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Emerging Development of Wireless Localization Technologies Aided with Reconfigurable Intelligent Surfaces: A Comprehensive Survey

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A B S T R A C T

Wireless localization technologies have undergone a paradigm shift with the advent of the emerging trend which is the Reconfigurable Intelligent Surfaces (RISs). This paper presents a comprehensive survey of the state-of-the-art RIS-aided localization techniques, exploring the transformative impact of intelligent surfaces on location-based services. The survey comprehensively reviews existing wireless localization methods, ranging from the localization techniques in the wireless communications generations. It addition the challenges posed by conventional localization methods are discussed, including accuracy and coverage issues. In response to these challenges, the incorporation of RIS is explored as a promising paradigm to enhance the precision and reliability of wireless localization. The core of the paper focuses on the integration of RIS into localization systems, highlighting how these RISs can be strategically deployed to enhance accuracy, mitigate multipath effects, integration in different propagation environment and solve non feasible localization problems. The survey encompasses a wide range of applications, including outdoor positioning, indoor positioning, and Internet of Things (IoT) devices, showcasing the versatility of RIS-aided localization across various scenarios. Also, critical design aspects are examined, including propagation regions, hardware requirements, deployment strategies, necessary measurements, multiplexing, and signalling systems.

Introduction

User equipment (UE) positioning in wireless communication systems has become one of the important stirred requirements imposed by the Federal Communications Commission (FCC) and European Commission (EC)[1] to enable the operators dealing with the emergency calls [1]. In addition, it can serve more applications such as positioning aware communication, advertising that depending on geographic location and so on [2]. Since the advent of fourth generation (4G), specialized localization reference signals have been taken into account while designing and standardizing communication systems. So, in 4G communication systems and under 3rd Generation Partnership Project (3GPP)[2] standard, the localization of the UE can be achieved by the concept of time difference of arrival (TDoA), which depends on the difference of arriving time from multi base stations (BSs), or anchors[3]. It is required at least three non-collinear anchors for two-dimensional (2D) localization and at least four non-coplanar anchors for three-dimensional (3D) scenarios. So that will require more cellular infrastructure densification and precise system synchronization [3]. A reference signals are allocated for positioning and become standardization mandatory part of the system to fulfil positioning accuracy about 10 m. Conversely, the use of antenna arrays in both UE and the anchors together with the high carrier frequencies as well as the wide bandwidth may improve the positioning accuracy to 1 m [4]. In contrast, the UE localization in fifth generation (5G) is possible to achieve using one anchor, but this conditioned with equipping the UE and the anchor with large antenna arrays and required rich multipath propagation environments at the communication coverage [5]. This may use in GPS-denied environments and will decrease the dedication of the multiple anchor infrastructure [6][7]. Also the localization could be obtained through estimating the time of arrival (ToA) and the angles measured from the arrival or departure signal line with respect to the transmitter or receiver, i.e., angle-of-arrival (AoA) or angle of departure (AoD) [8][9].

While better positioning accuracy will be achieved in beyond 5G thanks to the available large bandwidths and higher frequencies [10][11] , the communication systems beyond 5G and the promised six generation (6G) require high speed communication as well as precise estimation of the UE position at the serving coverage, that can be achieved thanks to the wide bandwidth, high frequency bands and the use of massive multiple input multiple output (MIMO) antennas [12][13]. The use of antenna arrays with massive antennas takes a great attention in beyond 5G communication systems to enhance the communication performance and might also be exploited to obtain accurate UE localization [14]. It is worth to note that the propagation at high frequencies may undergo to line of site (LoS) blocking aspect because of the obstructed objects between the UE and the anchor, that can be relatively compensated by multipath aided positioning, in which multipath can behave as constructive source for positioning geometry, nevertheless the other electromagnetic (EM) waves interactions remain uncontrolled [15].

In the massive MIMO antennas, when the distances between elements in the antennas are large, related to the wavelength, that produce extremely large aperture arrays (ELAA) that allow to achieve accurate location estimation performance [16]. The ELAA could be performed using different technologies like cell-free massive MIMO and coordinated multipoint [17]. On the other hand, the integration of large number of antennas in small area [18], i.e., increase the antennas densification, may produce an aperture called spatially quasi-continuous aperture antenna, i.e., a holographic MIMO array [19]. This quasi-continuous antenna array can be realized by the promising solution which is the Reconfigurable Intelligent Surfaces (RISs) [20].

1. The History And The New Directions of Localization

Over the past few decades, wireless localization has become a crucial service for many applications [21]. In general, a UE position can be determined at the network level (uplink positioning) or at the UE level (downlink positioning). A variety of measurements, such as the radio signal's ToA, TDoA, phase difference-of-arrival (PDoA), AoA, AoD, and received signal strength (RSS) can be taken into consideration in the formulation of position estimation. Another localization technique is proximity, in which the position of certain reference entities (such as BSs) close to the users is used to estimate the coarse location of the UE. Techniques like cellular ID (CID) and enhanced-CID (E-CID) are examples of this type [2][22]. There are two primary types of positioning

[1] The FCC and EC are regulatory bodies that oversee and regulate communication and telecommunications within their respective jurisdictions. They play critical roles in shaping the regulatory framework for communication technologies and services in their respective regions, (FCC in United States and EC in Europe).

[2] The 3rd Generation Partnership Project (3GPP) is a collaboration between telecommunications standards organizations to develop globally applicable specifications for mobile communication technologies, including the evolution of 3G and the development of 4G (LTE) and 5G technologies.

[3] The term "base station" refers to the transceiver that offers connectivity in wireless communication systems. Whereas the term "anchor" is used to indicate a geometry reference for localization purpose in addition to its work of wireless connectivity, so it will be used in this paper as in many references like [18][46].

platforms: ad-hoc[4] terrestrial positioning systems and cellular-based positioning systems. Below will describe them in some details:

1.1 Ad-hoc positioning systems:

The ad-hoc positioning systems utilize several measuring techniques, such as ToA, TDoA, AoA, AoD, and RSS to determine the user's position [2][3][18]. These measurements can be acquired using specific technical solutions including, ultra-high frequency radio frequency identification (UHF-RFID), ultrasounds, ultra-wide bandwidth (UWB), millimeter-wave[5]. (mmWave), as well as visible light-based technologies such as light detection and ranging (Li-DAR) and visible light positioning (VLP) technologies. Table 1 provide a concise summary of the key features of each ad-hoc technology used for wireless location, together with the corresponding attainable precision in localization [3][13][23].

Table 1 Common ad-hoc localization methods, including UHF-RFID, UWB, mmWave, Li-DAR, and VLP [13].

