RISE-6G:
Localization, Sensing, and Their integration with Reconfigurable Intelligent Surfaces

Hexa-X and ICT-52 Workshop on 6G

January 18, 2023

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Consortium

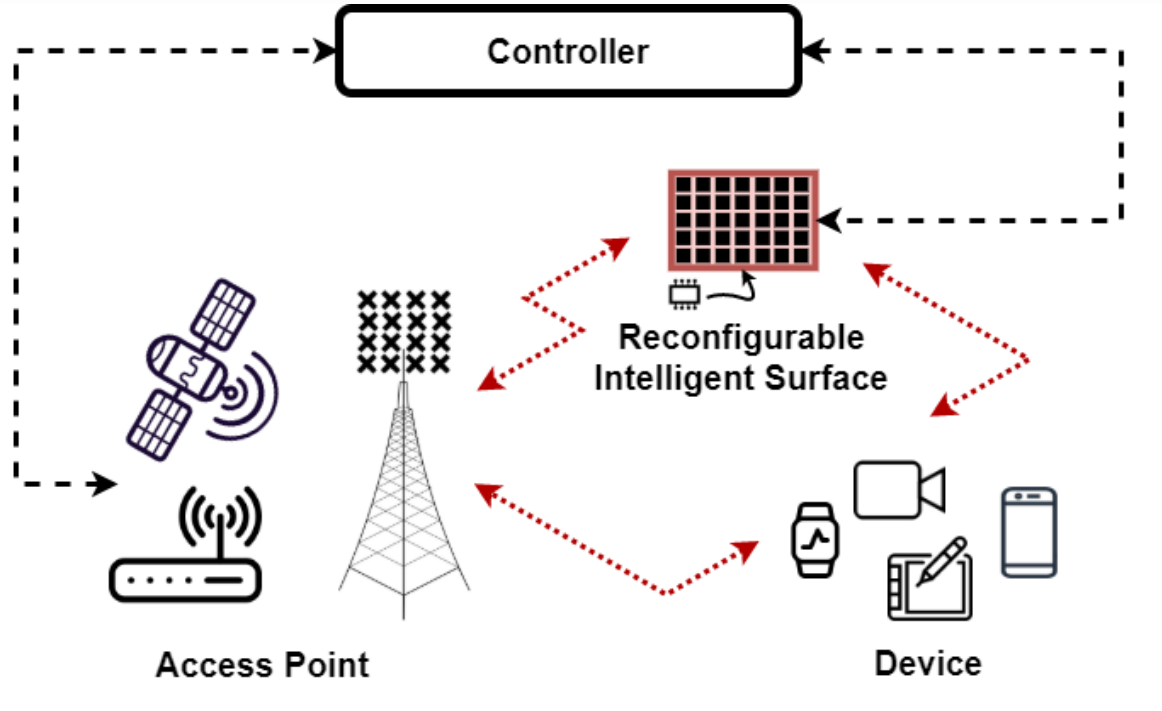
Education, Research Institutes (7)

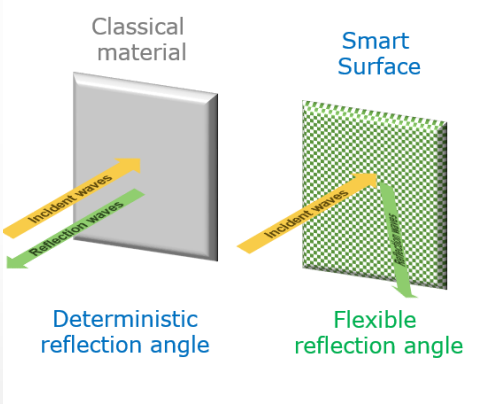
Manufacturers, Telecom Operators and Technology Providers (4)

Verticals (2)

Reconfigurable Intelligent Surfaces for Smart Radio Environments

- *Definition:* Reconfigurable Intelligent Surfaces (RISs) are ultra-low-power surfaces of metamaterials whose responses can be electronically controlled.





RIS is a new type of system whose elements' responses can be adapted to the status of the propagation environment through implicit or explicit control signalling.

The design and control of multi-functional RISs for enhancing wireless communication, localization, and sensing.

Project Vision

Design, Prototype and Trial radical technological advances to FORGE a programmable wireless propagation environment

All-in-one architecture

- *RISE-6G architecture can be seamlessly integrated into existing ones*

Evolutionary hardware

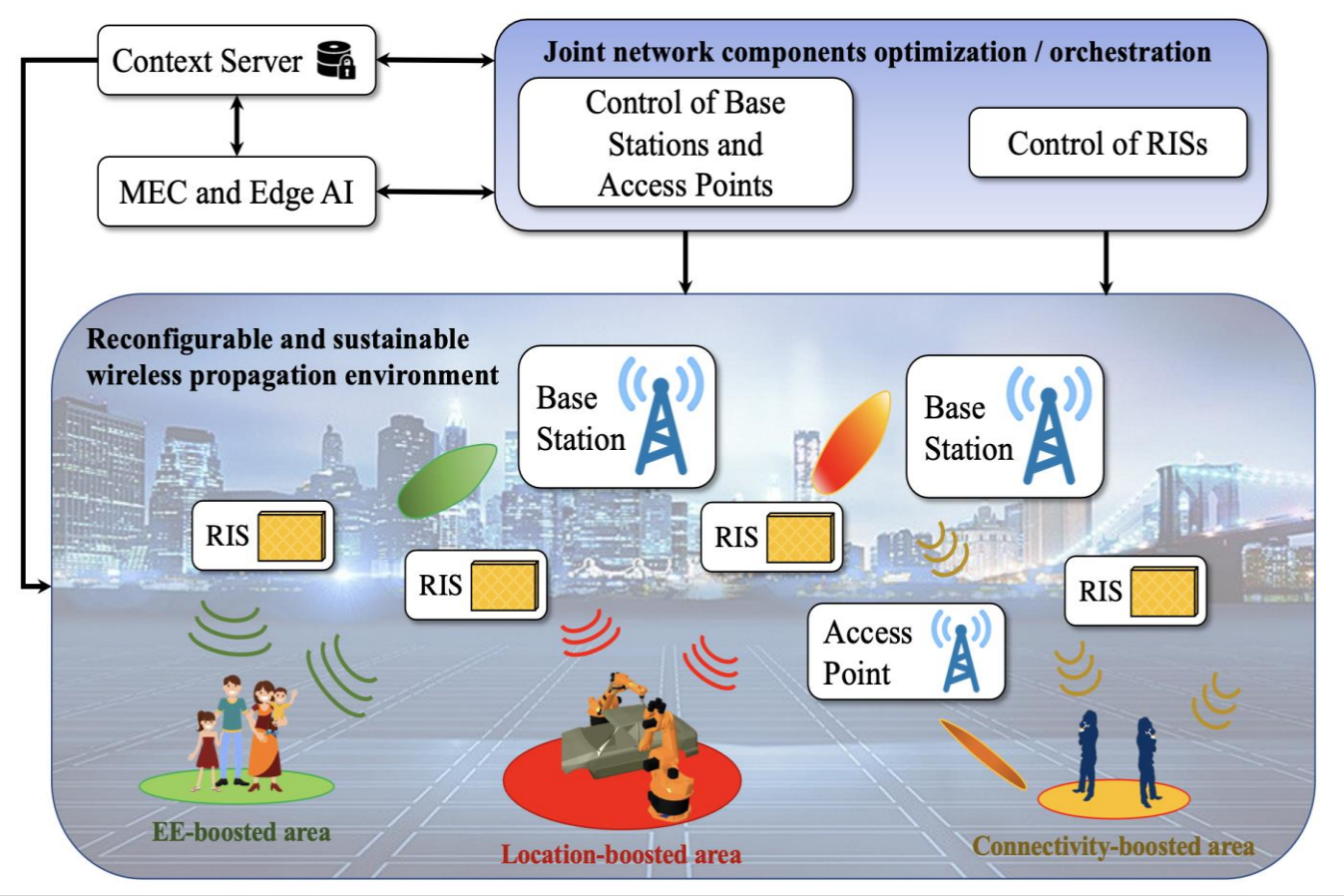
- Low-complex and easy-to-install

Intelligent control

- AI-based orchestration

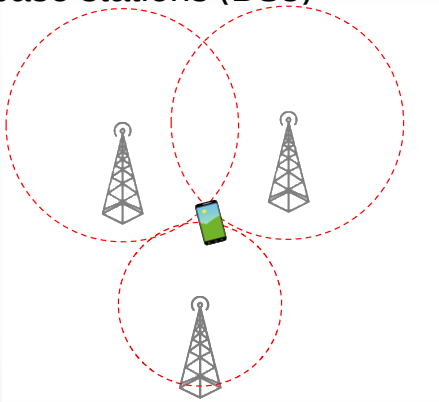
Overarching prototype

- *Different operating frequencies integrated into existing network architectures*

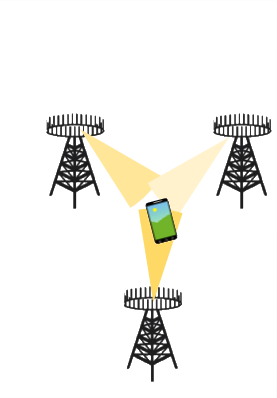


Preliminaries on Localization and Sensing (1/2)

