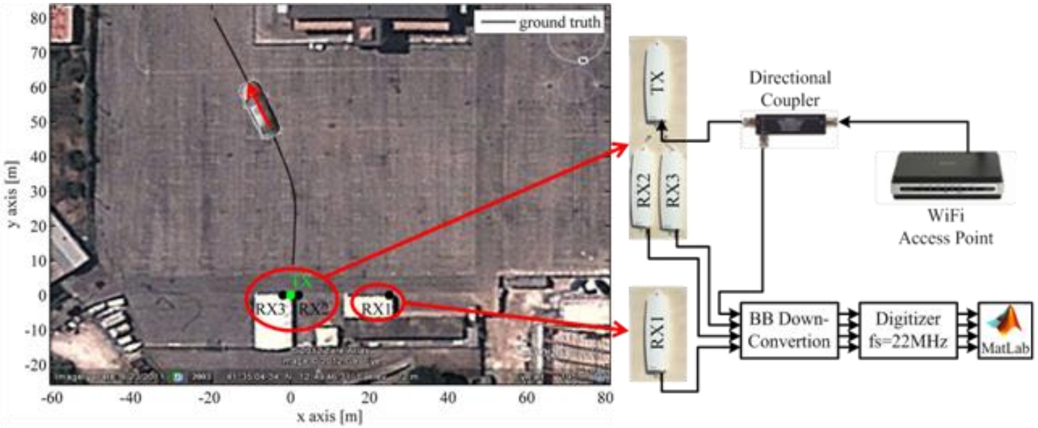
(Sequence of Range-Doppler maps obtained over consecutive scans)

double bounce of the farthest target on the metallic wire fence



metallic fence delimiting the parking area

Surface vehicles monitoring with WiFi based PCL (II)



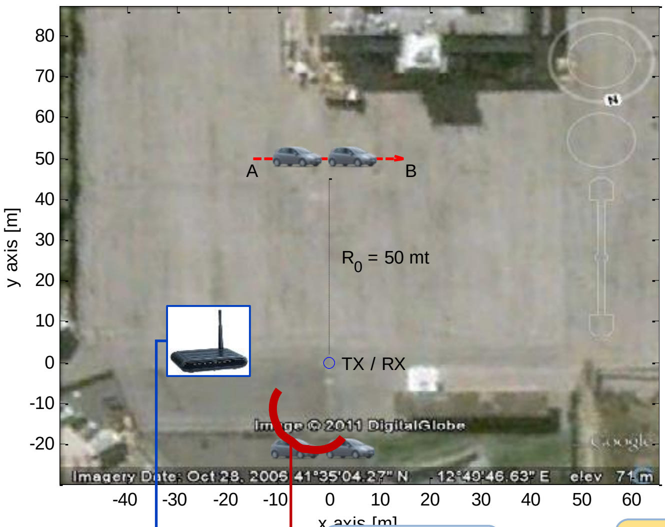
Experimental equipment exploiting 3 Rx channels

A GPS receiver was used to collect the ground truth.

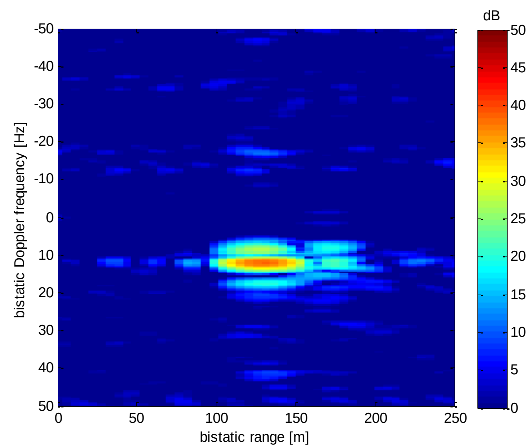
PCL results exploiting pre-filtered Range (using Doppler info) and DoA measurements from 2 PCL sensors

P. Falcone, F. Colone, A. Macera, P. Lombardo, "Two-dimensional location of moving targets within local areas using WiFi-based multistatic passive radar", IET Radar Sonar & Navigation, vol.8, no.2, pp. 123-131, February 2014.

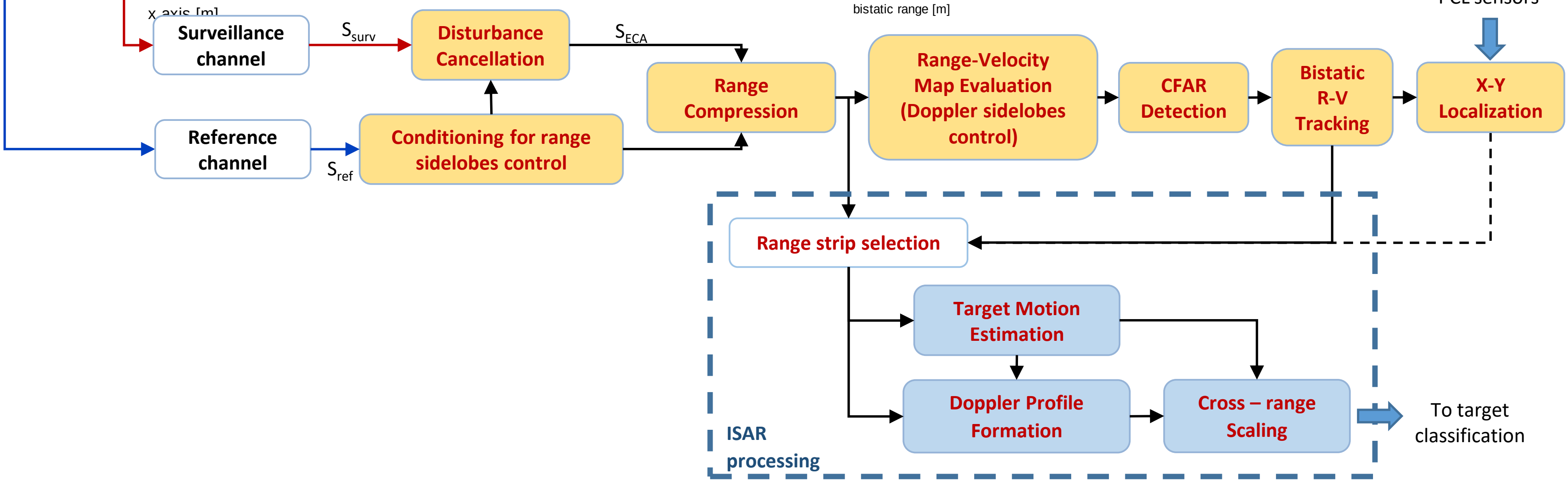
Surface vehicles monitoring with WiFi based PCL (III)