	UHF-RFID	**UWB**	**MMWAVE**	**LI-DAR**	**VLP**
Typical Frequency	865-868 MHz	3.1-10.6 GHz	28, 60, 77 GHz	200 THz	400-790 THz
Typical Bandwidth	200 kHz	larger than 500 MHz	larger than 2.1 GHz	---	150 MHz
Localization Technique	RSS, PDoA	ToA, TDoA	ToA, TDoA, AoA	ToA	RSS
Coverage	less than 10 m	less than 100 m	less than 100 m	less than 500 m	less than 10 m
Accuracy	less than 5 m	less than 10 cm	less than 1 cm	less than 1 cm	less than 15 cm
Cost	very low	moderate	moderate/high	high	very low

1.2 Cellular-based positioning systems:

Cellular networks are designed mainly to support high-quality communications. In past generations, positioning, was formerly thought of as an add-on service for communications, but now days, cellular networks are also conceived to give customers location information, which covers a larger region than terrestrial ad-hoc solutions. So, localization and communication have just lately been developed together, and sixth generation (6G) mobile networks will push this integration much further [24]. Table 2 presents the primary characteristics of cellular localization for several generations, up to and including 6G. The characteristics in this table along with the associated features, use cases, and key performance indicator (KPI), including cell identification (CID), ToA, observed and uplink time difference-of-arrival (OTDoA, UTDoA), uplink angle-of-arrival (UAOA), multi round trip time (MULTI-RTT), location service (LCS), positioning element (PE), positioning protocol (LPP), LTE position reference signals (PRS), new radio positioning protocol A (NRPPA), and emergency services (ES). Indeed, the upcoming 6G is anticipated to have a significant influence on how cellular-based systems approach wireless localization [13][25].

Table 2 Cellular-based localization techniques, features, use cases, and KPI [13].

	2G	**3G**	**4G**	**5G**	**6G**
Maximum Frequency	1900 MHz	2100 MHz	6 GHz	90 GHz	3 THz
Typical Bandwidth	200 kHz	500 kHz	20 MHz	100 MHz	500 MHz
Enhanced Techniques	CID, assisted ToA, OTDoA	CID, assisted TOA, OTDoA	E-CID, UTDoA	UAoA, Multi-RTT, NR E-CID	Enhancing Previous Techniques (e.g., assisted with RIS and AI)
Localization Features	LCS	PE	LPP, PRS	NRPPA	Joint Communication & Sensing protocol
Use Cases	ES	ES	ES	ES, industry, logistics, e-Health, aerial	Holographic Localization and Communications, Teleportation
KPI Horizontal Positioning Error	less than 100 m, 67%	less than 100 m, 67%	less than 50 m, 67%	less than 10 m (3 m),	less than 10 cm, 99.9%
KPI Vertical Positioning Error	NA	NA	less than 3 m, 67%	less than 3 m, 80%	less than 10 cm, 99.9%
Positioning Latency	NA	NA	NA	less than 1 sec	less than 0.1 sec

2. Emerging Applications For Localization

For complete prospection, some potential emerging applications that require high-accuracy localization and low-latency are presented in this section. For example, if we assume a localization scenario enabled by RIS, the intelligent surface in outdoor can acts as a passive reflector for assisting the BS in estimating the location of the UE. The indoor intelligent surface can be active, and it

[4] The term "ad-hoc" is a Latin phrase that has been adopted into English. It is commonly used as an adjective to describe something that is created for a particular purpose as-needed basis. In communications, it implies that the communication network is created for a specific purpose, without a predefined structure or planning.

[5] The mmWave band, which covers frequencies from 30GHz to 300GHz, is very interesting to both science and business because it has a lot of bandwidth resources [71].

allows holographic localization and mapping. Some application cases in the direction of this idea are listed below.

2.1 Industrial Internet of Things

Precise location is essential to fully use sensors and actuators in industrial internet-of-things (IoT) scenarios. Everything (such as sensors, machines, tools, and people) may have attached tags that are wirelessly linked to offer communication services and high accuracy positioning. For instance, mobile robots need accurate information about where they are and what's around them in order to move through crowded warehouses [26].

2.2 Simultaneous Wireless Information and Power Transfer

6G is expected to encourage systems with high directivity and radio clusters that look like pencil beams. As a result, it will be possible to not only send information quickly through the beams that are created, but also energize the devices through the same communication link. To focus the power flow correctly and reduce the amount lost energy, localization with very high accuracy is needed [27][28].

2.3 Intelligent Transportation Systems

Accurate location can help with better traffic flow and the guidance of self-driving cars and drones through the avoidance of accidents. This can make services like autonomous flying taxis possible [29][30].

3. Localization Feasibility with The Aid of Intelligent Surfaces

The Reconfigurable intelligent surfaces can be fabricated using different technologies and controlled by adjusting its phase profile. RISs represent a breakthrough technology whereby surfaces are endowed with the capability to actively modify the impinging EM wave [10][31], as visualized in Figure 1.

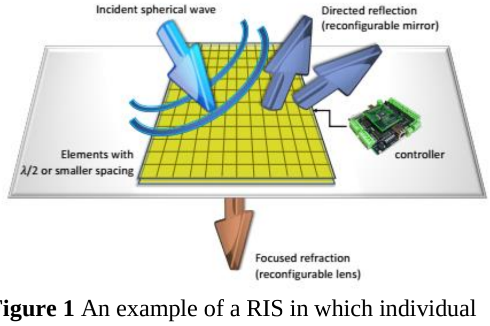

Figure 1 An example of a RIS in which individual elements are adjusted via a controller [10].

RISs have remarkable helpfulness which is enhancing the communication coverage even in NLoS case [32]. It can work as mirror or lens, transmitter, receiver or as an anomalous reflector or steerable reflector [33]–[35] RISs can works in different frequency ranges, it can work from about some gigahertz (GHz) to mm wave bands where RISs can be exploited to obtain significant benefits in terms of coverage. In greater ranges, i.e., 0.1–1 terahertz (THz), high performance gains can be obtained but the propagation may suffer from severe path loss, high sensitive to obstacles blockages, atmospheric absorption and also there is a hardware challenges and limitations [36][37].

The reflection of the incident signal on the RIS, i.e., the electromagnetic response to the incident wave, can be controlled using software, then RIS may refer to software defined surfaces (SDSs). RIS be worthy of special care among the modern recently appeared technologies as it has many advantages, first it can boost the communication quality by controlling the reflection of the signal incident from the BS and redirect it towards a UE [31][38].

In recent years, noteworthy exert effort has been carried to improve the fabrication of the RIS, modelling its channel, performance gains, study RIS control and investigate RIS-assistance communication system [39][40]. The smart propagation environments will become not imagine concept but will be real and implemented practically thanks to the RIS technology that next generation communication network will witness. It’s expected in future to coat the objects and buildings walls with RISs to enhance the communication performance and overcome NLoS signal blockage by the mean of virtual LoS (VLoS) through the RIS, also; it could exploit RISs for accurate UE localization [41][42].