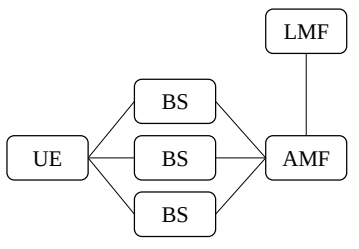
- **Localization (synonym: positioning)** is the process of determining the 2D or 3D location of a connected device (a user equipment (UE)), based on uplink (UL) or downlink (DL) measurements with respect to several base stations (BSs)



Positioning based on round-trip-time measurements



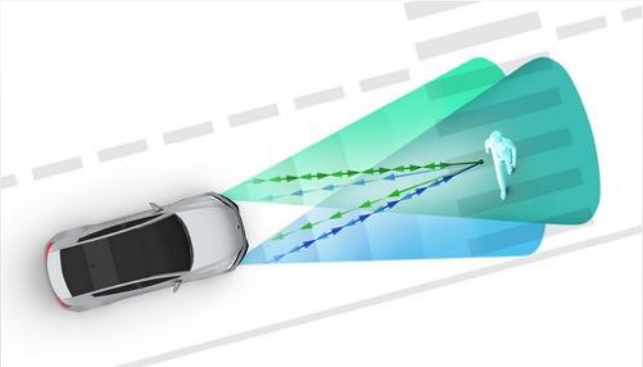
Positioning based on downlink angle-of-departure measurements



5G positioning architecture with location management function (MF) and access/mobility MF

Positioning requires

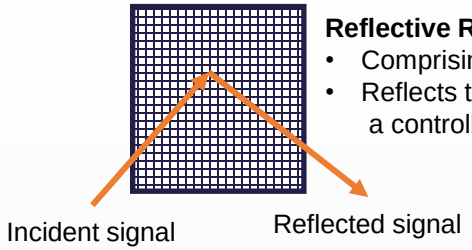
- Reference nodes with known location and orientation
- Time synchronization between reference nodes
- Pilot signals in uplink or downlink
- Measurements from the signal
- Fusion of measurements to compute UE position



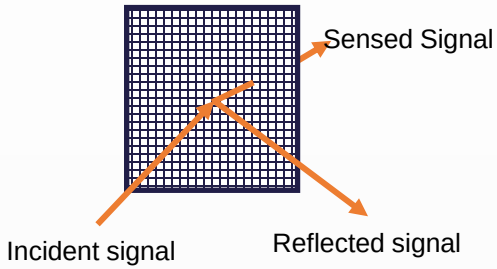
- **Performance metrics:**
  - *Accuracy [m]:* indicator of localisation error (e.g., 90% percentile)
  - *Latency [s]:* time between request and available position estimate
  - *Availability [-]:* fraction of space or time the service is available with required accuracy, latency
- **Sensing:** the detection and estimation of changes or events in the environment, including for use in positioning
  - **Radar-like sensing** (monostatic, bistatic)
  - **Non-radar like sensing:** activity monitoring, channel sensing

Preliminaries on Localization and Sensing (2/2)

- **RIS taxonomy in RISE-6G**

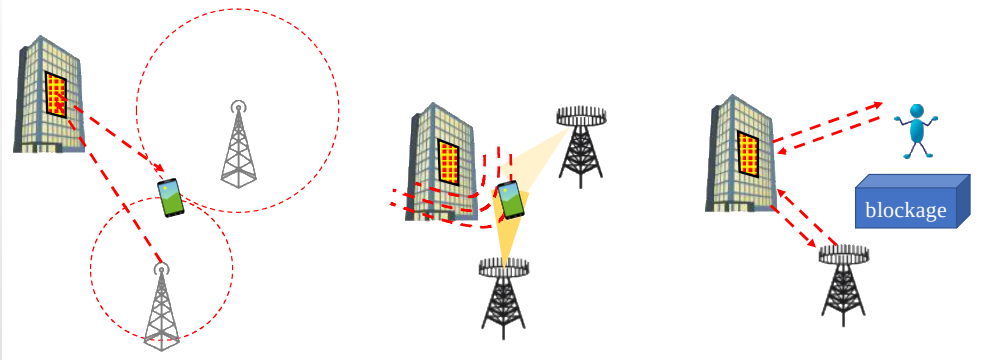


Reflective RIS
- Comprising passive elements
- Reflects the incident signal in a controllable manner



Hybrid RIS
- Comprising hybrid meta-atoms
- Simultaneously reflects a portion of the incident signal and senses a portion of it
- Becomes exclusively receiving RIS if the reflected portion is zero

- **Role of RIS in localization**
  - *Enabling:* provide localization capabilities that were no present without RIS
  - *Boosting:* improve performance of existing system



Challenges for RISE-6G:
- Architectures and different problem variations
- RIS control strategies
- Methods for localization and sensing
- Attainable performance from synthetic and real data

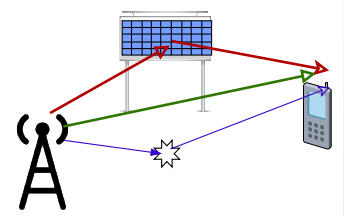
- **RIS can act as**
  - *Infrastructure:* providing additional angle or delay measurement and new position reference (i.e., as an additional virtual BS/anchor)
  - *Device to be localized:* providing low-energy positioning with existing infrastructure

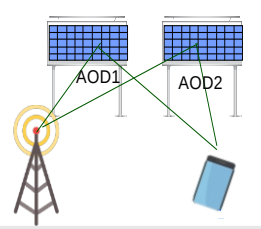
RISE-6G Architectures

- **Results:**
  - Defined 5 distinct architecture
  - Corresponding localization / sensing scenario
  - Corresponding data flow and signalling

- **Architectures for the following 5 scenarios:**

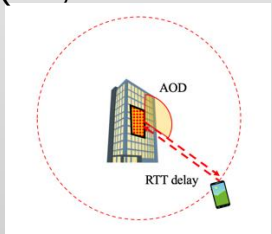
1. RIS-enabled localization with angle-only (at least 2 RIS) or angle & delay (at least 1 RIS) measurements





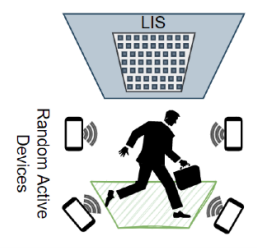
Benefit:
Localize device with 1 single-antenna BS

2. RIS-enabled localization without access points (i.e., no measurements to/from BSs)



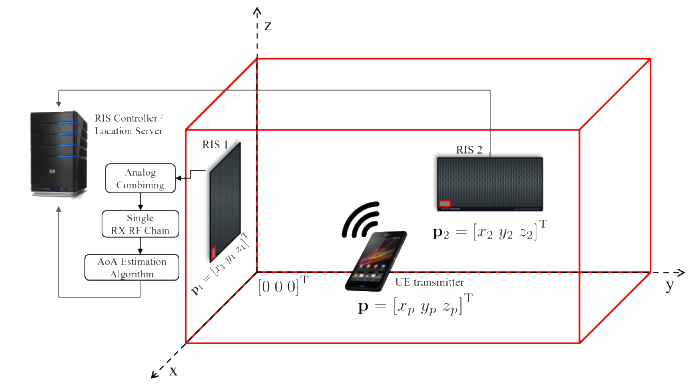
Benefit:
Localize device without BS

3. Receiving RIS to detect passive users (sensing)



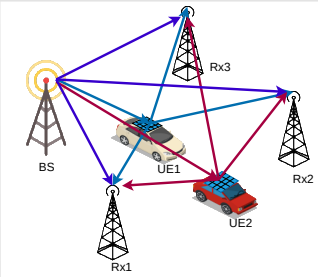
Benefit:
Detect users without BS

4. Hybrid RIS-enabled localization without access points (i.e., no measurements to/from BSs)



Benefit:
Localize device without BS

5. Mobile RIS localization (RIS as UE)

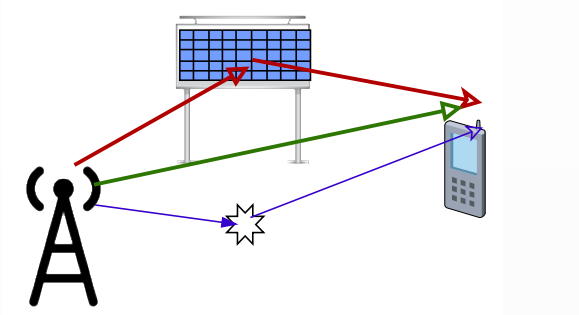


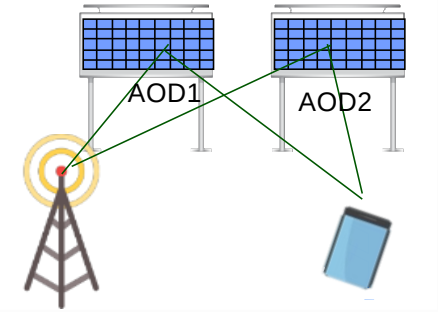
Benefit:
Localize RIS

RIS-Enabled Localization with Angle-Only or Angle & Delay Measurements

- **Scenario**

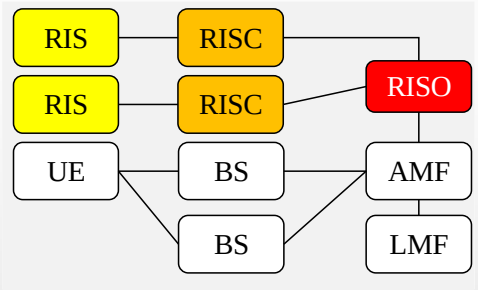
Benefit:
Localize device with 1 single-antenna BS