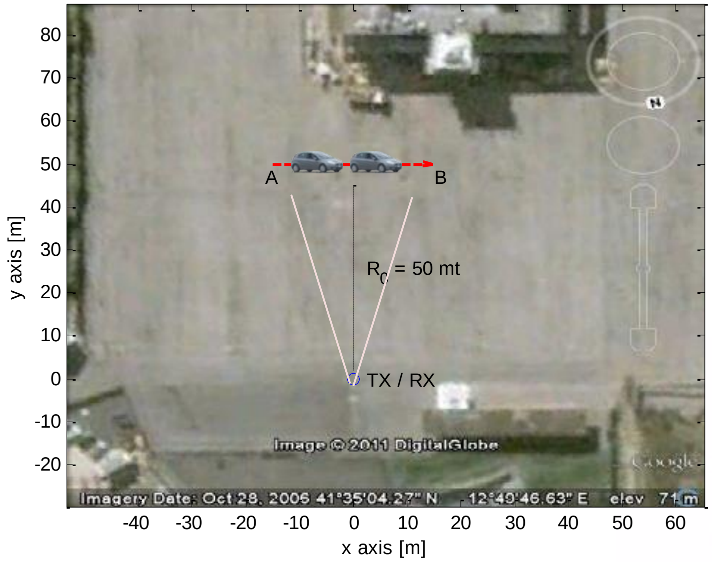
Experimental test for a WiFi-based PCL using 2 identical cars



The targets can be easily detected but they cannot be resolved.

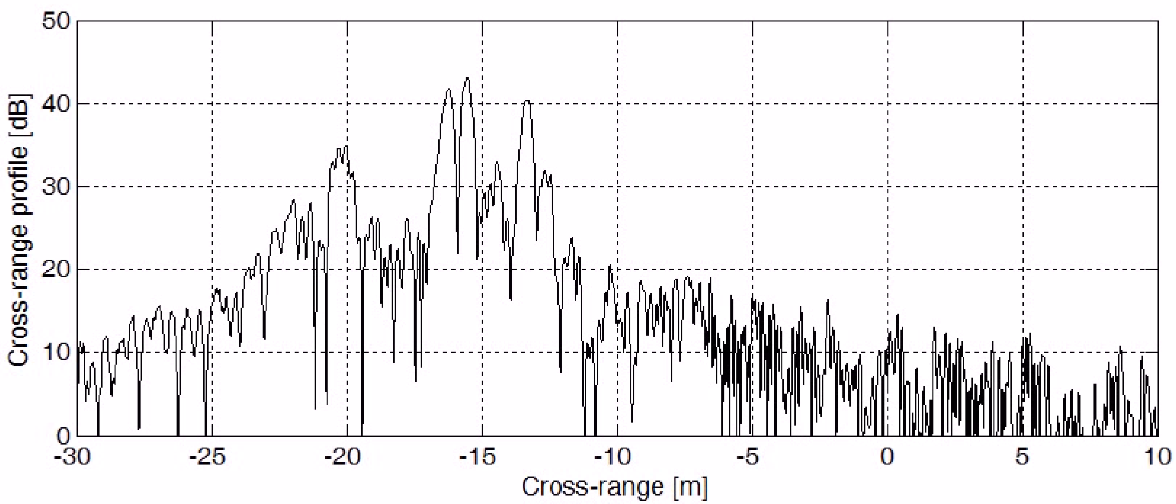


Surface vehicles monitoring with WiFi based PCL (IV)



Sequence of cross-range profiles obtained at consecutive CPIs of 6 seconds each

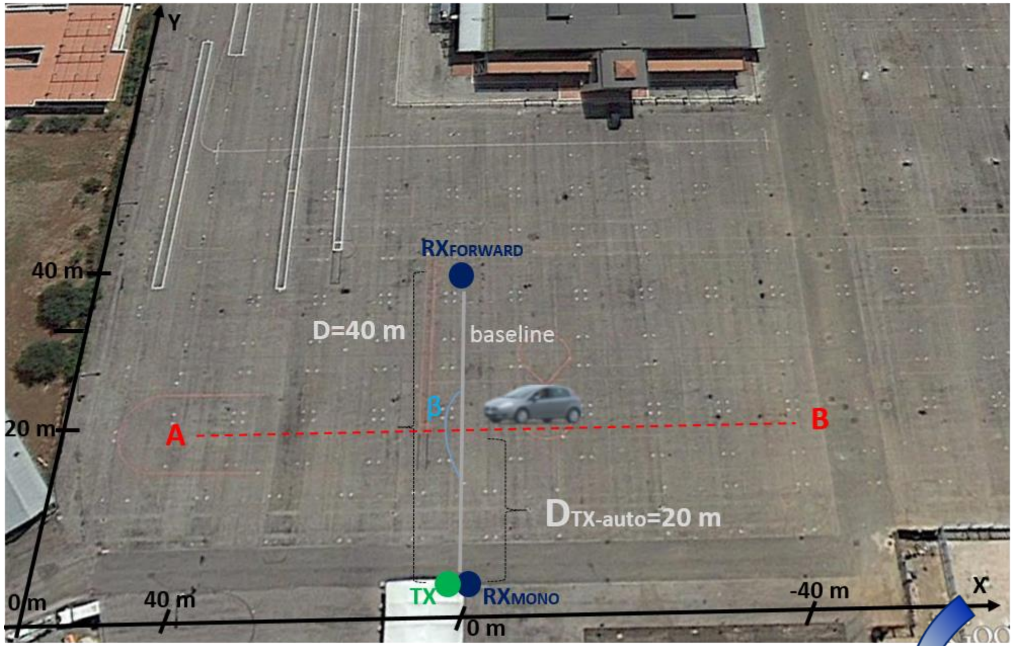
(the CPIs are largely overlapped with temporal displacement: 0.1 sec; Total acquisition: 10 sec)



F. Colone, D. Pastina, P. Falcone, P. Lombardo, "WiFi-based passive ISAR for high resolution cross-range profiling of moving targets", IEEE Trans. on Geoscience and Remote Sensing, 52(6), pp. 3486-3501, June 2014.

