MFEs 2022-2023

OPERA – Wireless Communications Group

Ecole polytechnique de Bruxelles

Distributed localisation of terminals in 6G wireless networks

Information: François Horlin, François Quitin, Evert Pocoma Copa
Students: ELEC, PHYS
Type: Theoretical

MOTIVATION

Geolocation services are of high importance in applications like navigation, infotainment, social networks, etc. They have been studied for several years now and integrated in wireless networks, but the focus has only been on centralized localization: all the information about the signals observed at multiple base station antennas is collected and processed in a common place denoted Fusion Centre (FC) where localization algorithms are implemented. Such algorithms are based on properties of the observed signals such as: time-of-arrival (ToA) and/or angle-of-arrival (AoA).

At the same time, the demand for high performance cellular networks is still increasing, on one hand due to the explosion of the number and variety of connected devices, and on the other hand to the ever-growing capacity requirements. To meet this demand, it is expected that the new 6G cellular networks will deploy a much higher number of base station antennas in the same area. This concept of dense cellular networks calls for the distributed implementation of the localisation algorithms: instead of implementing the localization centrally in the FC, it is implemented in a distributed fashion at the base stations located close to the wireless transmitter. In that case, the localization happens closer and closer to the edge of the cellular network. All the base-stations (BS's) involved in the distributed localization reach a consensus on the position of the transmitter, i.e., the user position is available at each BS. Such distributed localization involves several exchanges of "optimal-minimal" information between BS's, taking into account the network logical topology (one BS communicates only with a selected group of BS's, such as neighbouring BS's) and network physical geometry (e.g. all BS's are located side by side in a straight line, in the lamppost in the streets).

The objective of this master thesis is to conceive and assess distributed localization and tracking algorithms for 6G networks. A special care will be taken to the efficient exchange information among the base stations involved in the distributed localization process.

OBJECTIVES

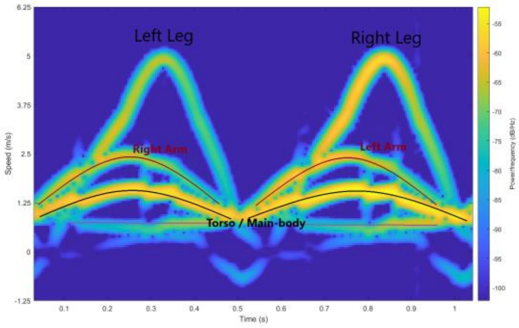
- Design distributed positioning algorithms for 6G networks
- Optimize the signal representation to support the distributed localisation
- Assess the positioning accuracy/precision as a function of the network logical topology
- Assess the positioning accuracy/precision as a function of the network physical geometry

CONTACT

François Horlin, francois.horlin@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Radars for human gait analysis

Information: François Horlin, Jean-François Determe, Hasan Can Yildirim
Students: ELEC, BIOMED, PHYS
Type: Theoretical and/or experimental



MOTIVATION

There is considerable interest in developing reliable and cost-effective technologies enabling healthy living. When people are active (walk, run or spring for instance), their limbs follow repetitive instantaneous speed patterns containing unique and discriminative features useful for healthcare applications, such as assisted living (fall detection of elderly people…) and bio-medical applications (illness detection…). Interestingly illnesses impacting the patterns can be classified in different categories: (i) anatomic asymmetry yielding left and right gait mismatches; (ii) nerve system illness like the Parkinson's disease yielding non periodic patterns over multiple cycles; (iii) muscle mass asymmetry similar to the anatomic asymmetry, but often unconsciously compensated when moving.

While cameras are often the first option considered for such applications, they do not work well in dark conditions and are subject to privacy concerns. On the contrary, radars not only provide very clear representations of the movements (see the instantaneous speeds in the figure above), but are also less invasive and enable a continuous monitoring of the scene with a possible recording of the observations for further offline analysis.