Requires:
- RIS with time-varying configurations
- Knowledge of RIS configurations and response
- Knowledge of RIS location and orientation
- (Coarse) synchronization between UE and RIS

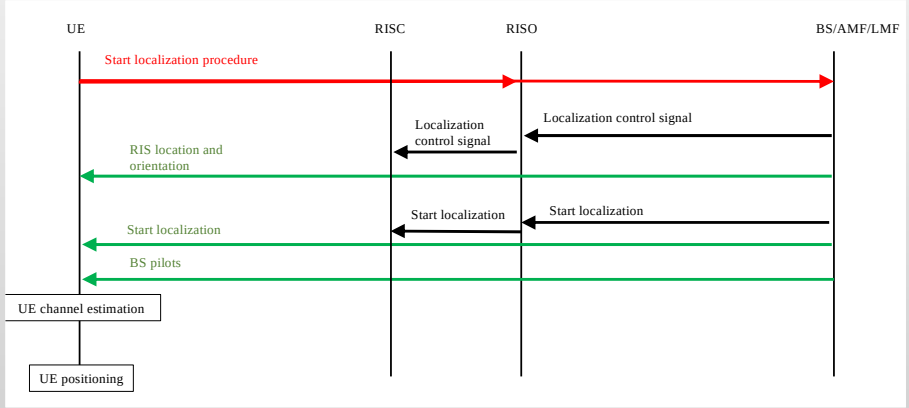
- **Architecture**

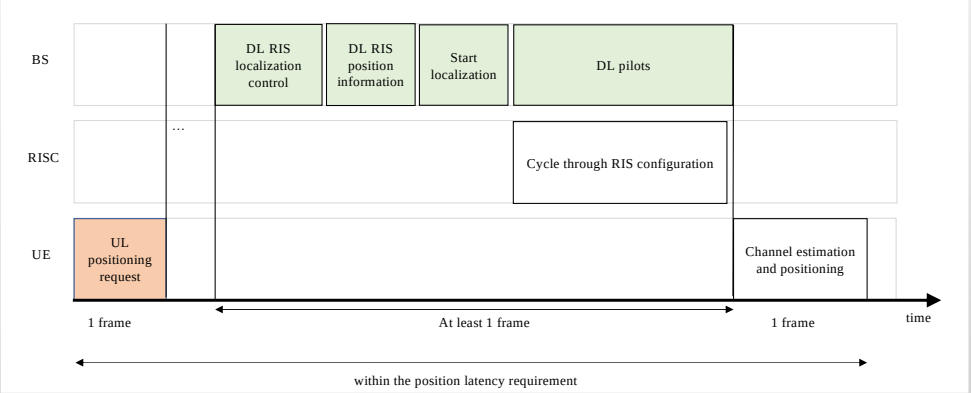


RIS controller (RISC): the controller associated to a single RIS device. The controller can be part of the RAN element or directly interact with a RAN element (gNb or eNb in 3GPP jargon). In addition, it may directly interact with O-RAN near-RT RIC. Expected time granularity: 10-50 ms.

RIS orchestrator (RISO): the orchestrator is placed on a higher (hierarchical) layer and orchestrates multiple RISCs and/or RAN elements. It can directly interact with 3GPP AMF, ETSI MEC orchestrator or ETSI NFV orchestrator. Time granularity is expected between 100 ms – a few seconds.

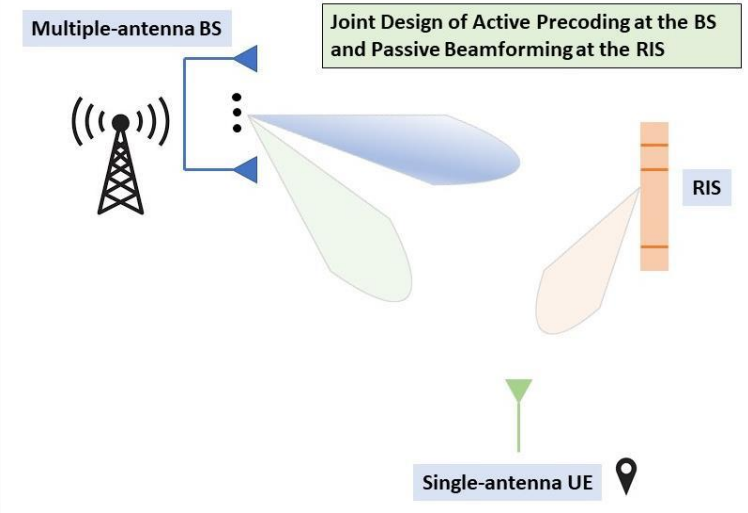
- **Data flow**

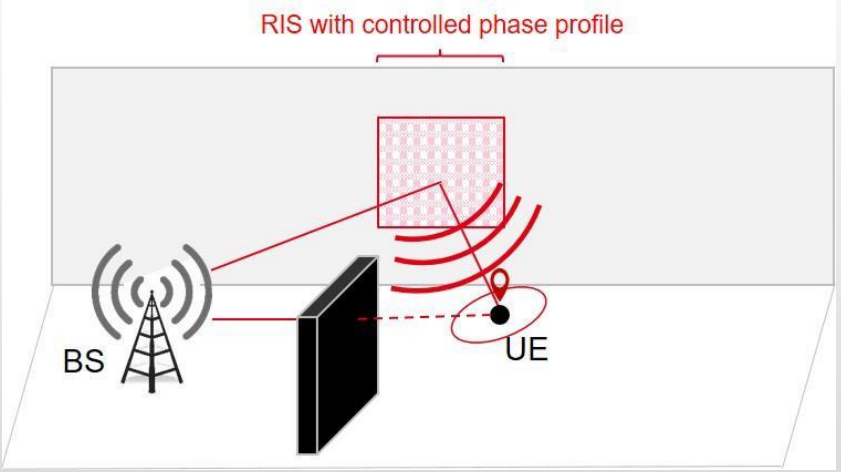




RISE-6G RIS Control

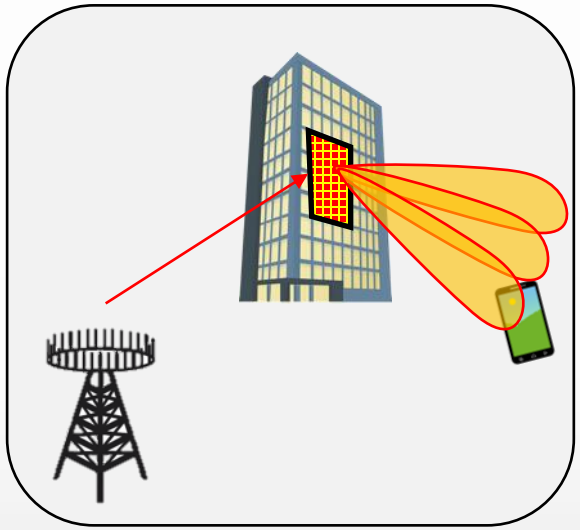
- Control of the RIS is performed by the RIS controller (RISC)
- The RISC requires external information to determine the RIS configurations
  - In the form of channel state information
  - In the form of location information
  - In the form of a sequence of pre-determined configurations from a codebook (random or deterministic, e.g., sweeping across a portion of space)
- The RIS configurations should be optimized for positioning or sensing performance
  - Accounting for other RIS(s)
  - Accounting for BS(s)
  - Accounting for RIS properties (e.g., hardware impairments)
- RISE-6G developed / analyzed several RIS control strategies
  1. Basic RIS configurations: directional, derivative, multi-beam, random configurations
  2. RIS configurations optimized together with BS precoding
  3. RIS configurations suitable for near-field positioning
  4. RIS configurations that account for RIS hardware models



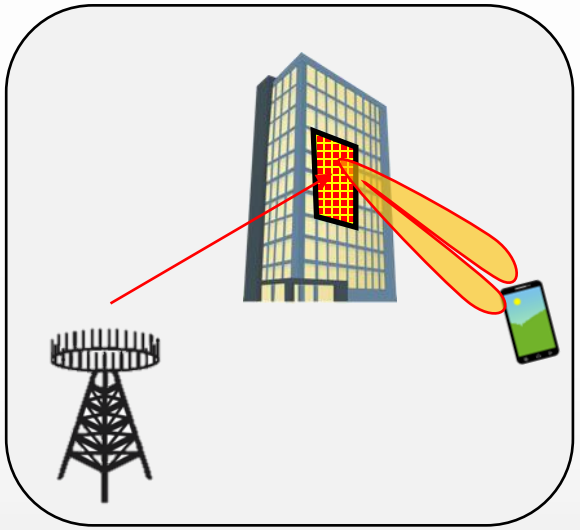


RISC: Basic RIS Configurations (directional, derivative, multi-beam, random configurations)