Surface vehicles monitoring with WiFi based PCL (V)

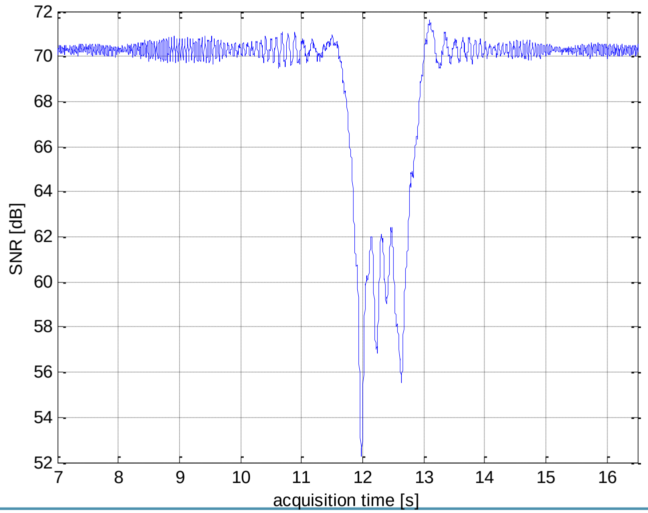
Enabling vehicles classification by exploiting a forward scatter geometry.



- Target Velocity: between 3.5 – 5 m/s
- Employed vehicles:

Car model	Dimensions (l, w, h)	N. of tests	Label
VW Polo	3.97 x 1.65 x 1.45 m	19	1
Ford Fiesta	3.93 x 1.76 x 1.49 m	19	2
Nissan Micra	3.71 x 1.54 x 1.54 m	21	3
Fiat Punto	4.04 x 1.69 x 1.49 m	20	4
Opel Corsa	3.81 x 1.64 x 1.44 m	19	5

Vehicle signature



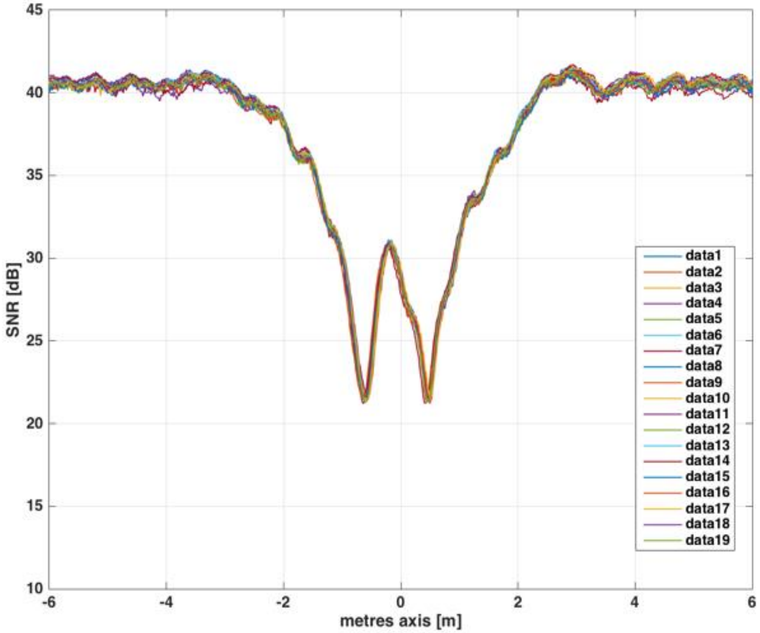
T. Martelli, F. Colone, P. Lombardo, “First experimental results for a WiFi-based passive forward scatter radar”, IEEE Radar Conference 2016, 2-6 May 2016, Philadelphia (PA, USA).

Surface vehicles monitoring with WiFi based PCL (VI)

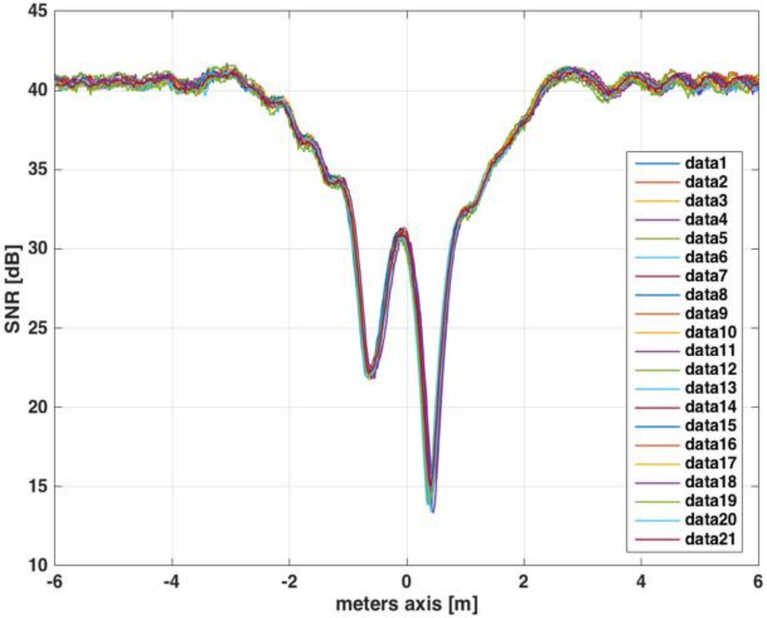
The vehicle signatures can be potentially exploited for classification purposes because:

- the same target along different tests has the same vehicle signatures.
- each target yields a characteristic signature.