The goal of the master thesis is to build a radar capable of capturing the frequency variations known as micro-Doppler due to the motions of the limbs. This is done by performing a time-frequency analysis of the received signal. By inspecting the resulting Doppler spectrum and applying classification algorithms, illnesses will be detected.

OBJECTIVES

- Model typical and abnormal human gaits when walking
- Understand the radar principles, implement the Doppler spectrum estimation
- Validate the algorithms experimentally with a radar platform
- Apply classification algorithms for illness detection

CONTACT

François Horlin, francois.horlin@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Monitoring the crowd dynamics with radars

Information: François Horlin, Philippe De Doncker, Laurent Storrer, Dejvi Cakoni
Students: ELEC, INFO
Type: Theoretical and/or experimental

MOTIVATION

Mass events are very important and symbolic events in the life of dynamic cities. Unfortunately, disasters occurring during such mass events are significantly increasing worldwide. Three risky behaviors have been identified when thousands of people are gathering in a given area. First, panic behavior that occurs if some sudden event makes people behave irrationally, believing their life is in danger. Next, stampede situations occurring when a crowd starts rushing massively towards a single point where crushes are likely to appear. But the main danger is crowd turbulence appearing when the crowd density is too high, causing people movements several meters away by the crowd in a totally uncontrolled way due to unintentional forces from neighbouring bodies.

There is therefore a lot of interest in understanding and measuring the dynamics of crowds. Many applications can benefit from this information, such as the real-time management of people flow for social distancing monitoring, or the management of scenes of disaster during large events.

Measuring crowd dynamics requires time-stamped position and speed information of the people. The goal of this thesis is to leverage the time variations of the Doppler frequency shifts in the signals gathered by a radar due to moving people in a crowd. This process is also known as micro-Doppler analysis and is widely used for movement analysis. The objective is to transpose that analysis at the scale of a crowd. It involves the simulation of crowd dynamics, the study of time-frequency transforms to analyse the Doppler frequency shifts evolution, and the definition of crowd-specific radar metrics as well as the use of machine learning classification techniques on the output of those transforms to assess the crowd density and detect critical situations.

OBJECTIVES

- Develop a simulation environment to emulate crowd dynamics
- Design metrics for crowd monitoring
- Implement various time-frequency transforms (short-time Fourier transform, Wigner-Ville distribution, wavelet transform, …)
- Apply feature extraction and classification techniques based on machine learning on the output of those transforms (support vector machines, neural networks…)

CONTACT

François Horlin, francois.horlin@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Design of a low-cost passive radar on Raspberry Pi

Information: François Horlin, Philippe De Doncker, Hasan Can Yildirim, Evert Pocoma Copa
Students: ELEC, INFO
Type: Experimental

MOTIVATION

Passive radars opportunistically capture existing communication signals to detect and track objects. Thereby they do not emit any additional signals. This reduces the complexity of the device and allows to avoid additional exposure to electromagnetic waves.

Wi-Fi, based on the IEEE 802.11 standard, is the most popular WLAN technology, i.e. a typical household consists of tens of Wi-Fi devices connected to one or more access points. The main Wi-Fi standards use the orthogonal frequency-division multiplexing (OFDM) modulation due to its ability to efficiently deal with multi-path channels which are typical for indoors wave propagation. From a passive radar point of view, Wi-Fi is an excellent opportunity for detecting/tracking individuals and objects due to its wide availability.

Nexmon-CSI is an open-source tool that enables to capture the channel state information (CSI), in other words an estimate of the multi-path channel, with different devices including the Raspberry-pi and smartphones. Such tool introduces the possibility to build an accessible low-cost passive radar platform.

The goal of the master thesis is to build a WiFi-based passive radar with Nexmon on a Raspberry-pi 4. Two challenges inherent to the system will be addressed. First, since Nexmon estimates the CSI based on synchronized beacons, it loses the information in the phase relevant for Doppler processing. Second the beacons are only transmitted by the base station every 100 ms, which incurs a significant aliasing in the Doppler processing.