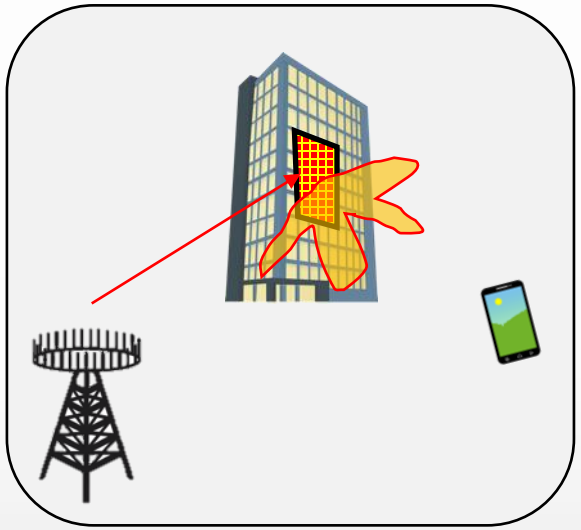
- Basic beam types



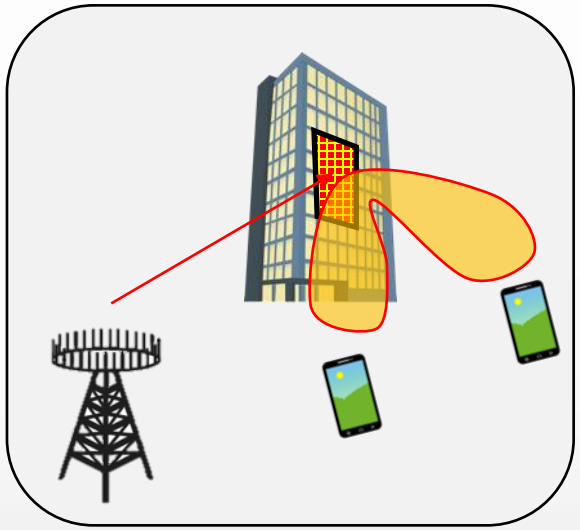
Directional
- Width can be controlled by switching off elements
- Provides immediate AOD indicator
- Can exploit prior UE location knowledge to reduce resources



Derivative
- Generates null in certain direction
- Optimal for localisation with accurate prior UE location information



Random
- No directionality
- Cannot exploit prior location information
- Can cover entire angular span with few RIS configurations



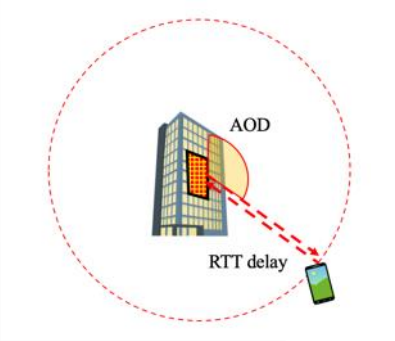
Multi-beam
- Illuminates several directions, with reduced gain

Rahal et al. "Constrained RIS phase profile optimization and time sharing for near-field localisation," Proc. *IEEE VTC-Spring*, 2022.
Fascista et al. "RIS-aided joint localisation and synchronization with a single-antenna receiver: Beamforming design and low-complexity estimation," *IEEE JSTSP*, 2022.
Rahal et al. "Arbitrary beam pattern approximation via RISs with measured element responses," Proc. *EuCNC & 6G Summit*, 2022.

RIS-Enabled Localization without Access Points

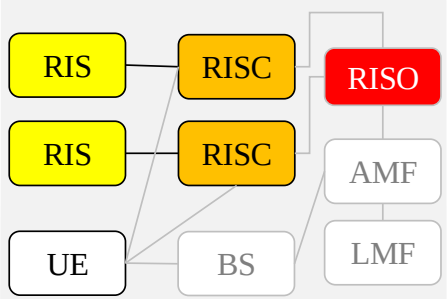
- **Scenario**

Benefit:
Localize device without BS



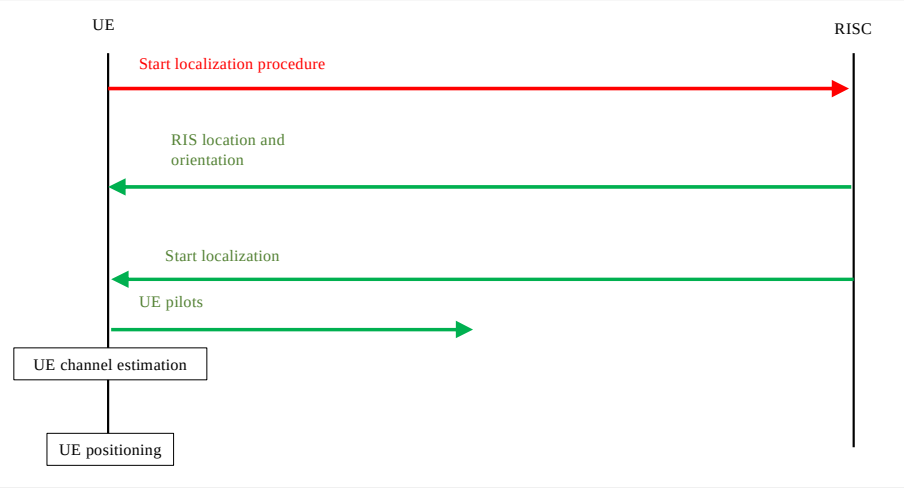
Requires:
- full-duplex UE
- RIS with time-varying configurations
- Knowledge of RIS configurations and response
- Knowledge of RIS location and orientation
- (coarse) synchronization between UE and RIS

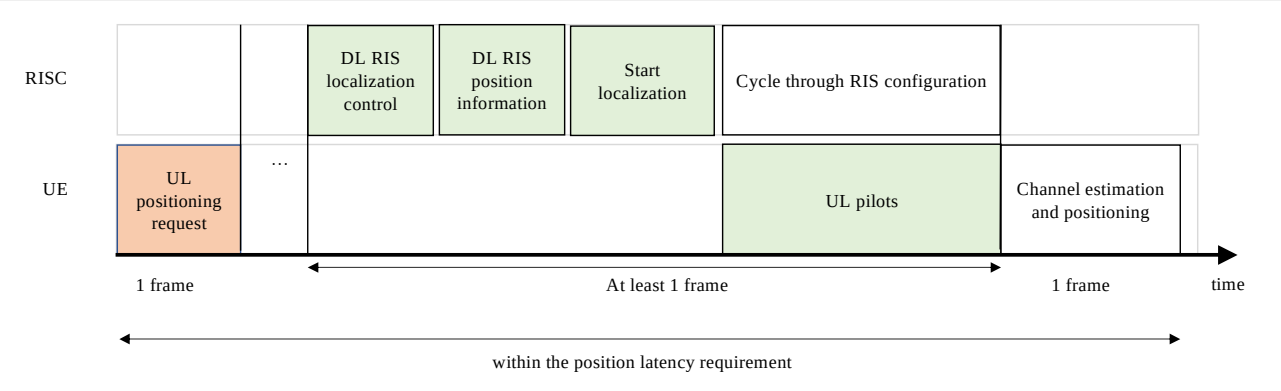
- **Architecture**



- Could operate stand-alone or as part of the network

- **Data flow (stand-alone)**

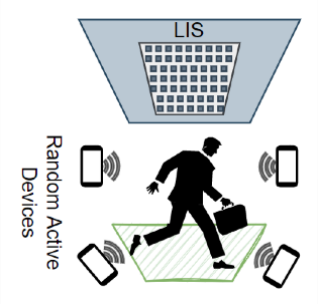




Receiving RIS to Detect Passive Users

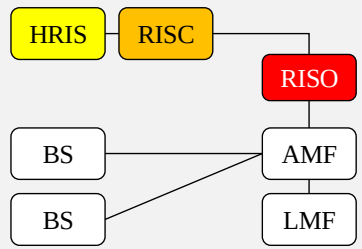
- **Scenario**

Benefit:
Detect users without BS

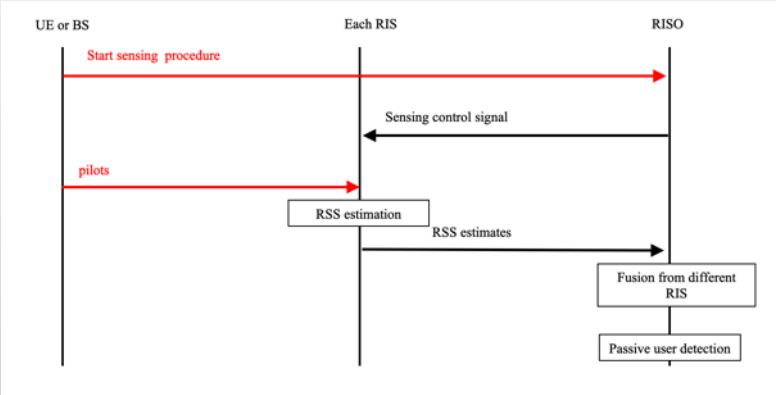


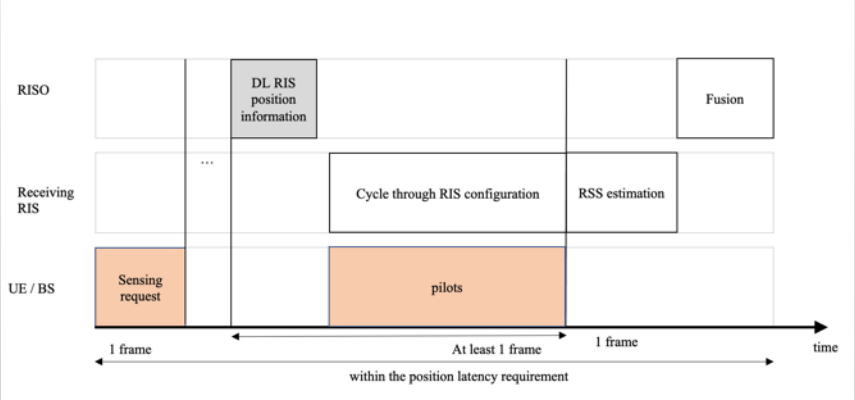
Requires:
- Receiving RIS
- Measuring of received signal strength