VW Polo

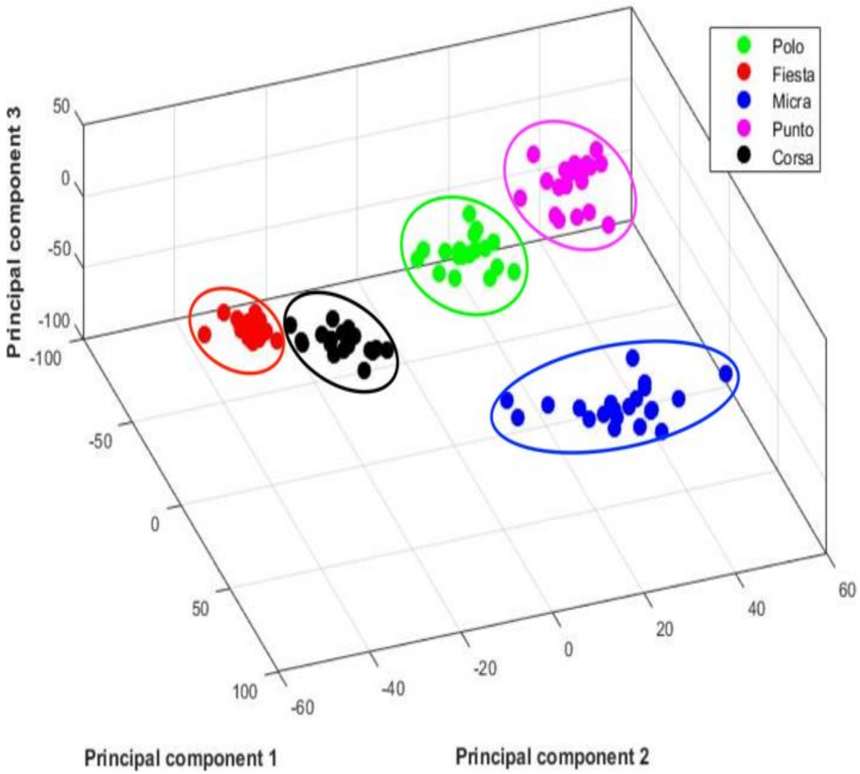


Nissan Micra



Surface vehicles monitoring with WiFi based PCL (VII)

Location of Training Dataset in PCA space



Classification results using a conventional k-NN approach

		Actual Labels					
Total=145		1	2	3	4	5	
Predicted Labels	1	28	0	0	0	0	28
	2	0	28	0	0	1	29
	3	0	0	31	0	0	31
	4	0	0	0	30	0	30
	5	0	0	0	0	27	27
		28	28	31	30	28	

- A. Losito, M. Stentella, T. Martelli, F. Colone, "Automatic vehicles classification approaches for WiFi-based Passive Forward Scatter Radar", Int. Conference on Radar Systems RADAR 2017, Belfast (UK).
- M. Stentella, A. Losito, T. Martelli, F. Colone, "Stand-alone WiFi-based Passive Forward Scatter Radar sensor for vehicles classification", Int. Conference on Radar Systems RADAR 2017, Belfast (UK).

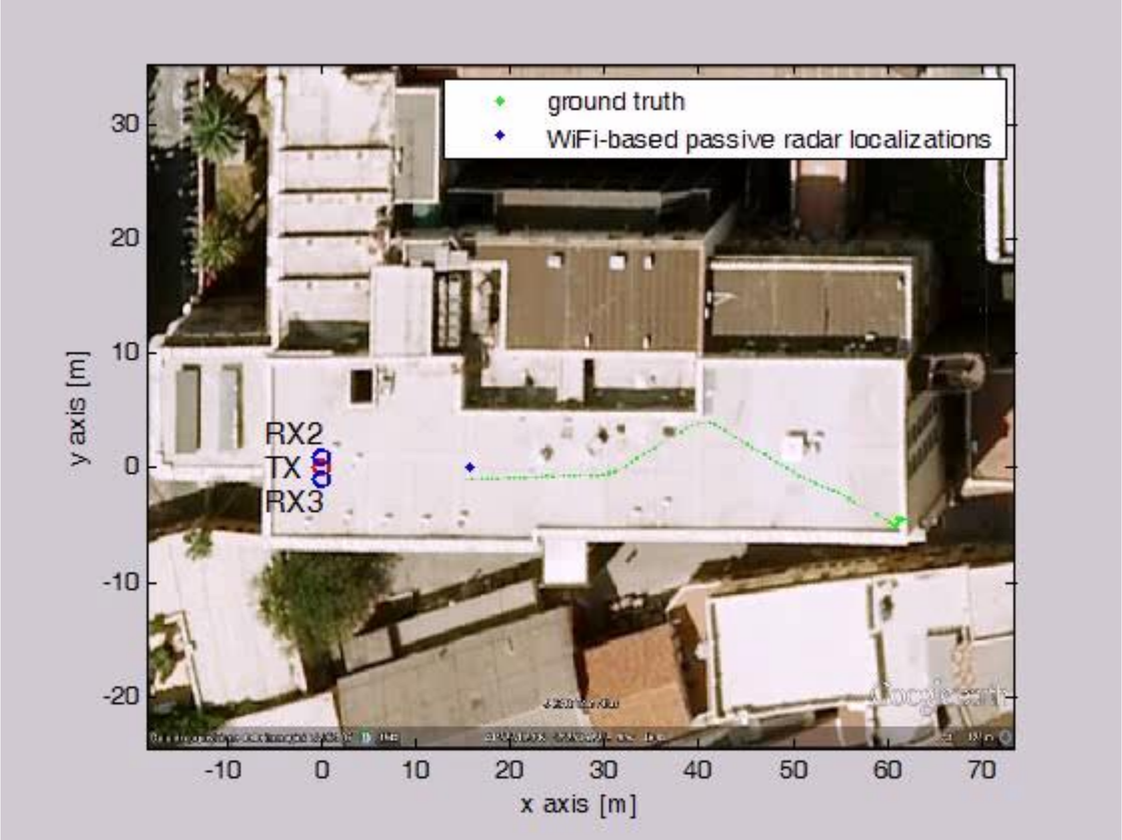
Indoor applications for WiFi-based passive radar sensors (I)