OBJECTIVES

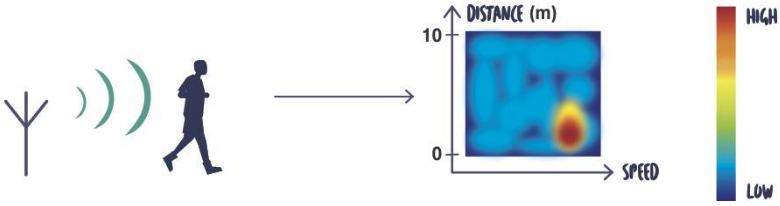
- Discover Nexmon and its implementation on a Raspberry-pi
- Acquire the CSI in different scenarios from beacons transmitted by a WiFi base station
- Investigate the Doppler phase reconstruction by taking the static environment as a reference
- Characterise the Doppler of moving individuals or objects under aliasing

CONTACT

François Horlin, francois.horlin@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Design of a real-time radar for indoor monitoring

Information: François Horlin, Jean-François Determe, Dejvi Cakoni, Laurent Storrer
Students: ELEC, INFO
Type: Experimental



MOTIVATION

In order to detect and track objects in an indoor environment, one of the most widely used technology is radars. Radars transmit well designed signals, to build range-Doppler maps (RDM) of the environment where each object is identified by its distance and speed from the radar.

The Infineon Position2GO radar works at 24 GHz, with a bandwidth of 200 MHz and two receive antennas. It covers a range up to 20 m, has a range accuracy of the order of 1m and is capable to estimate the signal angle-of-arrival. It is therefore well suited to monitor the movements of individuals or objects in an indoor environment. Until now, the radar has always been interfaced with a computer where the baseband samples are collected and the radar processing applied offline in Matlab.

The group owns a good knowledge of the radar functionality, i.e. all functions necessary to make the radar work. It is composed of algorithms implemented to build the RDM, detect the targets and form the clusters corresponding to a single person or object.

The goal of the master thesis is to move one step further and build a real-time radar composed of the Infineon platform connected to a Raspberry pi 4 where the algorithms are efficiently implemented in python to work real-time. The radar will enable the continuous monitoring of an indoor environment over long periods of time.

OBJECTIVES

- Understand thoroughly the radar functionality (RDM, detection, clustering)
- Discover the Infineon radar platform Position2GO and test it offline
- Interface the Infineon platform with a Raspberry pi
- Implement the radar functionality in python on the Raspberry pi 4

CONTACT

François Horlin, francois.horlin@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Numerical modelling of the radar signature of crowd turbulence by using an iterative physical optics method

Information: Philippe De Doncker, François Horlin, Laurent Storrer, Dejvi Cakoni
Students: ELEC, PHYS
Type: Theoretical and/or experimental

MOTIVATION

Monitoring crowd dynamics is of outermost importance for the management of scenes of disaster during large events. The main danger in large public events is referred to as *crowd turbulence* which appears when the crowd density is too high, causing people movements several meters away in a totally uncontrolled way due to unintentional forces from neighbouring bodies.

Radars are foreseen as a promising solution to monitor crowd dynamics and to detect crowd turbulence by measuring in real-time range-Doppler maps of the moving crowd. However, a fine model of the crowd turbulence radar signature is impossible to get experimentally, due to evident safety reasons. The development of numerical models taking into account multipath propagation through people potentially very close to each other and moving in a turbulent way, is thus necessary.

In this thesis we propose to address this challenge by hybridizing integral equations and physical optics in an iterative way to emulate multiple-bounce propagation through crowds. The models will be validated through experiments on non-turbulent cases and/or reference results already obtained by the research group.

OBJECTIVES

- Develop a new numerical methodology to model the radar signature of moving crowds.
- Develop dynamical models of crowd turbulence.
- Apply machine learning strategies on range-Doppler maps to identify features that characterizes crowd turbulence.
- Deduce the feasibility of using radars to detect the advent of crowd turbulence.