In fact, the precise estimation of UE location can improve the performance of communication systems, this is called location aware communication systems. An example, the estimated position information with other radio parameters measured for long time can setting up maps for radio environment to give many appropriate chances in term of resource allocation without requiring the knowledge about the instantaneous channel state information (CSI), also, the previous knowledge of UE location can reduce the latency of the communication. Indeed, an efficient estimation of the CSI can be made using less number of pilots when the position of the UE is known [13]. The interaction between the digital and physical world depends on the capability of a device to estimate its own position in addition to the position of other objects in the operating environment, that is known situational awareness. Some applications of that are the healthcare, robots, automated vehicles, and human-to-machine interaction. Depending on the application and needs, a range of technologies, including LiDAR, inertial measurement units (IMUs), or cameras, as well as radio-based can be used to gain situational awareness. These include satellite location, radar, UWB, cellular, or WiFi. Due to its dual communication and sensing capabilities and general resistance to environmental conditions like poor lighting, radio-based solutions are appealing [10][12][28][43].

The basics of passive RIS aided localization has been introduced in [43]. Where some of RIS-based positioning applications are shown in Figure 2 (a-c). In (a), the obstacles that make the propagation in NLoS while using RIS can improve positioning accuracy, the near-field localization in (b) that make the wavefront curved can exploited to remove the effect of clock biases and other benefits can be obtained using near-field localization and the availability of large number of multipaths in indoor environment, RISs can help to estimate the location in harsh industrial environments as in (c).

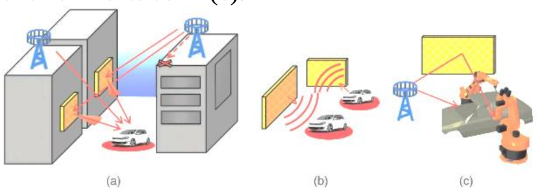

Figure 2 RIS-based positioning applications [43]

The exploiting of AoA and AoD in addition to the ToA for positioning is more common in 5G and beyond at millimeter and sub-terahertz wave. These schemes require the adoption of large antenna and bandwidth; on the other hand, it increase probability of signal blockage by obstacles hence resulting into NLoS propagation. Thanks to the RIS technology where controlled passive reflection for EM waves to steer the wave to desired direction can be realized. Even though the RIS arise to enhance communication, it has several applications and benefits such as in term of power consumption, coverage enhancements, localization, and mapping. Those concepts, benefits and associated challenges have been also introduced in [43].

4. Emerging RIS-Aided Wireless Localization Technology

In this section, we review the recent advancement of RIS-aided localization in wireless communications based on the system model and other parameters under consideration as shown in Table 3. Differences between the system model under consideration and the approach used to estimate UE position are discovered. The classification is categorized based on near-field or far-field propagation models and system setup such as number of antennas at the transmitter and receiver or other metrics.

Table 3 Overview of RIS localization algorithms, system model and other parameters

Ref	Field	BS	RIS	Antenna Setup	Localization Technique	Ch. Link	UP/DL	Frequency	Signal Type	Sync. Type	2D/3D	Special Characteristics
[1] 2021	Far-field	Single BS	Single RIS	SISO	AoD, ToA	LoS, VLoS	DL	30 GHz	OFDM	Async.	3D	----
[10] 2020	Near-field	Multi BS	Single RIS	MIMO	TOA, POA, AOD, AOA	VLoS	DL	27-33 GHz	Single carrier	Async.	2D	----
[11] 2020	Far-field	Single BS	Single RIS	MIMO	AoD, AoA, ToA	VLoS	DL	60 GHz	OFDM	Sync.	2D	joint communication and positioning
[13] 2023	Near-field	Single BS	Single RIS	MIMO	ToA, AoA, RSS	LoS, VLoS	UL	28 GHz	OFDM	Sync.	2D	Holographic
[18] 2021	Near-field	Single BS	Single RIS	MIMO	TOA, AOA, RSSI	LoS, VLoS	UL	28 GHz	OFDM	Sync. Async.	3D	joint communication and localization
[20] 2018	Near-field Far-field	Single BS	Single RIS, Multi RIS	MISO	AoA, ToA	LoS	UL	----	NA	-----	3D	Large RIS
[44] 2022	Near-field	Single BS	Single RIS	MISO	Angles and distances	VLoS	UL	28 GHz	PRS	Sync.	2D	compressed sensing (CS)
[45] 2022	Near-field	Single BS	Single RIS	SISO	Angles and distances ML	VLoS	DL	28 GHz	NB signal over T transmissions	Async.	2D	Phase-Dependent Amplitude Variations
[46] 2022	Near-field	Single BS	large linear RIS	SISO	ToA, TDoA	LoS, VLoS, NLoS	DL	3.5,28 GHz	OFDM	Async.	2D	6G localization

