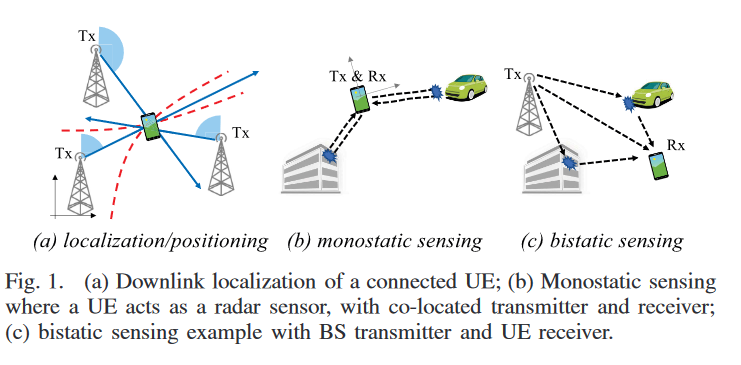
1. Fundamentals

1.1 Introduction

1) Localization and positioning are used for estimation of the state of a connected device in a global frame of reference.

2) Monostatic sensing is a local process, and can thus rely on a tailored, highly specialized, and hardware friendly waveforms, without strict standardization constraints.

3) Bistatic sensing is similar to communication and localization (i.e., when the transmitter or receiver have an unknown position). Localization can be seen as a special bistatic sensing.



With radar systems and communication systems expected to **operate in similar frequency bands**, **there is a potential convergence**, both in terms of hardware and signals, **of sensing and communication systems**.

Integrated sensing and communication (ISAC) are expected to be the main features of 6G.

1.2 Models and Problem Definitions

1.2.1 Generic Observation Model

1.2.1.1 Channel Model

The channel between a transmitter with  Antennas and a receiver with  over frequency  and symbol  can be approximated by:



where  is the number of multipaths,  is the complex channel gain,  is the Rx array response as a function of angle of arrive (AoA)  in azimuth and elevation,  is the Tx array response as a function of angle of departure (AoD),  is the time of arrive (ToA),  is the Doppler shift, and  is the symbol duration.

1.2.1.1 Signal Model

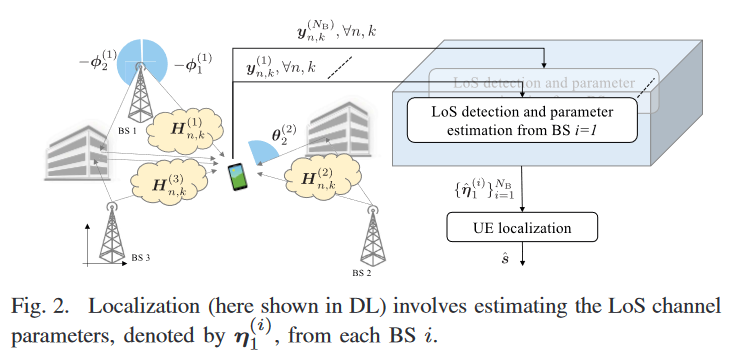
The observation at the Rx is:



where  is the **orthonormal analog Rx combiner** with  using  RF chains,  is the -th transmitted signal over the -th subcarriers with  with , and  is the circular symmetric complex Gaussian random noise. Here  and  denote the average transmit power and noise power spectral density, respectively.

1.2.2 Localization Problem

In localization problem, the UE has an unknown state , which should be inferred from observations of the form .



The channel can be split into two parts, one is LoS path, the other is NLoS path. The LoS channel contains geometric information related to the -th () UE state  via parameters  and :









where  is the wavelength at the carrier and and  denote the antenna element response at the Tx and Rx, respectively. And  is due to the lack of synchronization.

In localization, the AoA and AoD are different. For example, In DL, the AoA depends on UE position and orientation, while the AoD only depends on UE position.

The NLoS channels are traditionally considered as a disturbance.

1.2.2 Sensing Problem

An important difference in sensing compared to localization is that the number of objects is a priori unknown in sensing.