- **Architecture**



- **Data flow**

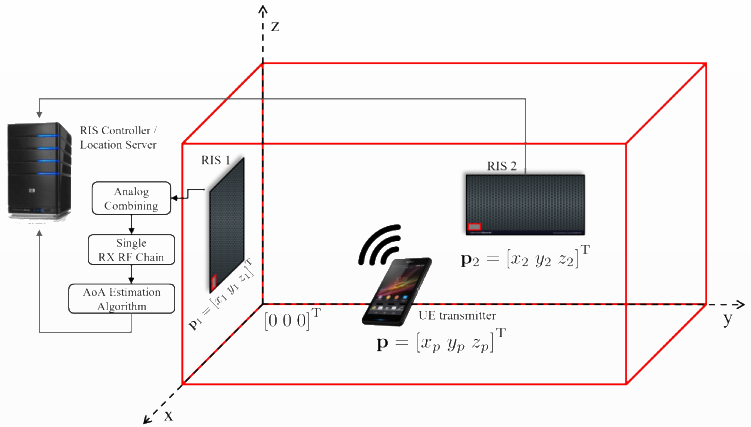




Hybrid RIS-Enabled Localization without Access Points

- **Scenario**

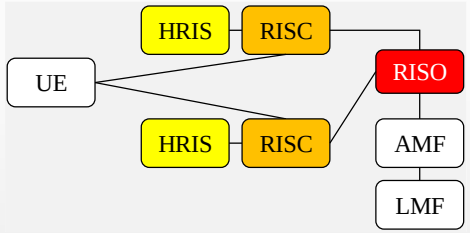
Benefit:
Localise device without BS



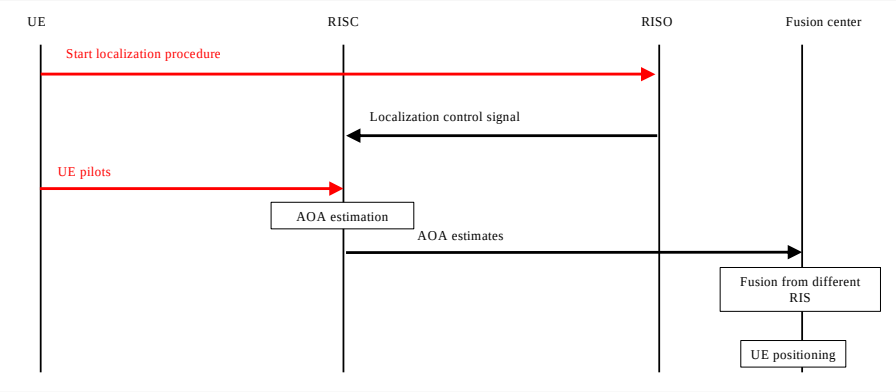
Requires:

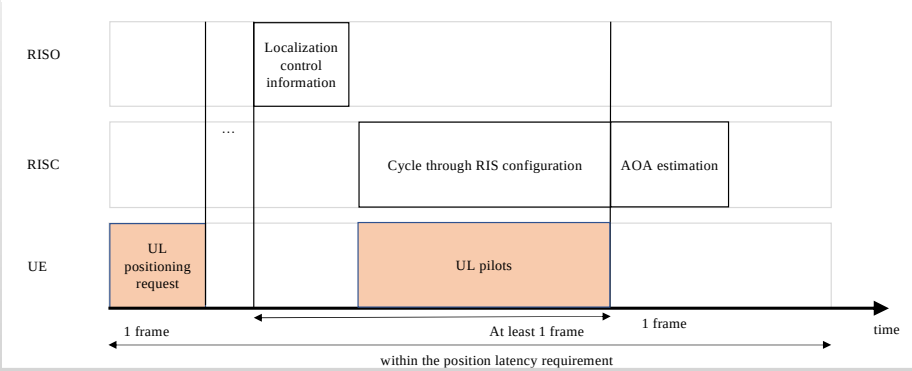
- Several RISs with time-varying configurations
- Knowledge of RIS configurations and response
- Knowledge of RIS location and orientation
- (coarse) synchronization between UE and RISs

- **Architecture**



- **Data flow**

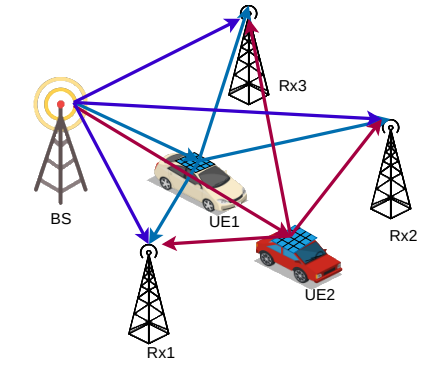




Mobile RIS Localization

- **Scenario**

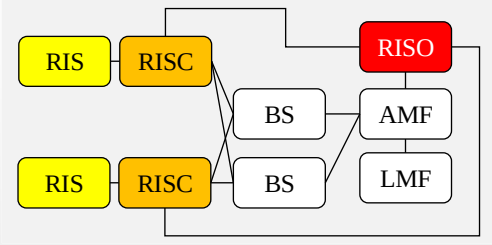
Benefit:
Localise RIS



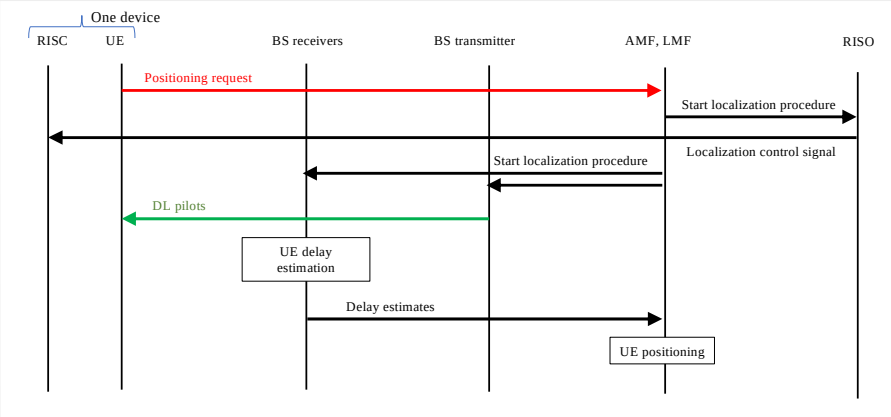
Requires:

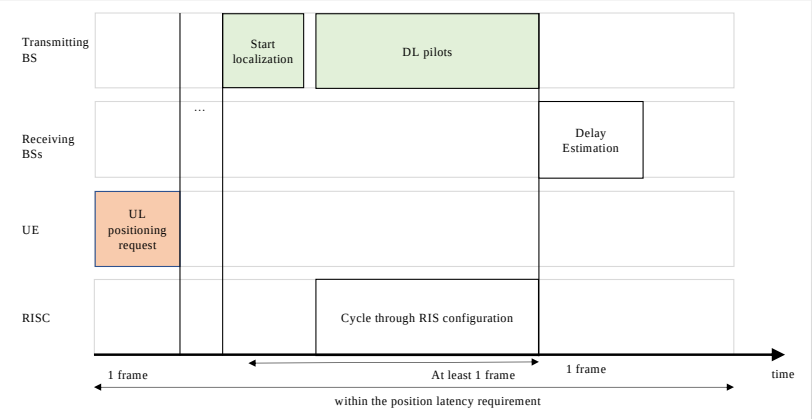
- RIS with time-varying configurations
- Several BS receivers