[47] 2021	Near-field Far-field	Single BS	Single RIS, Multi RIS	SISO	AoD, ToA	VLoS	DL	28 GHz	OFDM	Sync.	2D	6G localization
[48] 2022	Near-field	Single BS	Single RIS	SISO	Angles, ToA	VLoS	DL	28 GHz	OFDM	Sync.	3D	6G localization
[49] 2022	Far-field	Single BS	Single RIS, Multi RIS	MIMO	AoD, AoA, ToA	LoS, VLoS	DL	30 GHz	OFDM	Sync.	3D	----
[50] 2020	Far-field	Single BS	Multi RIS	SISO	AoD, AoA, ToA	LoS, VLoS, NLoS	DL	28 GHz	OFDM	Sync.	2D	Beyond 5G
[51] 2021	Near-field	Single BS	Single RIS	MISO	ToA, DoA	VLoS	UL	MmWave	Reference signals	Sync.	2D	6G localization
[52] 2022	Near-field	Single BS	Single RIS	MIMO	ToF, AoD, AoA	LoS, VLoS	DL	60 GHz	OFDM	Sync.	2D	Active RIS
[53] 2022	N/A	Single BS	Two RISs	SISO	RSS	LoS, VLoS	DL	2 GHz	Pilot signals	Sync.	2D	----
[54] 2022	Far-field	Single BS	Multi RIS	MISO	AoA,	LOS	UL	4.9 GHz	Pilot signals	Sync.	3D	ISLAC
[55] 2022	Far-field	Single BS	Multi RIS	MISO	AoA, TDoA	LOS	UL	mmWave	Pilot signals	Sync.	3D	ISLAC
[56] 2022	Far-field	Single BS	Multi RIS	MIMO	AoA, AoD	NLoS, VLoS	DL	28 GHz	Reference signals	Sync.	3D	ISLAC Bayesian localization algorithm
[57] 2022	Near-field	No access points	Single RIS	----	ToA, AoA	LoS with RIS	---	28 GHz	OFDM	Sync.	3D	ISLAC self-localization
[58] 2021	Near-field	Single BS	Single RIS	SISO	AoA, ToA	VLoS	DL	28 GHz	OFDM	Sync.	2D	ISLAC
[59] 2020	Far-field	Single BS	Single RIS	MIMO	AoD, AoA, ToA	LoS, VLoS	DL	60 GHz	OFDM	Sync.	2D	Large RIS multiple UEs
[60] 2021	Near-field	Single BS	Single RIS	SISO	ToA, AoA,	LoS	UL	28 GHz	Pilot signals	Async.	3D	RIS as Lens
[61] [62] 2021	PL model	Single AP and multi-UE	Single RIS	SISO	RSS	LoS, VLoS, NLoS	DL	2.4 GHz	Single tone signal	Sync.	2D	Indoor
[63] 2020	Near-field	Single BS	Single RIS	SIMO	ToA, AoA	VLoS, NLoS	DL	UWB Single	Pilot signals	Sync.	2D	Indoor UWB
[64] 2022	Near-field	Single BS	Single RIS	MISO	ToA & CoA	VLoS, NLoS	UL	28 GHz	OFDM	Async.	3D	Indoor
[65] 2022	Free space	Single BS	Multi-RIS	MISO	ToA, AoA	LoS, VLoS, NLoS	UL	5 GHz	Reference signals	Sync.	2D	indoor
[66] 2022	Far-field	NO access points	Multi-RIS	----	AoA	Pilot symbol	UL	30 GHz	OFDM	Sync.	3D	Receive RF chain. indoor
[67] 2022	Far-field	Single BS	STAR RIS	SIMO	AoA, ToA	LoS, VLoS	UL	mmWave	SRS	Sync.	2D	STAR-RIS Indoor and outdoor
[68] 2022	Near-field	Single BS and multi-UE	Single RIS	SISO	ToA	LoS, VLoS	DL	3 GHz	OFDM	Sync.	2D	Joint localization & communication
[69] 2022	Far-field	Single BS	Two RIS	MIMO	AoA/AoD	LoS, VLoS	UL	28 GHz	OFDM	Sync.	3D	Channel Estimation & Localization
[70] 2022	Far-field	Single BS	Single RIS	MISO	AoA, ToA	LoS, VLoS	DL	28 GHz	OFDM	Async.	2D	Localization and Synchronization
[71] 2021	Far-field	Single BS	Two RIS	MIMO	AoD, AoA	LoS, VLoS	DL	28 GHz	Pilot signals	Sync.	2D	Joint Beam Training & Positioning
[72] 2022	Near-field Far-field	Multi BS	Single RIS. Multi RIS	SISO	Angles	LoS, VLoS	UL	3 GHz	Pilot signals	Sync.	3D	Integrated Sensing and Communication
[73] 2020	Far-field	Two AP	Single RIS	SISO	Angles	VLoS	UL DL	3 GHz	Single-tone RF signal	Sync.	3D	RF sensing, human posture
[74] 2022	Near-field Far-field	Single BS	Single RIS	MISO	ToA, AoA	VLoS	DL	28 GHz	Pilot signals	Sync.	3D	holographic
[75] 2022	Far-field	Single AP and two UEs	Single RIS	SISO	AoA, AoD, PL	VLoS	DL	MmWave	Pilot signals	Sync.	2D	Cooperative between 2 UEs
[76] 2022	Near-field	Two BSs	Single RIS	SISO	AoA, AoD, ToA	VLoS	DL	30 GHz	OFDM	Async.	2D	RIS location
[77] 2021	Far-field	one Tx BS and M- Rx receivers	Multiple RIS	---	ToA	LoS, VLoS	DL UL	30 GHz	OFDM	Async.	3D	Multiple RIS-Enabled Users
[78] 2021	Far-field	Two BS (Tx & Rx), multi target UEs	Single RIS	MIMO	AoA, AoD	VLoS	DL UL	30 GHz	Pilot signals	Sync.	2D	Two BS (Tx & Rx)

[79] 2020	Far-field	one access point	Single RIS	SISO	RSSI	VLoS	DL	2.4 GHz	signal	Sync.	2D	Fingerprinting, Machine Learning positioning
[80] 2022	Far-field	One BS, multi IoT UEs	Single RIS	MISO	AoD, AoA	LoS, VLoS	UL	20 GHz	Pilot sequence	Sync.	3D	RIS-Assisted IoT
[81] 2022	Near-field	Single BS	Single RIS	MISO	AoD, AoA, ToA	VLoS	UL	60 GHz	OFDM	Sync.	2D	Passive and active beamforming

4.1 RIS Aided Localization in Near-Field and Far-Field Model

When an antenna emits an EM wave in free space, Maxwell's equations uniquely specify the field distribution, yet the wavefront seems to have a varied form depending on the observation distance [82]. The EM wave's radiation field can be split to far-field region and the near-field (or Fresnel) region [83][84]. The near-field area is further subdivided into reactive near-field and radiating near-field (or Fresnel region). Because the reactive near-field area corresponds to communication at extremely close ranges (in the order of the wavelength), radiating near-field is indicated by near-field. The split line between the near-field and the far-field regions is constrained by Rayleigh distance (or Fraunhofer limit), this boundary proportional to the square of the antenna aperture (or square of the number of antennas) and inversely proportional to the signal wavelength [85][86].

In 5G massive MIMO communication systems, the Rayleigh distance is often only a few meters, which is insignificant and can neglected in practice use. As a result, the wavefront in this far-field area will be modeled as planner wavefront that only depends on the AoA or AoD. In beyond-5G and future 6G communication systems, which extremely large MIMO (XL-MIMO) systems, or may use large RISs, the Rayleigh distance can therefore be several hundreds of meters that's a result of the increasing in the antenna aperture and the decreasing in the signal wavelength making the near-field region and spherical shaping of the wavefront no longer insignificant. For example, the radiating near-field region reaches up to 200 meters for an antenna with a diameter of 1 meter transmitting at a carrier frequency of 30 GHz. This spherical wavefront assumption model depends not only on the AoA and AoD, but also on the distance between the transmitter and the receiver [83][87]. The spherical wavefronts can be used to produce focused beams in a particular spatial area, or beam focusing, which is not possible with conventional far-field beam because signals can only be directed in one direction [88]. Consequently, a significant amount of communication in 6G networks will occur in the radiating near-field area, as shown in Figure 3.

There are several research efforts in the literature to use the RIS aided localization with different scenarios in near-field and far-field model, some of them will have been mentioned in brief details here.