Advantages of passive radar for indoor localization and tracking (e.g. people location and navigation along buildings, automotive safety, vehicle navigation or asset tracking):

- It complements existing technologies at reasonable cost;
- with respect to technologies such as RFID , IEEE 802.11 wireless LAN, and ultrasonic, it does not require the target objects to be equipped with a cooperative device → it is well suited for specific surveillance applications such as intruder location, detection, tracking and identification of unauthorized vehicles in a forbidden area, etc.;
- with respect to technologies such as infrared, it does not require direct line-of-sight and is a "longer" range signal transmission → feasibility of uncooperatively and covertly detecting people moving behind walls ;
- with respect to video surveillance, it is not subject to the blind spots and potentially intrusive equipment → it could be used in public areas or private commercial premises.
- no extra signal is transmitted → this limits the energy consumption, prevents possible interferences with pre-existing systems, and makes the sensor free from any issue related to human health.

Indoor applications for WiFi-based passive radar sensors (II)

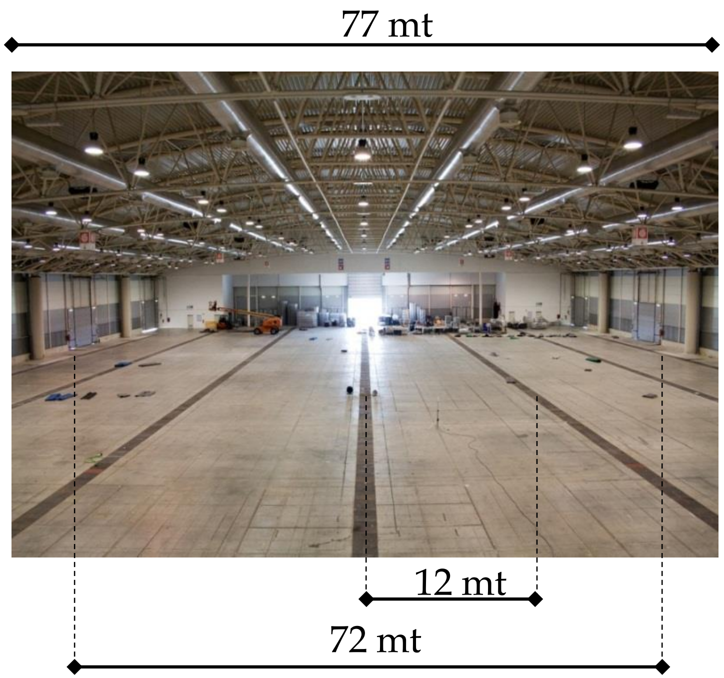
Example of intruder detection application: Human target walking on the roof of our faculty, equipped with a GPS receiver to collect the ground truth.



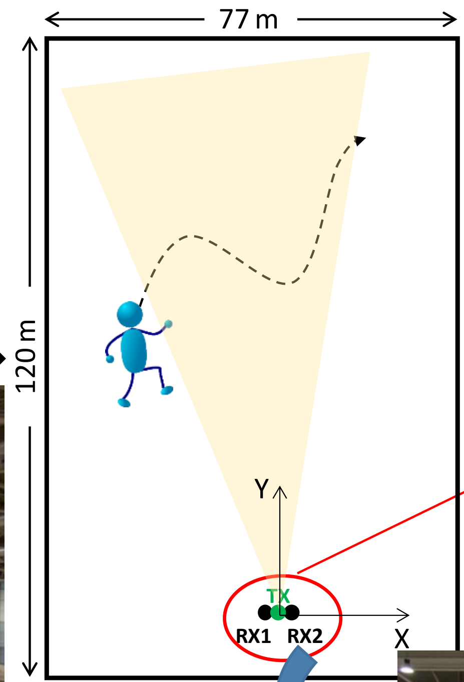
Indoor applications for WiFi-based passive radar sensors (III)

FP7 EU Project ATOM

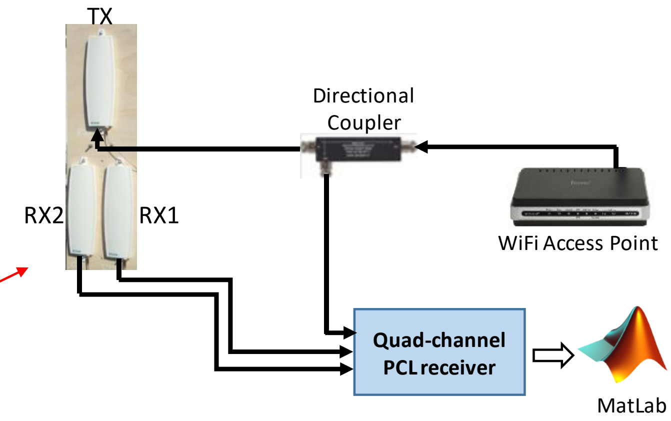
Airport detection and Tracking Of dangerous Materials by passive and active sensors arrays

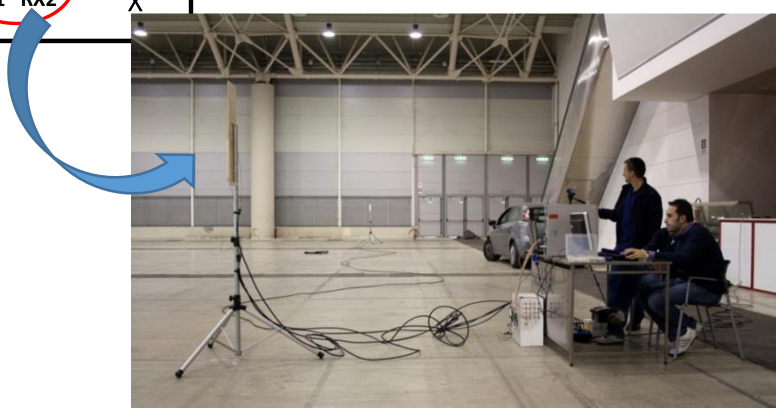


Wide exhibition hall of "Nuova Fiera di Roma"