- **Architecture**



- **Data flow**





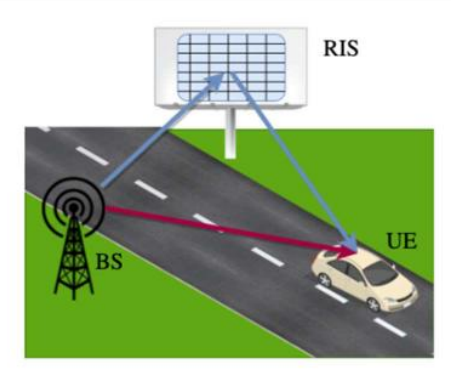
Localization and Sensing Techniques

- **Most methods involve several stages**
  - Estimate channel parameters (angles, delays, signal strengths) from waveforms
  - Estimate user positions from channel parameters
  - Estimate target locations / properties from channel parameters
- **Channel parameter estimation**
  - Far-field ToA and AOD estimation of a signal reflected by an RIS
  - Far-field ToA and AoD estimation in full-duplex of a signal reflected by an RIS
  - Near-field ToA and AoD estimation of a signal reflected by an RIS
  - AOA estimation at a sensing RIS
- **Localisation**
  - Localization of one or more RISs
  - RIS-enabled SISO localization
  - RIS-enabled full-duplex localization without access points
  - RIS-enabled near-field localization
  - Hybrid-RIS-enabled localization without access points
  - RIS-enabled near-field location and velocity estimation
- **Sensing**
  - RIS-enabled full-duplex localization and sensing without access points
  - Robot trajectory sensing with hybrid RIS
  - Passive user detection and localization with a hybrid RIS
  - AI-based intrusion detection using intelligent surfaces at mmWave
  - Graph-based radio MAP cartography for RIS-aided fingerprinting localization

Channel Parameter Estimation (1/2)

Far-field ToA and AoD estimation of a signal reflected by an RIS

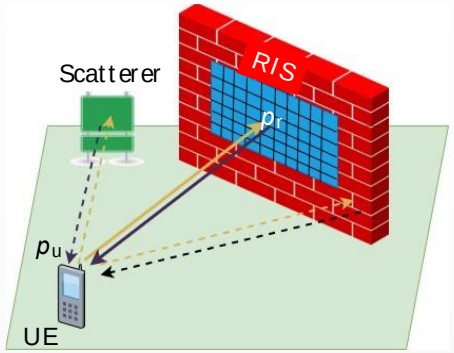
Scenarios



Method: LOS path estimation, subtraction, RIS path estimation

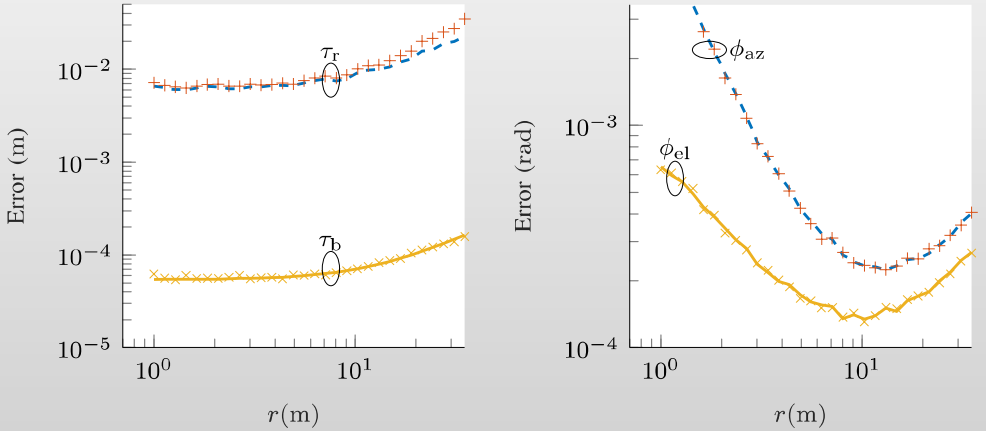
Far-field ToA and AoD estimation in full-duplex of a signal reflected by an RIS

Scenarios



Method: 1D Delay estimation, 2D AOD estimation

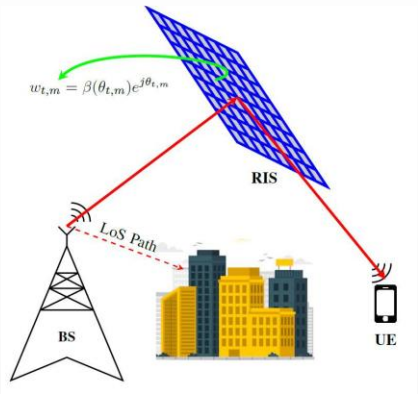
Results



Channel Parameter Estimation (2/2)

Near-field ToA and AoD estimation of a signal reflected by an RIS

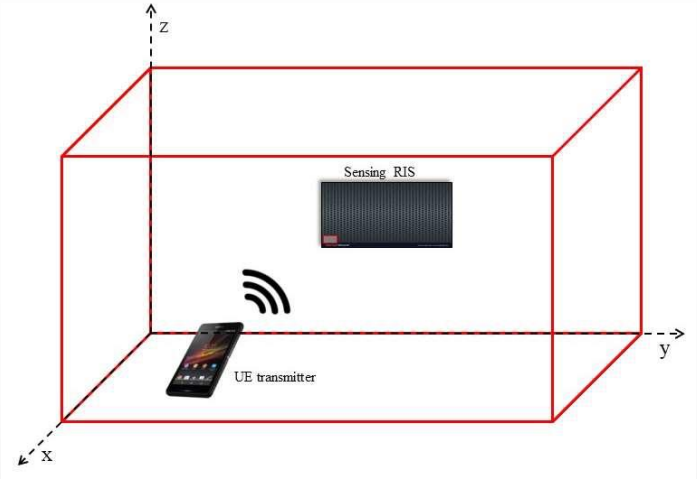
Scenarios



Method: Assume far-field and apply previous methods. Then, use near-field model to compute the range.

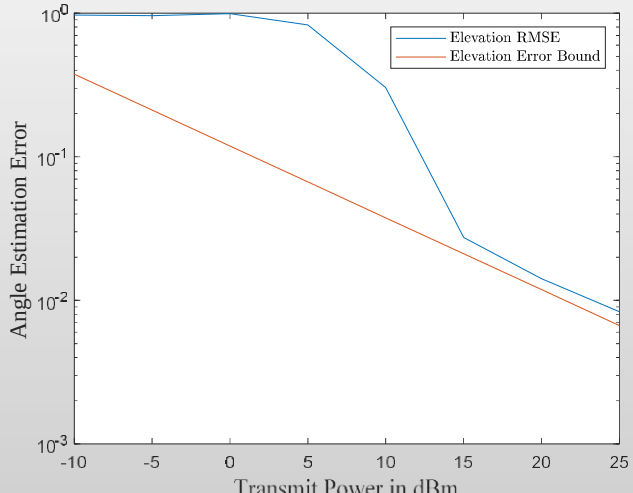
AoA estimation at a receiving RIS

Scenarios



Method: Use compressive sensing to detect the strongest path based on beamspace observation.

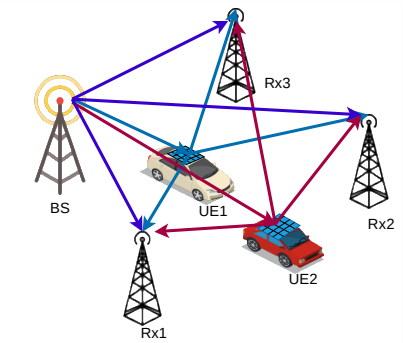
Results



Localization (1/3)

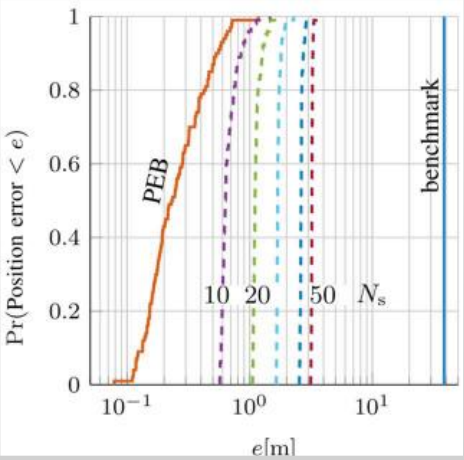
Localization of one or more RISs

Scenarios



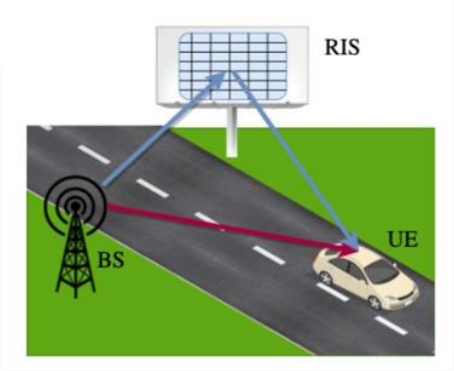
Method: LoS path removed to obtain TDoA measurements; RIS localized via gradient descent on the likelihood.