CONTACT

Philippe De Doncker, philippe.dedoncker@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Propagation analysis of Earth-observation satellites K-band channels

Information: Philippe De Doncker, François Quitin
Students: ELEC, PHYS
Type: Theoretical

MOTIVATION

Earth-observation satellites are rapidly developing in order to monitor the environment and/or human activities. Currently, data measured by the satellites are typically sent to the Earth on radio links working below 10GHz, i.e. in the X-band. However, the need for wider bandwidths and interference-free propagation conditions motivates the shift to higher frequencies, especially to the K-band, around 26GHz.

The downlink quality of Earth-observation satellites is heavily dependent on the link frequency due to atmospheric propagation conditions. On the other hand, higher frequencies allow one to use more directive antennas which could combine analog and digital beamforming.

In this thesis, we propose a full analysis of the satellite K-Band channel including beamforming capabilities in order to compare Earth-observation satellite performance in both the K-band and the X-band. Realistic Low-Earth Orbit (LEO) scenarios will be considered.

OBJECTIVES

- Identify and compare the main propagation mechanisms for space communications in the X-band and the K-band.
- Develop a propagation model for Earth-observation satellites orbiting on a Low-Earth Orbit.
- Compare X-band and K-band performances taking into account beamforming capabilities.

CONTACT

Philippe De Doncker, philippe.dedoncker@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Study of exposure in a stochastic geometry framework

Information: Philippe De Doncker, François Horlin, Quentin Gontier
Students: ELEC, PHYS
Type: Theoretical and possibly experimental

MOTIVATION

Exposure to Electro-Magnetic Fields (EMF) has been a major public concern for years. It triggers many debates among all relevant stakeholders (governments, public environmental agencies, network providers, non-governmental associations) whenever a new network generation emerges, as 5G today. 5G brings an important evolution in terms of pervasive connectivity for people and objects, offering high data rates and low latencies. This evolution is possible thanks to network topology changes through the deployment of small cells, and improvements in communication strategies through the use of massive MIMO directive antennas in base stations. Clearly, these two technological approaches will significantly impact EMF exposure.

In recent years, stochastic geometry (SG) has emerged as a very powerful approach for generic network performance analysis at the communication or network layers. But there are few applications to EMF exposure, although SG seems to be able to fill in the gaps of existing exposure modelling tools. There are therefore lots of improvements to be made for exposure models.

OBJECTIVES

The candidate will have degrees of freedom regarding the topic. Possible directions for next year are mentioned below and will be discussed with the master thesis promoters.

- Study of a scenario with static (and dynamic) beamforming. The candidate will compare different beamforming patterns (Frejér, flat-top, sinc, cosine, multi-cosine…). Depending to the ease of obtaining the model, the student will have the possibility to validate the model through an experimental dynamic beamforming set-up using Software Defined Radios.

- Including a time dependence to existing models using a sleep control system. Depending on the traffic, some base stations may be inactive during some time. This has to be modeled stochastically.

- Joint coverage-exposure metric for uplink transmissions (transmissions from smartphones, tablets, cars, traffic lights…). The candidate will include the power control and the duty cycle in the model. The model will be validated using measurements made in Brussels.

The student interested in this subject is invited to take a look at [1] and [2].

[1] Gontier, Quentin & Petrillo, Luca & Rottenberg, Francois & Horlin, Francois & Wiart, Joe & Oestges, Claude & Doncker, Philippe. (2021). A Stochastic Geometry Approach to EMF Exposure Modeling. IEEE Access. PP. 1-1. 10.1109/ACCESS.2021.3091804.
[2] Gontier, Quentin & Petrillo, Luca & Rottenberg, Francois & Horlin, Francois & Wiart, Joe & Oestges, Claude & Doncker, Philippe. (2021). Semi-empirical Model of Global Exposure using Stochastic Geometry. 1-5. 10.1109/ICCWorkshops50388.2021.9473645.