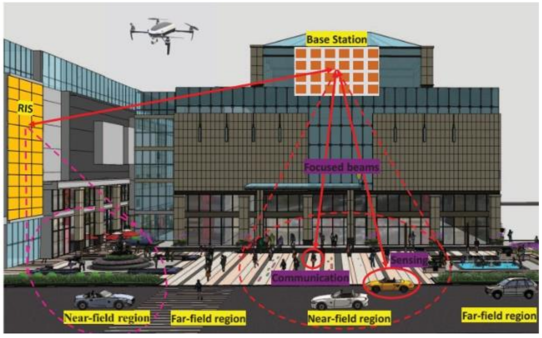

Figure 3 Illustration of near-field communication system. The radiating near-field region can be large distance when the system operates in the mmWave frequencies with a large antenna array or RIS [88].

A 3D RIS aided localization in addition to synchronization for SISO multi-carrier system has been conceded in [1]. To evaluate the estimation error, Cramer-Rao bound (CRB) is derived for the channel parameters. The intended parameters are AoD (elevation and azimuth) for the reflected signal by the RIS towards the UE and times consumed, i.e., ToAs, by the wave to travel from the anchor to the UE as LoS and through the RIS (VLoS). The authors proposed an algorithm to estimate the UE position with low complexity using two of one-dimensional searches for ToAs and one of two-dimensional search for AoDs. The simulation result shows that proposed positioning system can provide sufficient accuracy performance for positioning and synchronization to achieve the requirements of beyond 5G systems using single antenna in both anchor and UE.

The paper in [18] focus on the localization error bounds and limits in a communication model consists of one BS with multiple antennas with the assistant of RIS to estimate the location and orientation of a single antenna UE in near-field propagation model as shown in Figure 4. The authors make their potential to derive the CRLB for best position and direction estimations for synchronous and asynchronous signalling. This article tends to improve the joint communication and localization performance due to proposing different RIS phase profile designs and different scenarios. The obtained results give notable improvements in localization performance even in asynchronous model especially using proposed phase design which depend on SNR.

A single-anchor uplink RIS aided positioning algorithm is proposed to estimate the UE position in [44]. Each of the anchor, RIS, and UE has MIMO uniform-linear-arrays (ULAs) with different number of elements. The proposed scheme assumes a near-field propagation model with multipath environments but the LoS between the UE and the BS has been blocked. The hardness of deriving CRLB for positioning error's minimization in near-field model with multipath scatterers in addition to the RIS introduced by the authors to achieve SNR maximization instead of minimizing the localization error by the CRLB. In addition, a design for optimized RIS phase is used depending on maximizing the SNR at the anchor. A compressed sensing (CS) is adopted in the proposed scenario as well. This achieves a notable enhanced gain in the accuracy of localization.

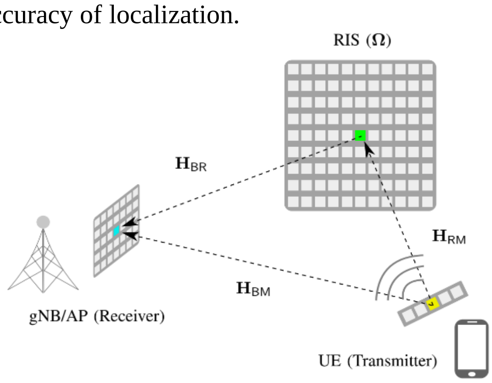

Figure 4 RIS aided localization scenario. [18]

The manuscript in [45] takes up the geometric near-field localization of single antenna UE which served by a single antenna anchor through a RIS by VLoS. What is meant by geometric near-field is the distance between the RIS and UE is close to the RIS physical size. The authors take into account the practical issue of RIS phase dependent amplitude and resort CRB to get lower bound. Low complexity localization criteria is discussed where RIS phase profile tuning using approximate maximum likelihood algorithm have been introduced and investigated. It concludes that RIS amplitude effect negatively the accuracy of the estimation and this loss may be recovered using the proposed algorithm to tune the RIS profile to attain the CRB.

The scenario in [46] deploy single anchor node with the aid of RIS to localize UE with orthogonal frequency division multiplexing (OFDM) downlink approach under LoS and VLoS propagation conditions. It is tended to make the propagation regime of the RIS is near-field regarding to the UE and the anchor. Then the UE is considered to be invisible by the anchor. The effects of the natural scatterers, also trade-off between bandwidth, latency, and overhead was considered. By increasing operating frequency and using electrically large RIS, most of the positioning estimation systems will lie in the near-field propagation regime. So, the authors propose a linear RIS which is different from conventional planar RIS. This RIS can occupy less portions of area than planar RIS and it is easier to implement as shown in **Figure 5**. Two methods of positioning have been proposed to estimate the position of UE for narrowband and wideband systems.

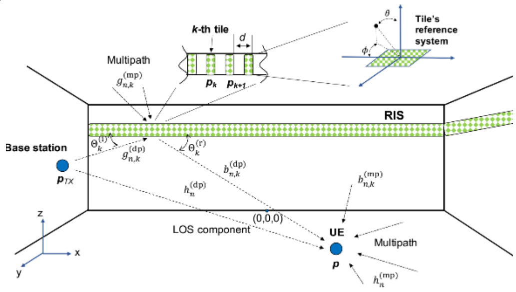

Figure 5 Large RIS Scenario [46]

Location estimation leveraging the RIS that use single antenna, at the anchor and UE, is studied in [47] for far and near fields regions. The model used in this study is an extended from SISO model in [1]. The authors in [47] tend to exploit the curvature of the wavefront in near-field signal and gave an idea that the localization accuracy can be improved in near-field at short distances especially when LoS signal is existed, and the performance is accepted in harsh blockages when LoS absent as shown in Figure 6, this fact is proved using the Fisher Information (FIM).

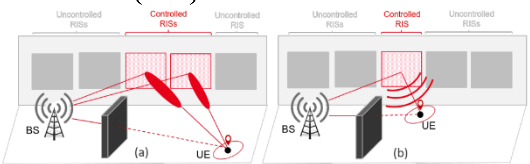

Figure 6 NLoS for both, (a) far-field, (b) near-field wireless positioning with multiple RISs [47]

Different designs of phase profile have been investigated in [48] to minimize positioning error bound (PEB) and enhance the estimation of UE position located in NLoS with respect to the transmitter in near-field propagation and downlink OFDM scenario as shown Figure 7. Time-sharing between different profiles is considered to obtain the optimization for phase profiles considering prior UE position knowledge. FIM and PEB for this scenario is also derived, then an optimization for phase profile to assist an accurate positioning is proposed. The simulation results for the considered scenario demonstrated a significant enhancement in minimizing PEB compared with random RIS phase profile design.