**Sensing combines both detection and estimation, while localization is essentially an estimation problem.**

In both monostatic and bistatic sensing, the channel is broken up as . The former captures the part of the channel related to the objects, while the latter describes the part of the channel related to clutter, e.g., ground reflections, and is modeled statistically.

The signal and channel model are again of the form. Consider several point objects with state , including position  and velocity  for object .

For monostatic sensing, due to the two-way propagation, the gain is often much smaller than in :



where  and  denote the distance from the sensor to the object and the radar cross section of the -th object, respectively.

For monostatic sensing, the AoA and AoD are the same.

For monostatic sensing , while for bistatic sensing .

1.3 Performance Metrics

1) **Latency**: the time between the positioning request and the position being available.

2) **Availability**: the fraction of space or time that the localization and sensing service is available with sufficient accuracy.

3) **Scalability**: density of UEs that can be simultaneously supported.

4) **Accuracy**: combining all the observations yields a long vector , which depends on parameters  (with length ) and  (contains channel gains and clock bias). The Fisher information matrix (FIM) of  has elements:



denote the index of object. In most case, can been simplified as:

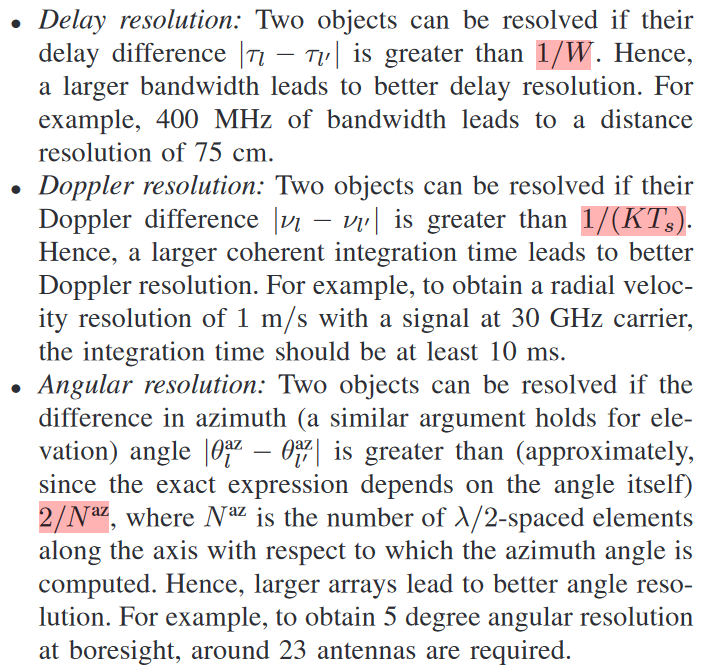


where  is the noise-free observation in . The following inequality holds:



Denote  as the covariance of the estimation of . When the FIM is not invertible, the problem is non-identifiable.

4) **Resolution**: is the ability to separate correlated signals. Resolution in one domain (channel gains, AoA, AoD, ToA and Doppler) is sufficient for objects to be separable. There are several domains for resolution:



1.4 Localization and Sensing Methods

Directly positioning: , all parameters are recovered at once.

Two-stage approach: first the geometric channel parameters (angles, delays, Dopplers) are estimated, and then the UE / object state is recovered.

Introduce the Two-stage approach next.

1.4.1 Channel Parameters Estimation

A common approach is to first obtain an unstructured estimate  of the channel from a least-squares (LS) estimator.

Vector and stack the channel :



where:





equation is in an appropriate form for **compressive sensing** methods.

Alternatively, we can express the LS estimates in a tensor form:



Now, is a classic harmonic retrieval problem in  dimensions ( in ).

1.4.2 Position Estimation

Estimating the state (expressed as  and the corresponding uncertainty ) of a UE (Localization) or an object (Sensing) now relies on the relationship between the estimated channel parameters.

Focus on the localization problem for concreteness. Starting from  and corresponding uncertainty  for each BS . The UE state is related to these channel parameters through:



where  and  is a known mapping from UE state to geometric channel parameters. The estimation of the state can be expressed as:



When estimation is finished, the final  is used to compute covariance  from:



2. State-of-the-Art and Challenges