Results



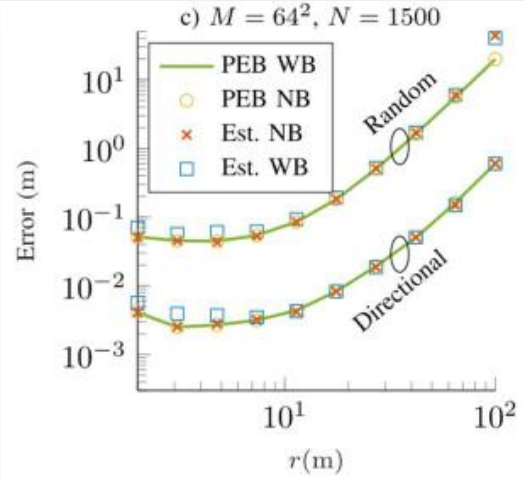
RIS-Enabled SISO Localization

Scenarios



Method: AoD constrains RIS to lie on a line. TDoA defines a hyperbola. UE location lies on the intersection of the line and hyperbola.

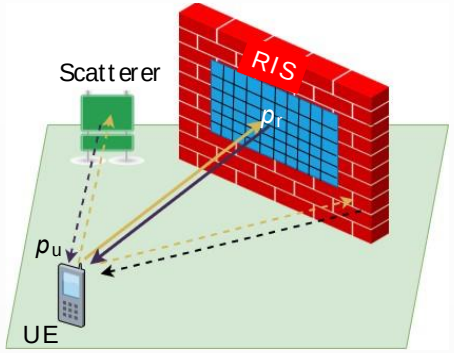
Results



Localization (2/3)

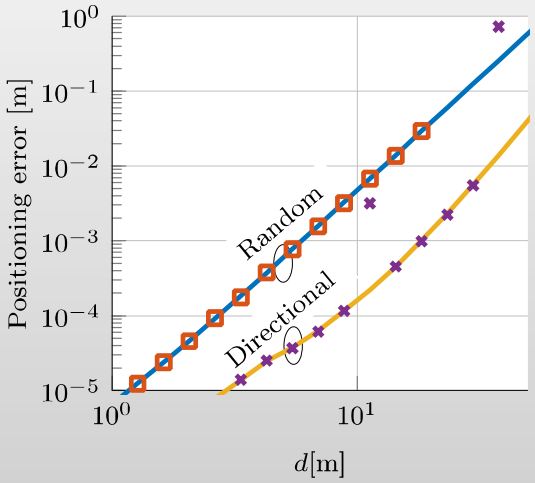
RIS-enabled full-duplex localization without access points

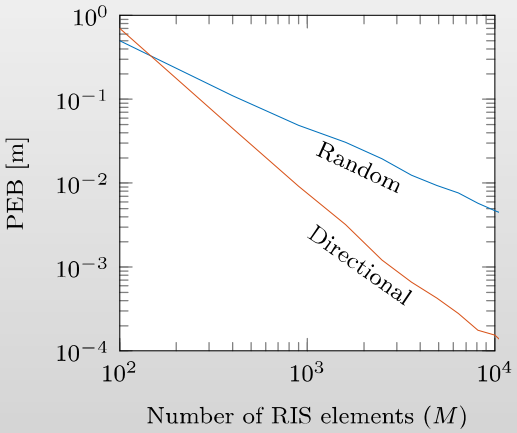
Scenarios



Method: AoD constrains RIS to lie on a line. ToA defines a sphere around the RIS. UE location lies on the intersection of the line and sphere.

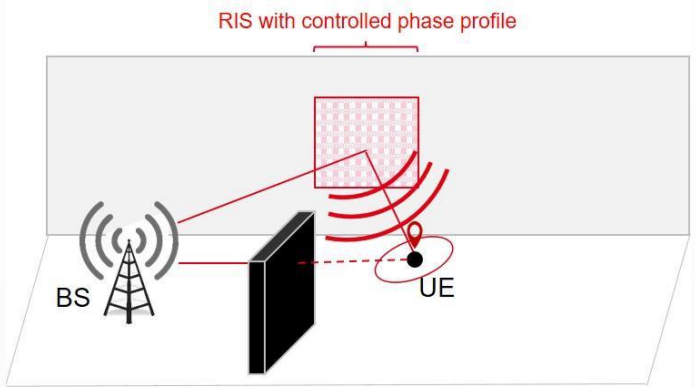
Results





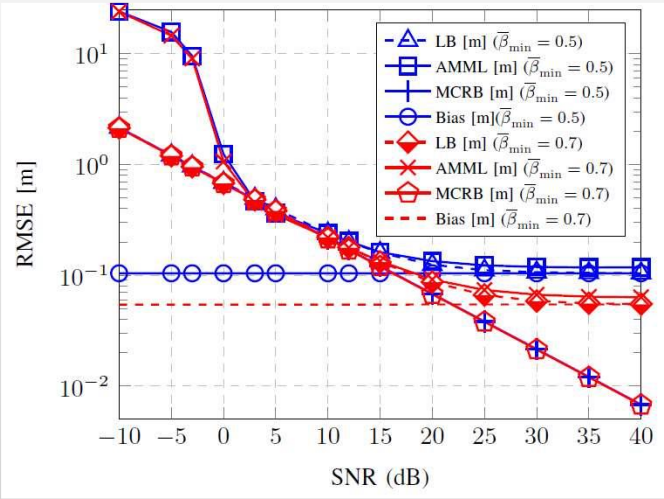
RIS-enabled near-field localization

Scenarios



Method: Near-field estimate of angles and range provides directly the UE location.

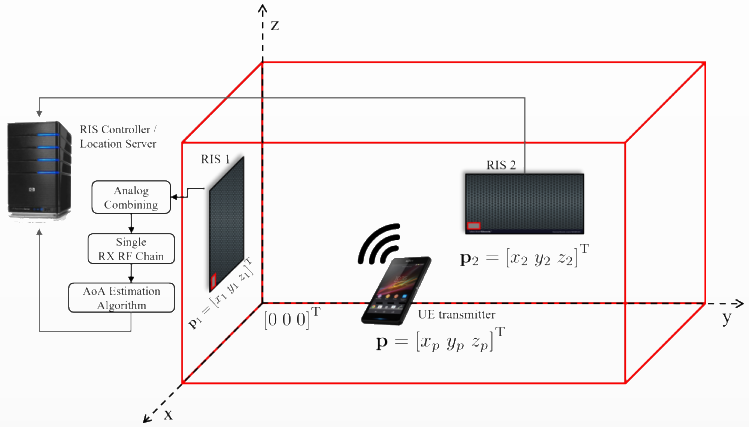
Results



Localization (3/3)

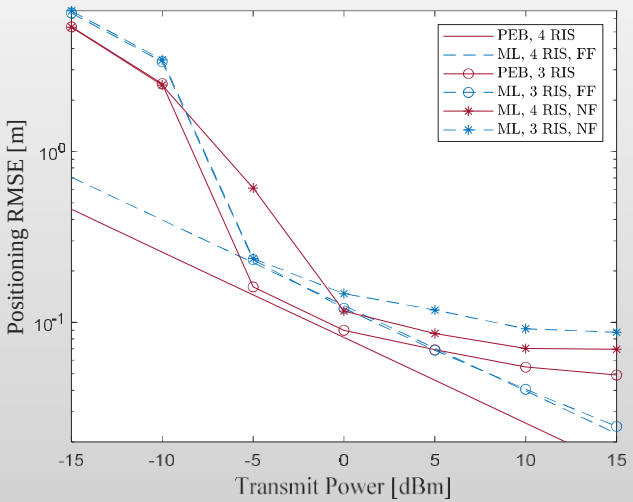
Hybrid-RIS-enabled localization without access points

Scenarios



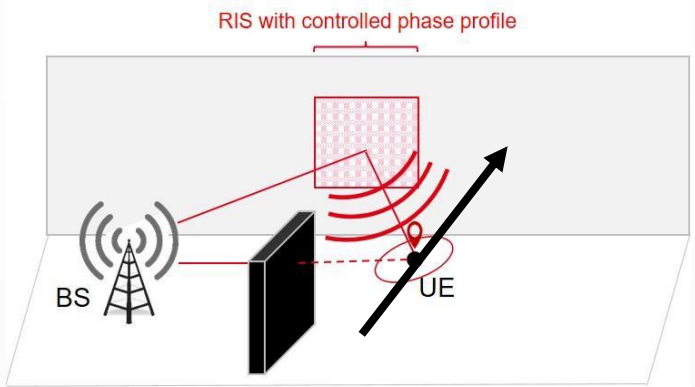
Method: Each AoA determines a line. The UE can be found through least-squares intersection of lines.

Results



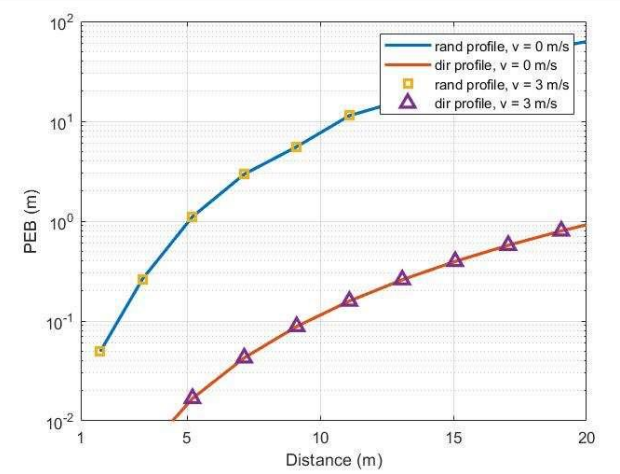
RIS-enabled near-field location and velocity estimation

Scenarios



Method: Fisher information analysis under different velocity.