The researchers in [49] assume that a RIS's location and orientation may be treated as prior knowledge for RIS-aided localization and construct Bayesian constraints for the localization. In this study, to explore the basic limitations of RIS-aided localization, it assumed that the UE receives the reflected signals from one or more RISs in addition to a LoS signal from the BS. Additionally, the UE and the BS are assumed both far-field with respect to RIS. Firstly, the researchers derive the FIM related to channel parameters to be able to derive the localization bounds. Thereafter, an equivalent Fisher information (EFIM) was derived. This paper also investigates the decomposability of the FIM into information got from the transmitter, information got from the RIS, and information got from by the receiver. After that EFIM has been transformed to FIM for the UE position and orientation then checked under certain RIS reflection profiles.

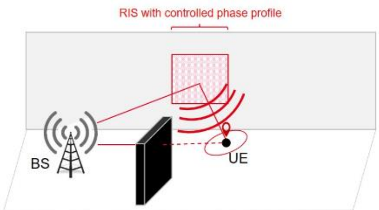

Figure 7 Single RIS in near field over SISO NLoS downlink positioning scenario.

The authors in [50] investigate a downlink, multi RIS, far-field synchronized, positioning system using the Fisher Information FIM metric. Two stage optimization is investigated to select the best RIS group to be activated to enhance the positioning performance by controlling the phase profile of the RIS elements. Compared with natural scatters, performance gain is noticed with specific limitation in noisy and interfering environments.

The researchers in [51] propose two stage RIS assistant positioning criteria depends on earlier statistical information of the UE location. This algorithm is abbreviated as passive positioning with RIS (PAPIR). The scenario observes the signal sent from UE to the BS, in uplink scheme, and exploit the ToA and direction-of-arrival (DoA) in addition to the statistical information to estimate the UE position. The coarse prior information about the UE location is used to design optimized RIS phase profile, this aimed to reflect the signal by the RIS in a manner make the SNR maximum at the BS.

A scenario of mmWave MIMO system localizing single UE in single anchor with the aid of active RIS, which has higher level of freedom, has been considered in [52]. The proposed positioning estimator depends on transmitting multiple pilot signals with particle filtering in addition to design RIS profile and design power split between the anchor and the active RIS. Also, they derive the CRLB for positioning and orientation of the UE and note that the simulation results consistent with the theoretical derivations and improvements achieved compared with using passive RIS.

The proposed system in [53] shows that it is possible to estimate an accurate location of a UE even when there are not enough anchors, i.e., the proposed system consists of one transmitter, one UE receiver and multi RIS which are configured with a certain phase profile to provide at least three separate paths between the UE and some selected nodes estimating the distances of the known nodes then estimate the UE position. The number of RISs is chosen to be two, then it extended to be more than two RISs to improve the localization performance. Simulation results show that the positioning accuracy inversely proportioned with the SNR at UE and could be increased by increasing the number of RIS, also by optimizing the position of the RISs.

Two parts works [54] and [55] are used to improve a two-step positioning performance of UE in mmWave positioning strategy using single BS and multi RIS with multi input single output (MISO) signal model. The first step in [54] entails modelling and analysing of angle estimation errors using 2D discrete Fourier transform (2D-DFT), while the second step in [55] involves designing and analysing biases in the relevant positioning algorithms. The final calculation of the location is determined by merging the estimates from the two steps. The effectiveness of the suggested placement method is proven by simulation results.

User localization and tracking are investigated in [56] for multi RIS aided MIMO system. A message passing algorithm is developed using Bayesian user localization and tracking algorithm, that’s to estimate and track the user location and AoA at the user in real time. In addition, to describe the basic performance limit of the investigated tracking issue, the Bayesian CRB was developed. The beamforming at the BS and RISs are optimized to reduce the derived BCRB. The simulation findings reveal that the proposed algorithm performs close to the derived BCRB and outperforms the counterpart algorithms when the temporal correlation of the user location is not exploited.

A unique use of RIS near-field localization is studied in [57]. The UE is allowed to estimate its own position by transmitting number of OFDM pilots and analysing the signal reflected from the RIS back to the UE without the need to any access points as depicted in Figure 8. The positioning was accomplished by extracting the signal reflected from the RIS among the undesirable multipath using random and directed RIS phase profiles, creating a coarse estimate of the position, then improving the estimation using maximum likelihood (ML). Finally, UE localization is assessed by CRLB, then the evaluation of the performance demonstrate that the suggested technique can achieve the given bound at high SNR values.

Differently from traditional near-field localization, in practice, reliable position estimate is challenge when the LoS link between the anchor and the UE is blocked by an obstacle, that what is investigated in [58]. The localization method is created using the proposed RIS phase, and the power optimization approach for the RIS assisted localization is examined. Using the developed RIS phase schemes, the suggested localization technique may achieve near-optimal localization performance, proving the usefulness of the given framework, in which both phase design methods virtually coincide with the ideal RIS phase.

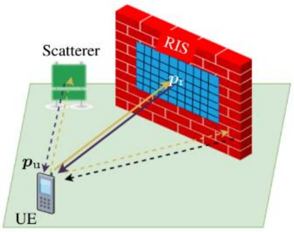

Figure 8 Single antenna UE and RIS system with multipath reflection from passive objects [57].

4.2 Large Intelligent Surface (LIS) Aided Localization

According to a recently developed wireless communication idea called the Large Intelligent Surface (LIS), the entire environment will be "intelligent" when future manmade structures become technologically active with integrated electronics and wireless communication. Continuously, the articles in [20] and [59] consider the positioning possibilities of a system with LIS.

So in [20], the UE is equipped with a single-antenna and located in front of the LIS with LoS and without scatterers as shown in Figure 9. It is noted that CRLB decreased in linear form with UE located in perpendicular centred line and quadratically for other UEs with the surface area of the RIS. Thereupon, a significant positioning performance using LIS compared to massive MIMO positioning may achieved tanks to larger surface area. Furthermore, this paper investigates the influence of using multiple smaller RISs occupy the same surface-area compared to one part of LIS. It has been showed that splitting LIS, for example, to four parts extend the range of position estimation and improve the average CRLB, but on the other hand increase the overheads for cooperating multiple smaller RISs.

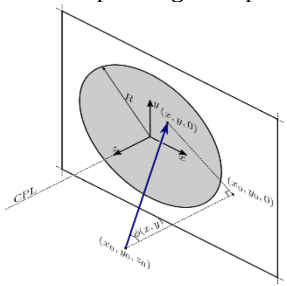

Figure 9 Positioning and transmitting model of the LIS [20].

Also, the LIS is used as reflector for estimating the position of multiple UEs in mmWave MIMO communication system, this concept is introduced in [59]. It is focused on the theoretical bounds obtained from equivalent FIM and investigate the effect of increasing the number of elements of the large surface and the phase shift of each element on the positioning accuracy which represented by PEB and orientation error bound (OEB). A comparison between system with and without the LIS aided localization is made and simulation results showed better performance in case of using LIS assistance localization.