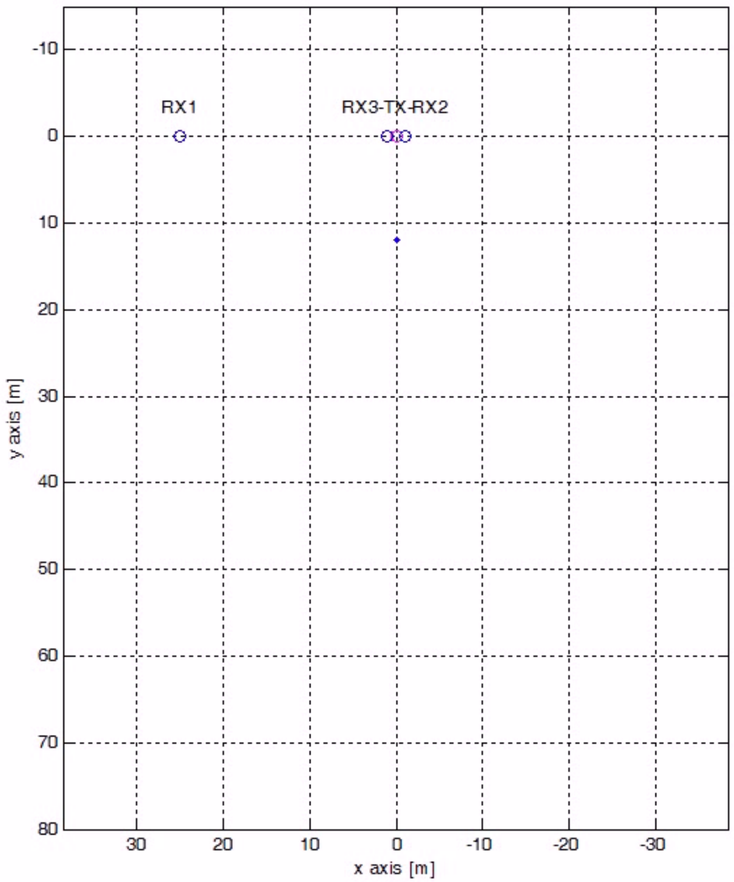


Indoor experimental tests for a WiFi-based PCL





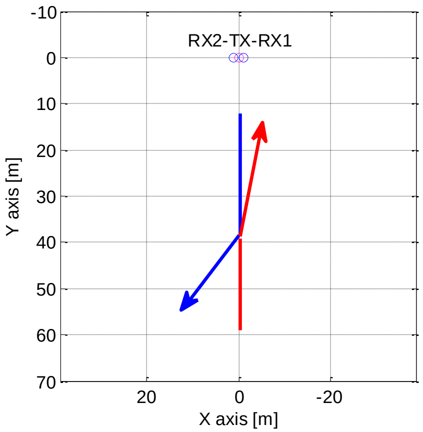
Indoor applications for WiFi-based passive radar sensors (IV)

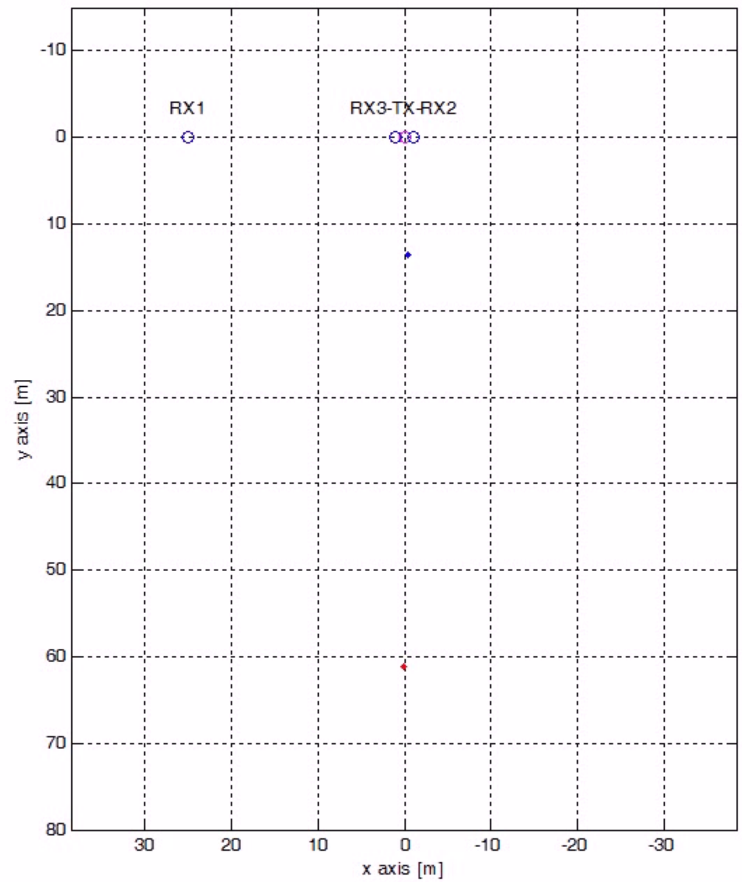


TEST #1: A single target walks forward the antennas location for a while and then changes its walking direction.

