Geolocation with Neural Network

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Overview

The steps of the project are given as follows:

- The Problem of Geolocation
- Localization Techniques
- Data simulation
- Geolocation method
- Model Fit
- Performance evaluation

The Problem of Geolocation

The localization problem corresponds to estimating the position and orientation of a user equipment (UE) with the assist of one or multiple anchor base stations (BSs) (with known position and orientation information).

A UE can send (uplink) or receive (downlink) known pilot signals to or from a BS. The received signals are distorted by the propagation channel, which is determined by the BS/UE states (position and orientation) and the environment (signals can be reflected by a wall, a reconfigurable intelligent surface (RIS) or an object).

Based on the knowledge of the pilot signals and a proper signal model, the channel can be estimated and the channel parameters (angle-of-arrival (AOA), angle-ofdeparture (AOD) and delay) of each path that signal propagates can be extracted. Finally, UE position and orientation can be estimated with its relative geometry relationships with known reference anchors (e.g., BSs and RISs).

Many localization systems have been developed and can be categorized as follows:

Criteria	**Types**
Application scenario	Outdoor, Indoor
Wireless technology	GPS, Cellular System, WLAN, WiFi
Localization Technique	Geometry-based, Learning-based
Signal type	Radio waves, LED signal, LIDAR
Functionality	Passive, Active
System structure	Centralized, Distributed, Clustered
Position Information	Absolute Position, Relative position
Information-sharing	Cooperative, non-cooperative

Table: Taxonomy of localization techniques.

Localization Techniques

Geometry-based localization is widely used in communication systems. The most common used are time-of-arrival (TOA), time-difference-of-arrival (TDOA), angle-of-arrival (AOA) which measure the distance or angle of a UE wrt multiple BSs with known positions. An alternative is the angle-difference-of-departure (ADOD), that estimates orientation alongside estimated position. A summary of their attributes is given in the table below

	Dimension	**TOA**	**TDOA**	**AOA**	**ADOD**
N. of BS needed per Meas.		1	2	1	2
Geometric Constr. per Meas.	2D	Circle	Hyperbola	Line	Arc.
	3D	Sphere	Hyperboloid	Line	Surface of arc revolution
N. of per Meas. for Pos. Estimation	2D	3	3	2	3
	3D	4	4	2	4
System requirement		System Syn/RTT/RSS	BS-BS Syn	Array at BS	Array at UE
N. of AOD for Ori. Estimation	1D		1 (2D position needed)		
	2D		1 (3D position needed)		
	3D		2 (3D position needed)		

Table: Geometry based localization (uplink).

The estimation procedure foresees formulating an objective function that contains geometric information and solving an optimization problem with geometric constraints. For more complex scenarios with many non-resolvable NLOS paths, the geometry information cannot be explicitly modelled.

Data Simulation

Two streams of data will be simulated: (1) the beaconing signals with related measurements (i.e. TOA, TDOA, RSSI, etc.); (2) a set of identified hidden variables that will be fed to the chosen model to improve the estimation of the location.

For the simulation of (1), one can use a statistical model describing the characteristics of the different required components or and ad hoc emulator. Overall, the specified parameters to achieve a simulation for a real data setting is given in the following table:

Parameters	**Default Simulation Values**
mmWave / THz Frequency f_c	60GHz/ 0.3 THz
Transmittion Power P	10 dBm
Noise PSD	-173.86 dBm/Hz
Noise Figure	13 dBm
Array Footprint (BS/RIS/UE)	$2x2cm^2/10x10cm^2/1x1cm^2$
AE Spacing Δ	$\lambda_c/2$
Bandwidth W	100 MHz
Number of Transmissions $\mathcal{G}$	10
Synchronisation Offset β	10 us
Number of Subcarries K	10
Signal Wave Model	SWM (near-field)
Localization Scenario	2D position, 1D Orientation
mmWave Array Dim N_Q (BS/RIS/UE)	$4x4/20x20/2x2$
THz Array Dim N_Q, $\check{N}_Q$ (BS/RIS/UE)	$20x20/100x100/10x10$
THz SA Dim $\check{N}_B/\check{N}_R/\check{N}_U$	$5x5/1x1/5x5$
Position p_B, p_R, p_U	$[0;0;0]/[5;5;0]/[10;0;0]$
Orientation o_B, o_R, o_U	$[0;0;0]/[-\frac{\pi}{2};0;0]/[\frac{5\pi}{6},0,0]$

Table: Default values for the required parameters of the simulation.