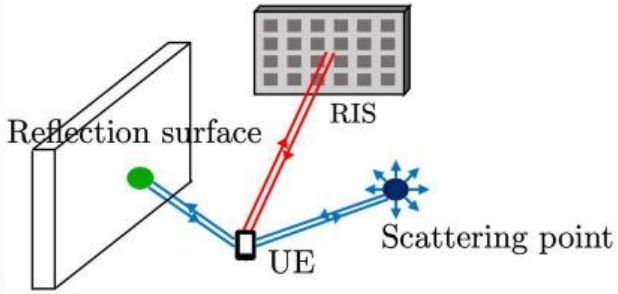
Results



Sensing (1/3)

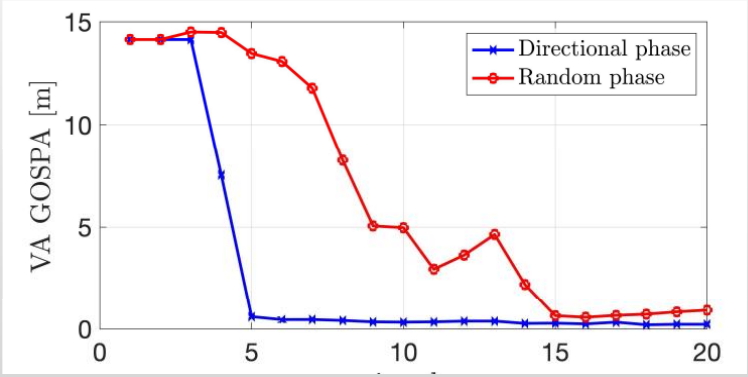
RIS-enabled full-duplex localization and sensing without access points

Scenarios



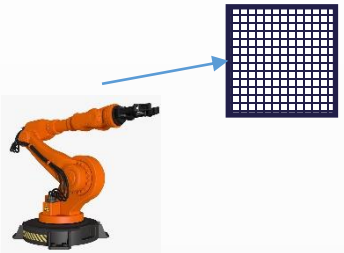
Method: UE localized as before. Objects tracked via random finite set filter.

Results



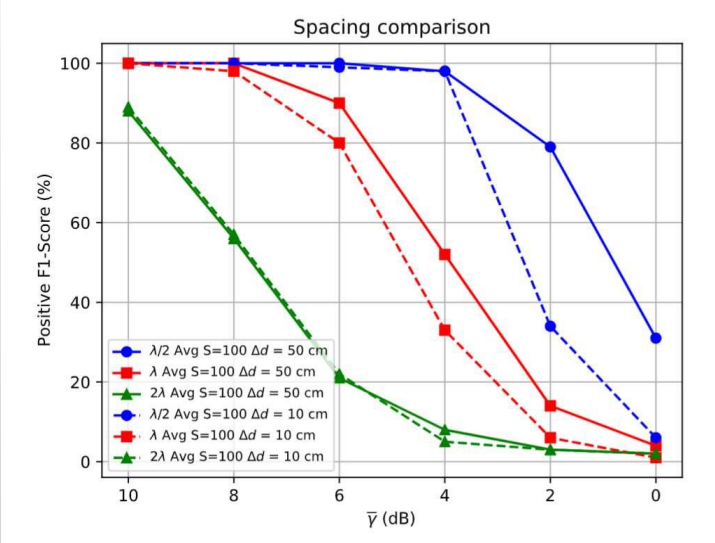
Robot trajectory sensing with a hybrid RIS

Scenarios



Method: Collect RSS, followed by supervised learning to detect trajectory deviation.

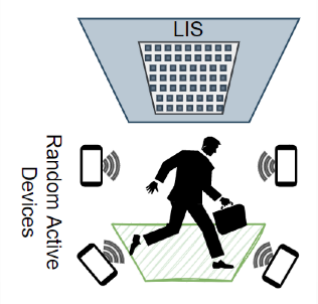
Results



Sensing (2/3)

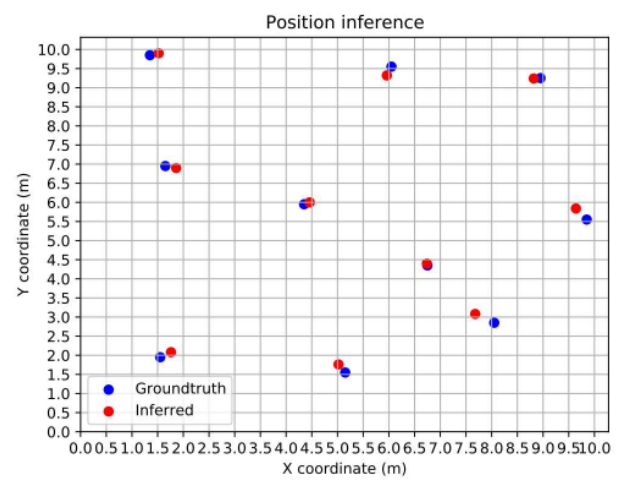
Passive user detection and localization with a hybrid RIS

Scenarios



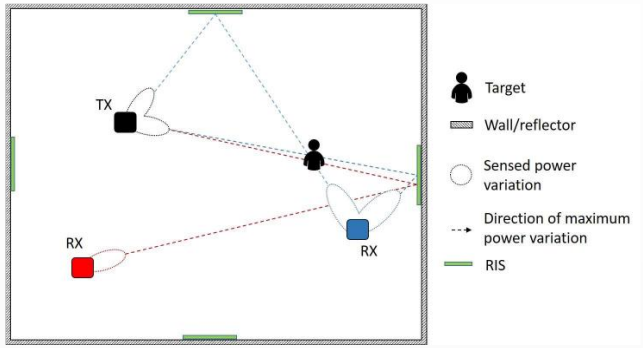
Method: Measure complex wavefront at RIS + machine learning to detect and localize passive uses.

Results



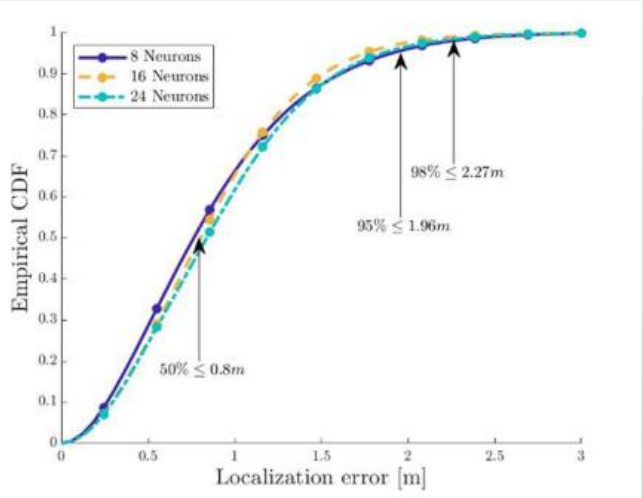
AI-based intrusion detection using intelligent surfaces at mmWave

Scenarios



Method: Directional RIS, several Tx and Rx for sensing. AI-based user localization.

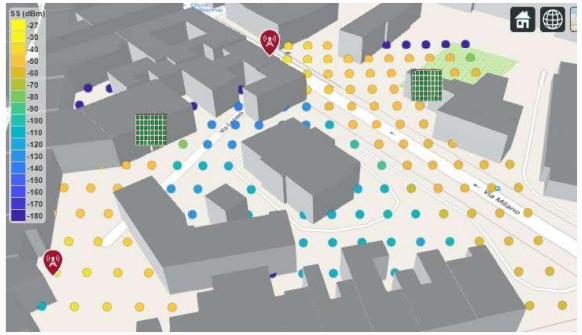
Results



Sensing (3/3)

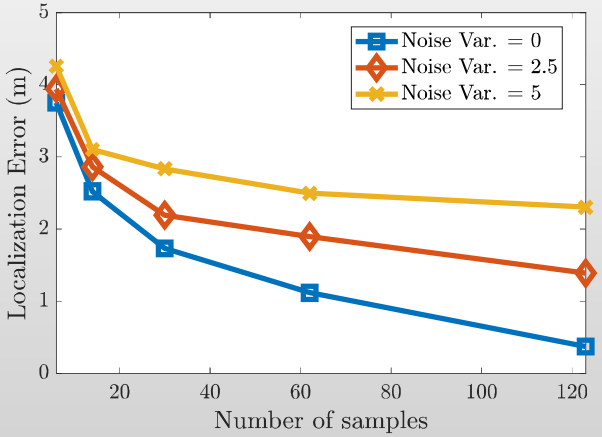
Graph-based radio MAP cartography for RIS-aided fingerprinting localization

Scenarios



Method: RSS measurements at active RIS combined with graph signal processing.

Results



Thank you for your attendance

RISE-6G website: https://rise-6g.eu/
Relevant deliverables (available online):
D5.1 - Control for RIS-based localisation and sensing (Intermediary Specifications)
D5.2 - Algorithms for RIS-based localisation and sensing (Intermediary Specifications)

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