Indoor applications for WiFi-based passive radar sensors (V)

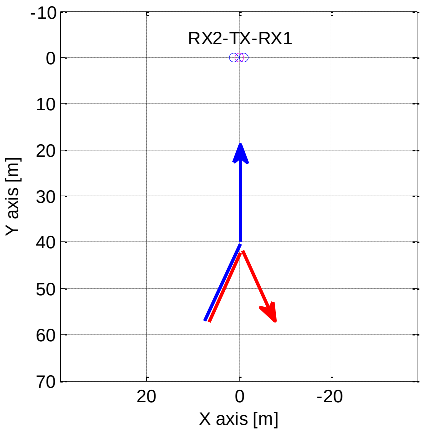
TEST #2:

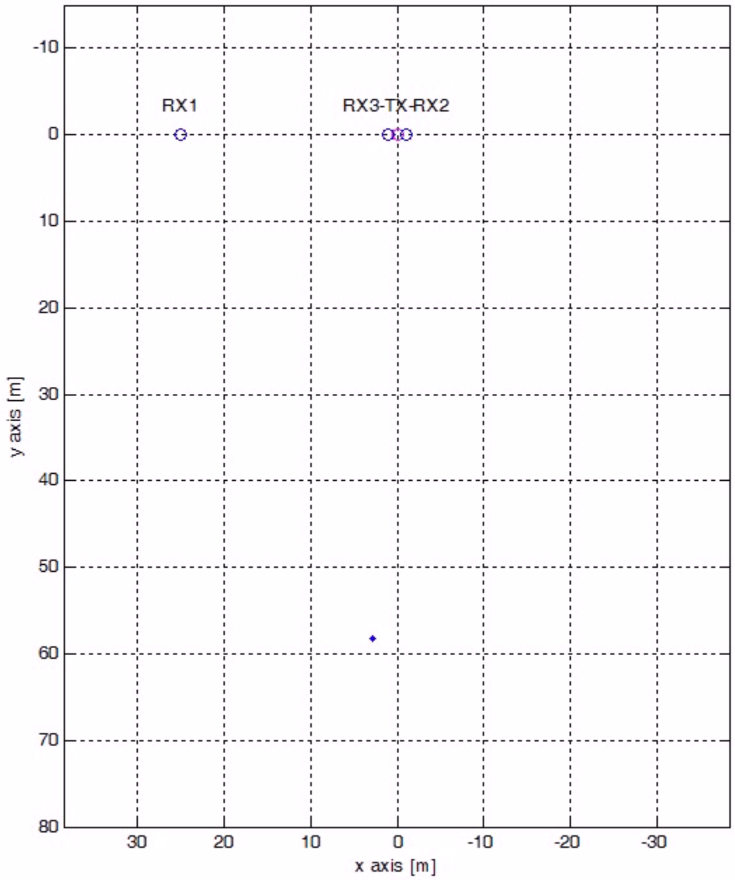




Indoor applications for WiFi-based passive radar sensors (VI)

TEST #3:

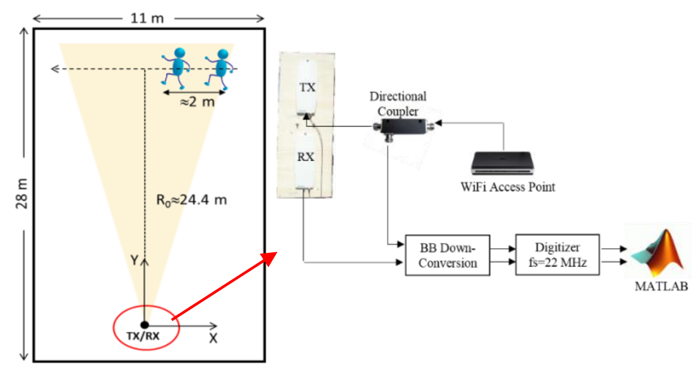




Indoor applications for WiFi-based passive radar sensors (VII)

Potential of ISAR techniques in resolving real human targets in a cluttered indoor scenario.

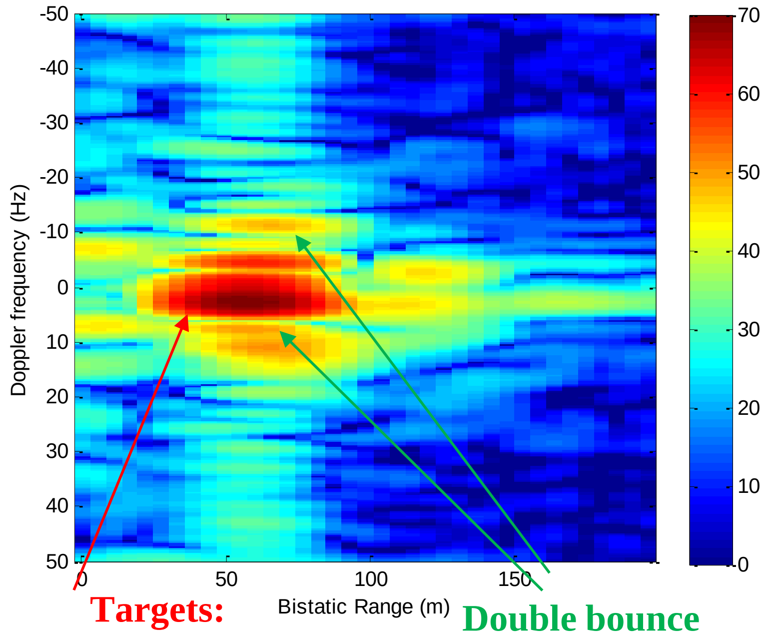
- The test were performed in the canteen of the school of Engineering at University of Rome "La Sapienza".
- A monostatic configuration has been employed.
- Two people move along cross-range direction with constant velocity (v ≈ 1.3 m/s).
- The human target have a fixed displacement of about 2 m.
- The total acquisition time is 10 s.

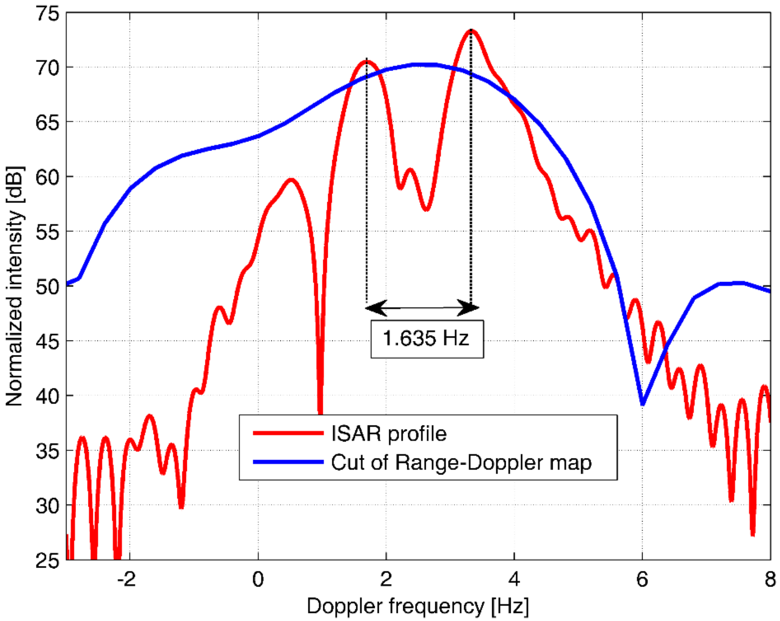


Indoor applications for WiFi-based passive radar sensors (VIII)