4.3 Localization Using RISs Working as Lens

The RIS can work as a smart reflector that defies Snell's law [89][90] or as a lens that exhibits a nearly continuous phase profile [60]. In [60] 3D localization of UE act as transmitter in near-field is performed using RIS working as a lens has been investigated. The RIS is near to receiver with single antenna having a radio frequency (RF) chain as shown in Figure 10. To evaluate the impact of various RIS configurations, several RIS phase profiles have been deigned. It has been shown that when a location information is available priorly, the RIS design that provide positional beamforming give better performance, while RIS design that provide random beamforming is preferred when there is no a priori information available. The investigation results indicate that when estimator works with low resolution, then the estimator performance may degrade.

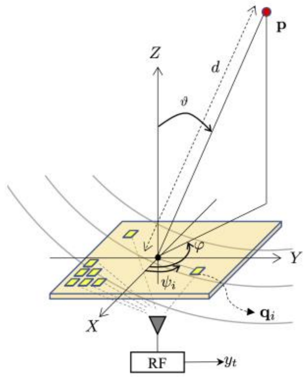

Figure 10 Single UE and RIS lens with a receiving antenna attached to RF chain [60].

4.4 Indoor RIS Aided Localization

Indoor localization has lately gained popularity because to the large range of services it can deliver by using the Internet of Things (IoT) and ubiquitous connection. In order to improve the services supplied to users, several methodologies, wireless technologies, and mechanisms have been presented in the literature to provide indoor localization services. It is intended to elaborate on the feasibility of using RIS to raise the accuracy of indoor positioning, inspired by the freedom provided by RIS to alter wireless signals [91].

The use of RSS-based multi user indoor RIS aided localization is proposed in [61]. The authors aimed to improve the localization accuracy by enlarging the values of received signal differences of the neighbouring locations, that’s through the programming the propagation environments by modifying the reflection coefficients of the RIS in a suitable optimized iterative algorithm. The scenario consists of emitting signal from an access point, this signal reflected by the RIS to the UE that make the RSS measurements for positioning. The AP and the RIS connected to a controller as in Figure11.

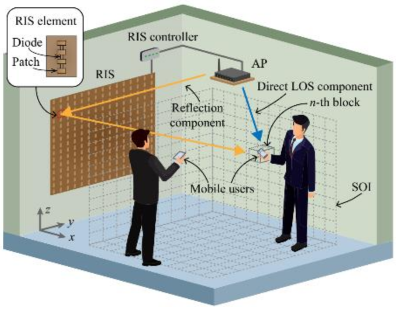

Figure11 RIS aided multi-user localization scenario [61].

In [63], a developed model of RIS aided indoor localization system at ultra-wideband (UWB) has been presented. It is realized in theoretical analysis and numerical results that the RIS with UWB signals can help to achieve accurate estimation for UE position with single access point. In addition, it has cost efficient, that's because it is need one access point and inexpensive RIS unit. It is proved that the limit number of receiving antennas leads to higher accuracy of ToA based positioning compared with AoA based positioning, that's due to the existing of multipath channels of UWB signals. Also, the CRLB of the developed positioning model is derived.

Furthermore, [64] analyses the performance limits of RIS-based near-field indoor localization in the asynchronous scenario, as well as the impact of each part of the cascaded channel on localization performance. The FIM and the PEB are derived. In addition, the equivalent-Fisher-information (EFIM) for the position-related intermediate parameters is derived. It has been demonstrated, using the derived EFIM, that the distance and the direction information of the user can be obtained when the spherical-wavefront of the near-field is considered for RIS-UE part of the channel, whereas only the direction of the UE can be inferred in the far-field model. The effect of the focusing control method on the performance of the PEB under both synchronous and asynchronous conditions is studied as well.

The article in [65] investigate indoor positioning with the assistant of multiple RIS distributed in a certain way to exploit the their capability to manipulate multipath signals. Two modes are used in this research. In the first mode, the implementation cost is reduced by giving each RIS constant reflection coefficients, while they are updated periodically in second mode. Also, two steps positioning criteria is used to enhance positioning accuracy. The area of interest is divided to subareas and the RISs configured corresponding each subarea. Each RIS gave an initial phase to localize the UE in a certain subarea, then RIS reconfigured to get more accurate positioning. The proposed scenario is shown in Figure 12.

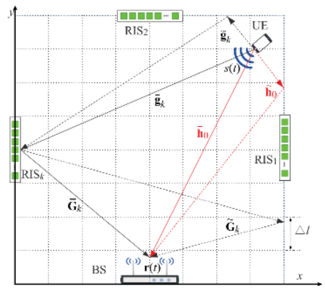

Figure 12 A scenario of distributed RISs assisted indoor positioning [65]

Multiple RISs are also used to design UE indoor positioning method in [66] each RIS equipped with a single receive RF chain. It is assumed that each RIS element combined with a waveguide, so the waveguides outputs be an input to the RF chain as in [92][93]. The proposed method estimates the direction of UE through the estimation of the AoA for each receiver using multiple phase profiles of the RIS. Then, ML positioning estimation method is used depending on the least squares line intersection from each RIS. Also, PEBs is derived to demonstrate the accuracy of the proposed positioning method compared with the numerical results for various system parameters.

The appearance of new version of RIS named STAR-RIS [94], abbreviation for simultaneously transmitting and reflecting RIS, stimulate the researchers in [67] to exploit it to enhance the localization for indoor and outdoor UEs at the same time. This type of RIS, originally, has been used to expand the communication range as well as improve the efficiency in term of spectrum and energy, also; it can be represented as a link between indoor and outdoor communication. In contrast of the traditional RIS, STAR-RIS can perform reflection and refraction at the same time, i.e., two UEs one is outdoor and the other in indoor can be served simultaneously by one STAR-RIS. The exploitation of STAR-RIS for localization can use one multi antenna outdoor anchor to localize one outdoor single antenna UE together with other indoor single antenna UE via sending uplink sounding reference signal (SRS) at both sub 6GHz and mmWave frequencies as shown in Figure13.

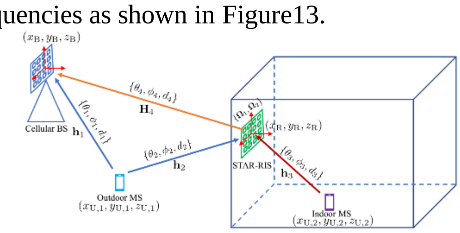

Figure13 STAR-RIS aided scenario for localizing indoor and outdoor UEs simultaneously [67].

4.5 Joint localization and Communication with RIS Assistant

As mentioned, localization will be implemented into communication systems as a crucial feature in the future. By sharing physical platform and spectrum resources, combined localization and communication systems can increase spectrum and energy efficiency and reduce hardware overhead [95].