CONTACT

Philippe De Doncker, philippe.dedoncker@ulb.be
François Horlin, francois.horlin@ulb.be
Solbosch campus, building U, level. 3, OPERA department

Spatial Data Focusing for Hyper-resolution Wireless Physical Layer Geocasting

Information: Philippe De Doncker, François Horlin, Guylian Molineaux
Students: ELEC
Type: Theoretical and experimental

MOTIVATION

GEOCASTING, or location-based multicasting, is the spatially confined broadcasting of information, targeting exclusive delivery to users within restricted geographical regions. It allows to offer location-dependent services and messaging to large groups of mobile devices that exist in the context of Internet-of-Things, Smart Cities, and Wireless Sensor Networks, e.g. for advertising and marketing, traffic management, emergency signaling, tourism, etc. Geocasting on the physical layer is traditionally implemented using beamforming to focus power in a desired direction. Beamforming's precision is however limited and large antenna arrays are required for high resolution geocasting. In contrast to beamforming, Spatial Data Focusing (SDF) attempts to address the geocasting issue directly, aiming for increased precision, reduced array size, and minimal complexity. SDF adopts the idea of channel-based modulation through the distributed transmission of information across elements in an array. Specifically, uncorrelated and orthogonal signals, that carry substreams of a global datastream, are transmitted over the sub-channels in a Multiple-input Single-output setup. At the receiver, differences in propagation conditions between each data substream are exploited to induce a location-dependent symbol distortion that restricts the spatial availability of the transmitted data.
Current SDF implementations have shown to match the precision of a 13-antenna beamforming array, with only 2 antennas.

Traditional beamforming (left) and Spatial Data Focusing (right)

Proposed Master Thesis Subjects:

"Experimental Prototyping of a Geocasting Spatial Data Focusing Array using Software Defined Radios"

The goal of this Master thesis is to develop an *experimental SDF setup*, using Software Defined Radios and a uniform linear array of at least 2 antennas. The study should assess the practical feasibility of SDF and compare its performance to simulation-based studies, in terms of connectivity and precision. The symbol distortion and BER behavior as a function of the receiver position should be assessed, first as a function of angle only, and secondly as a function of distance as well.

"OFDM-based Spatial Data Focusing Evaluation in 5G Massive MIMO Context"

This Master Thesis aims to investigate the additional degrees of freedom that a *5G massive MIMO (mMIMO) context* could offer SDF. In particular, the high number of antennas will allow to define subsets of antennas, to perform separate signal processing and improve performance/efficiency of SDF. For example, combining SDF and beamforming and achieve array gain (and hence improved robustness) on top of the high spatial focusing precision of SDF. Alternatively, they can be employed to realize a multi-user SDF scenario, where subsets of antennas in the mMIMO array are used to target individual users, each one with high precision. Additionally, subcarrier and pilot spacing in OFDM-SDF should be adjusted to 5G standards, and the impact evaluated.

"Multi-target Physical Layer Geocasting using Spatial Data Focusing"

This Master thesis should investigate the possibilities for a single SDF base station to *target multiple geographical areas*, and transmit a unique datastream decodable exclusively in its respective target area. The SDF transmitter-side signal processing should be expanded such that it can allocate resources in time, frequency, antenna, etc. to the different datastreams for optimal performance, i.e. as a function of their respective position and desired precision, while avoiding interference. Additionally, SDF receiver-side signal processing should be updated such that user terminals can distinguishing between relevant datastreams that are targeting their location and irrelevant datastreams that are targeting different locations and that can be ignored.

"3-Dimensional Geocasting using Planar Spatial Data Focusing Array"

Current SDF implementations use uniform linear arrays and multi-frequency transmission to achieve 2-dimensional focusing, i.e. in the azimuth and range domains respectively. The goal of this Master Thesis is to expand OFDM-SDF theory to planar arrays and allow for additional focusing along the elevation angle, to obtain a *3-dimensional geocasting scheme.*

CONTACT

Philippe De Doncker, philippe.dedoncker@ulb.be
François Horlin, francois.horlin@ulb.be
Guylian Molineaux, guylian.paul.molineaux@ulb.be
Solbosch campus, building U, level. 3, OPERA department