The two targets give rise to the presence of:

- a single peak in the cut of range-Doppler map at the range bin interested by the targets (with integration time = 0.5 s)
- two peaks in the ISAR profile (with integration time = 3 s and compensation up to the third order)





Targets:
they can be easily detected
but they cannot be resolved

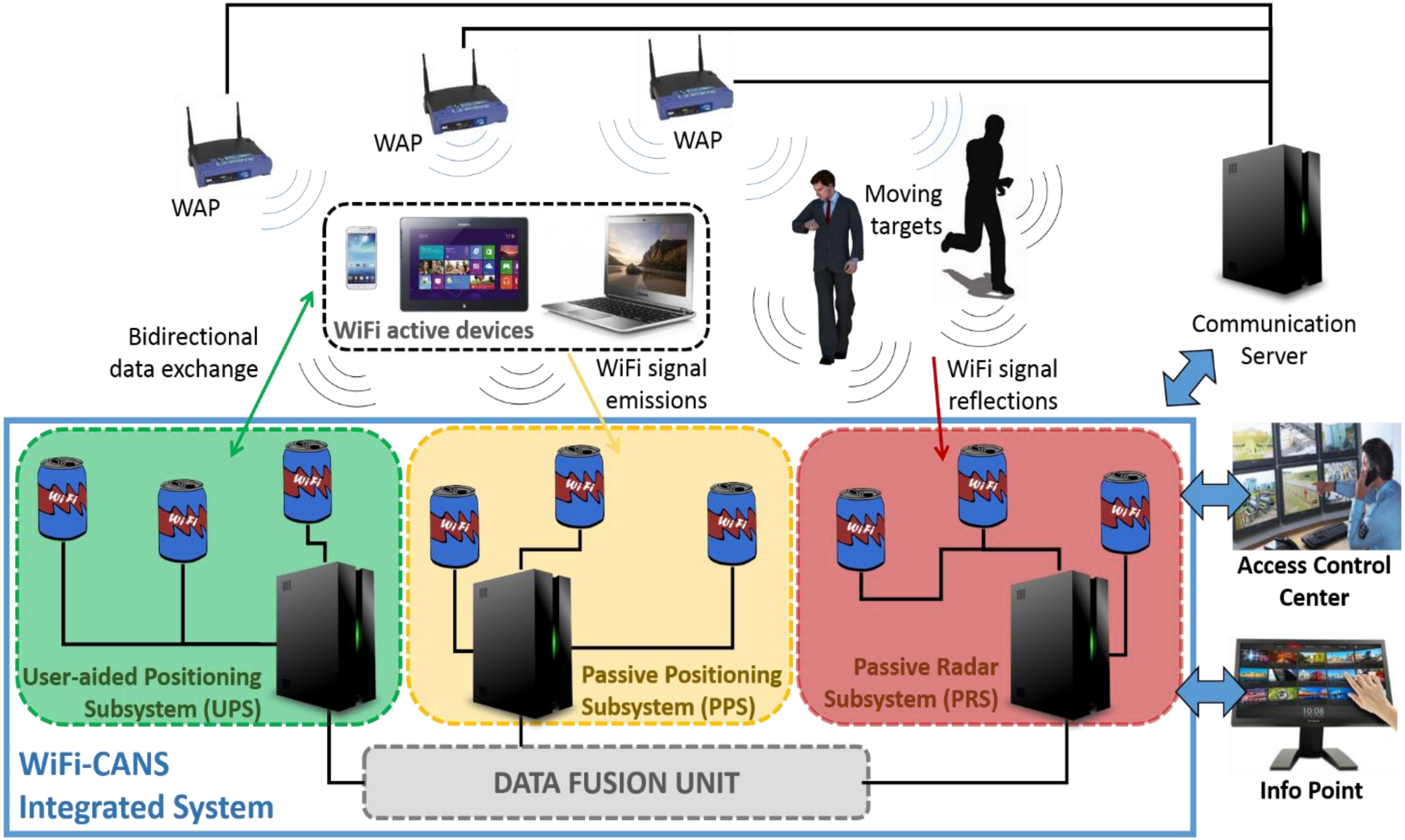
Double bounce

The results show that ISAR techniques can be exploited to improve cross-range resolution so that closely spaced targets can be discriminated.

D. Pastina, F. Colone, T. Martelli, P. Falcone, "Parasitic exploitation of WiFi signals for indoor radar surveillance", IEEE Transactions on Vehicular Technology, vol. 64, no. 4, pp. 1401-1415, April 2015.

Indoor applications for WiFi-based passive radar sensors (IX)

Integrated system able to provide its users with communication, automatic positioning, navigation, and surveillance capabilities based on the parasitic exploitation of WiFi signals.



Conclusions

- The effectiveness of PCL for short range surveillance applications has been demonstrated
- Advanced capabilities and improved performance can be obtained by exploiting:
  - A network of PCL sensors properly dislocated within the area to be surveyed
  - Favourable bistatic geometries there including forward scattering configurations
  - Long integration times to obtain more accurate positioning and high resolution profiles of the observed targets.
- A number of practical applications can be foreseen for such kind of sensors (aerial surveillance, ground-based traffic monitoring, indoor positioning) thus embracing the current trend of using standard, low-cost, and green technologies.

Acknowledgements

The colleagues of the University of Rome “La Sapienza”: Dr. Debora Pastina, Dr. Carlo Bongioanni, Dr. Paolo Falcone, Dr. Tatiana Martelli, Dr. Antonio Macera, Alessandro Losito, Michele Stentella.