Data Simulation

Simulators play an important role during the development of the wireless networks enabling IoT solutions, as the networks must be scalable and energy efficient without compromising security. Hence, simulators assist during the planning phase of a project to ensure that if customer demans scales, the correct technology was chosen to ensure the network can handle the increased demand.

Many simulator platforms for Wireless Sensor Networks (WSNs) exist, as

- ns-3
- OMNET++
- SimPy
- LoraSim (extension of the ones above). It has been further improved with LoraEnergySim
- LTE Matlab Toolbox (flexibility in the simulations)
- Sigfox simulator (low specs and very slow)
- NYUSIM Channel Simulator (extraction of the measurements)

Data Simulation - LoraSim

LoRaSim is a discrete-event simulator based on SimPy for simulating collisions in LoRa networks and to analyse scalability. This simulatr allows the used to place N LoRa nodes in a 2-dimensional space (grid layout or random distribution). M LoRa sinks (the data collection points) can also be placed within the space. A typical LoRa radio provides five configuration parameters: Transmission Power (TP), Carrier Frequency (CF), Spreading Factor (SF), Bandwidth (BW) and Coding Rate (CR). Energy consumption, transmission range and resilience to noise is determined by the selection of these parameters.

- Transmission Power (TP).
- Carrier Frequency (CF).
- Spreading Factor (SF)
- Bandwidth (BW)
- Coding Rate (CR)
- LoRa Packet Structure
- Airtime

Each LoRa node has a specific communication characteristic defined by the transmission parameters TP, CF, SF, BW and CR. For an experiment, each node's transmission behaviour is described by the average packet transmission rate λ and packet payload B. The behaviour of a node n during a simulation run is therefore described by the set $SN_n = TP, CF, SF, BW, CR, \lambda, B$.

Each LoRa sink is able to receive for a given CF multiple signals with different SF and BW combinations. This mimics the behaviour of LoRa sink chips such as the Semtech SX1301 which can receive 8 concurrent signals as long as these signals are orthogonal. Two of such chips can be used in a sink node to ensure that concurrent signals on all orthogonal SF and BW settings can be received simultaneously.

Data Simulation - LTE Toolbox

LTE provides standard-compliant functions and apps for the design, simulation, and verification of LTE, LTE-Advanced, and LTE-Advanced Pro communications systems. The toolbox accelerates LTE algorithm and physical layer (PHY) development, supports golden reference verification and conformance testing, and enables test waveform generation.

The following components can be implemented:

- Downlink channels
- Uplink channels
- Sidelink channels
- Signal Reception and Recovery (Synchronization, Channel Estimation, Equalization, Signal Recovery Procedures)
- End-to-End Simulation (Propagation Channel Models, i.e. Models for MIMO fading channel, EPA, EVA, and ETU; moving propagation channel; high-speed train MIMO channel, RMC, FRC, and E-TM configuration and waveform generation; link-level BER and conformance test)
- Test and Measurement (Describes waveform generation, visualization, and transmitter performance analysis)
- UMTS Test and Measurement (3G waveform generation, UMTS downlink measurement channel definition, UMTS downlink waveform generation, UMTS uplink measurement channel definition, UMTS uplink waveform generation)
- GNSS Simulation (Sampling rate of the GNSS receiver, Local navigation reference frame, Location on Earth in latitude, longitude, and altitude (LLA) coordinates, Number of samples to simulate, etc.)

Data Simulation - Sigfox Simulator

The Sigfox simulator created by Maarten Weyn which can be found at `https://github.com/maartenweyn/lpwansimulation/`. This simulator, like many others, focuses on the PHY layer and can be used to study this layer but should not be used to evaluate a LoRaWAN compliant network as it would then be considered incomplete.

Sigfox sends 3 messages using on a random frequency within a 200 kHz band in the 868 SDR band. Sigfox uses 100Hz ultra-narrowband GFSK modulation.

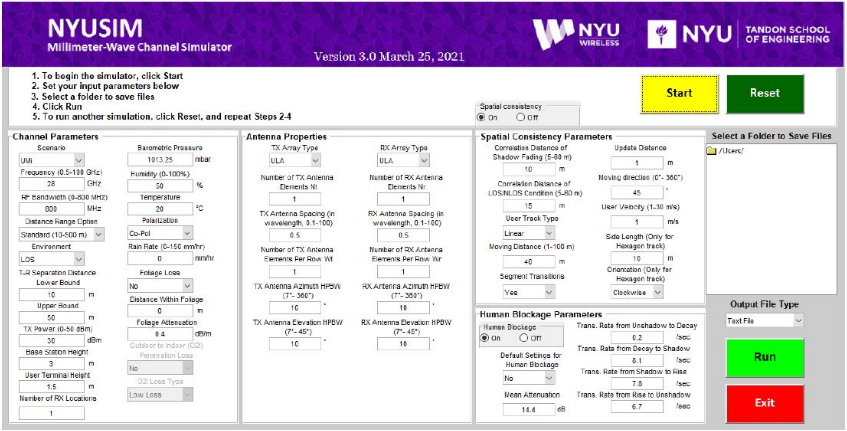
The simulator takes into account the spectrum use around 1 gateway, of course multiple gateways can detect signals which will raise the packet delivery ratio.

A difference between LoraWAN and Sigfox is that the LoraWAN gateways can dictate the transmit power to the endnodes, limiting their range. This also means there is more download traffic to the nodes. And the downlink also has to take into account the 10% duty cycle.

Parameters: Carrier Frequency, Bandwidth, Channel Estimation parameters. (no modelling of antennas or spatial).

Data Simulation - NYUSIM

The simulator performs Monte Carlo simulations, generating samples of CIRs at specific T-R separation distances.The range of T-R separation is provided by the user, and the actual T-R separation distance is uniformly selected from the user-specified distance range.



Specs of the Simulator:

- **Running Modes**: (1) Drop-based Mode; (2) Spatial Consistency Mode.
- **Scenarios**: (1)outdoor channel model; outdoor-to-indoor penetration (2); (3) indoor office.
- **Input Parameters**: There are 49 input parameters split as follows
  - Channel Parameters (Scenario, Carrier Frequency (GHz), RF Bandwidth (MHz), Distance Range Option, Environment, Lower/Upper Bound of T-R Separation Distance (m), TX Power (dBm), Base Station Height (m), User Terminal Height (m), Barometric Pressure, Humidity, Temperature, Rain Rate, Polarization, etc.)
  - Antenna Properties (TX Array Type, RX Array Type, Number of TX Antenna Elements, Number of RX Antenna Elements, TX Antenna Spacing (in wavelength), RX Antenna Spacing, etc.)
  - Spatial Consistency Parameters (Correlation Distance of Shadow Fading (5-60 m),Correlation Distance of LOS/NLOS Condition (5-60 m), UT Track Type, Track Distance (1-100 m), Update Distance (¡1m), etc.)
  - Humane Blockage Parameters (Default Settings for Human Blockage, Mean Attenuation, Rate from Unshadow to Decay (1/s),Rate from Decay to Shadow (1/s),Rate from Shadow to Rise (1/s), Rate from Rise to Unshadow (1/s)).

Data Simulation - NYUSIM

There are two sets of output files, i.e. (1) figures and (2) files (depending on the running modes). For simplicity, we report the ones of the drop-based mode only.

(1) Output Figures: Three-dimensional (3D) AoD power spectrum, 3D AoA power spectrum, a sample omnidirectional PDP, a sample directional PDP with strongest power, a series of PDPs over each receive antenna element, a path loss scatter plot generated after N continuous simulation runs with the same input parameters.

(2) Output Files: pathDelay (ns), pathPower (mWatts), pathPhase (rad), AOD (degree), ZOD (degree), T-R Separation Distance (m), Received Power (dBm), Path Loss (dB), RMS Delay Spread (ns), Ricean K-factor (dB), etc.