The authors studied in [11] exploit the optimized adaptive RIS phase profiles in a communication system with MIMO approach to improve localization and communication. The proposed adaptive RIS phase profiles updated sequentially and does not need active sensors and base-band processing units in the RIS. The simulation model focused on measuring the position and orientation estimation error as well as the data-rate between transmitter and UE and shows good results in both positioning and communication performance compared with the results for random phase shifters.

A localization and communication system that is simultaneously assisted by a reconfigurable intelligent surface is considered in [68] using downlink RIS-assisted OFDMA system. Then, a hybrid RIS discrete phase shifts design and subcarrier assignment problem is developed to reduce the PEB. An iterative procedure is suggested to find a suboptimal solution to the given non-convex mixed-integer problem using optimization techniques. Results from simulations are offered to verify the performance of the suggested approach.

The authors in [69] consider channel estimation problem in MIMO OFDM systems aided by RISs. A twin RIS structure with a relative spatial rotation is proposed to get the essential channel characteristics, such as angles, delays, and gains, for environment mapping and user localization. The simulation findings show that the suggested twin-RIS scenario and estimation algorithms can recover channel state information with exceptional accuracy, allowing for centimetre-level user location resolution.

A low complexity joint localization and synchronization with single antenna receiver scenario based on an improved design of the active precoding BS and passive RIS is proposed in [70],. Assuming prior knowledge of the user location, the theoretical PEB is determined and used as a measure to jointly optimize the BS-RIS beamforming. A combined recovery method for the user location and the synchronization offset is developed using a ML based estimate process. According to numerical study, the proposed system offers improved localization and synchronization performance, and the suggested estimator hitting the theoretical limits even at low signal to noise ratio (SNR) and with uncontrolled multipath propagation.

The beam training is considered and the optimal beam is estimated via ML approach in [71]. Using the estimated pairs of AoA and AoD, an iteration procedure is proposed to estimate the position of the mobile station which will be used to enhance the prediction of the blockage link and further improvement of the AoA and AoD initial estimation.

4.6 Integrated Sensing and Communication (ISAC):

Localization aims to estimate and monitor the location of an actively communicating user device, whereas sensing is focused on estimating and tracking the location of passive objects or users. Radio localization and sensing systems share common principles, including the presence of location references, user states, and measurements [96]. The ISAC is the mandatory requirement to achieve high accuracy for location awareness in wireless networks. To achieve high ISAC efficiency in complex wireless communications environments, its require to use the new technology which is the RISs [72]. Some examples of the applications that need ISAC are location-based services [97][98], item recognition and tracking [99]–[101] smart environments [102][103], and the IoT [104][105].

The paper in [72] introduce the basics of RIS-aided ISAC systems and focusing on the RIS-aided localization and communication scheme in beyond 5G networks. Two classifications of RISs have been considered, the first is the continuous intelligent surfaces (CISs) and the other is the discrete intelligent surfaces (DISs). Also, near-field and far-field propagation scenarios are taken in the investigation. The authors make their efforts to optimize the phase response RISs profile for different scenarios to show numerically that this optimized phase profiles can increase the SNR and improve the spectral efficiency then the positioning accuracy improved significantly.

A system of RF sensing for human posture recognition combined with RISs has been designed in [73] and shown in Figure 14. This combination is to overcome the radio environments limitation of the traditional RF sensing. Rather than using passive adapted environment, active customized environments is used to achieve wanted propagation properties. To get accurate recognition, the authors split the optimization of RIS configuration problem into two parts and propose a solution for each one. The simulation results proved good efficiency for designed algorithms and archived improving in the recognition accuracy.

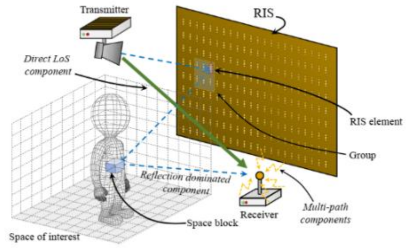

Figure 14 Posture recognition system using RIS [73].

4.7 Other Models and Scenarios of Localization Using RISs

A cooperation between two UEs has been proposed by the authors in [75] to improve the Far-field RIS-aided localization. The localization scenario consists of RIS, single antenna AP, and two single antenna UEs. The channel between the UE and the AP is assumed to be obstructed, see Figure15. The location of the UEs can be estimated in two phases using the AoA estimation exploiting the observation signals which consist of number of time slots. The first phase use half of the time slots, allowing the two UEs to receive AP signal after reflection from RIS, in contrast the cooperative signal received by one user from other while the AP is silent in the second half of the time slots. By estimating the path loss between the UEs the distance between them could be obtained. It is noted that the increasing in number of RIS profile discrete phases, number of RIS elements and the number of time slots result decrease the CRLB and improve positioning accuracy.

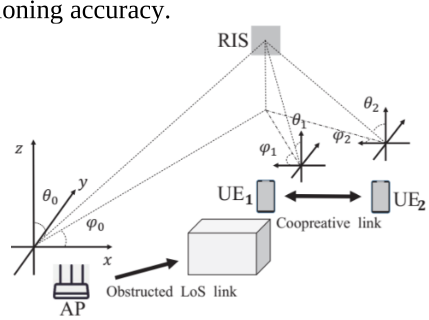

Figure15 RIS-aided localization with two UE cooperation [75].

The authors In [76] propose SISO multi carrier near-field system using bi-static sensing between a Tx and an Rx which are assumed to be in fixed known positions as shown in Figure 16. The proposed scheme involves two stage estimators with low complexity. A line search is performed in the first stage to estimate the ToA, the near-field is approximated to far-field to estimate the AoA and the AoD at the center of the RIS. Lastly, a quasi-Newton approach is used to fine-tune the estimated RIS location and orientation. The impact of several parameters on the proposed estimator's accuracy are examined, and the indicate that the estimator can attain the derived CRBs.

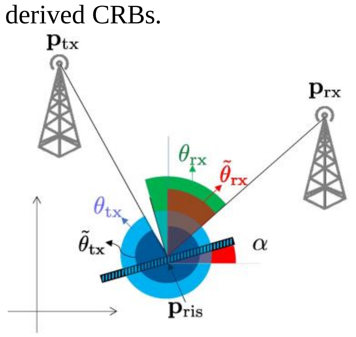

Figure 16 Single-antenna TX and RX, together with a RIS whose direction and location are unknown [76].

A semi-passive RIS based passive localization of multiuser system has been studied in [77]. The scenario consists of number of known positions asynchronous Rxs, one known positions Tx and multiple unknown positions UEs each one equipped with a RIS, so the UE only reflect the signal from the Tx to the Rxs through as in Figure 17. The position of UE is estimated using ToA for both LoS and NLoS paths calculated at the Rx. To avoid inter path interference between LoS and NLoS paths, orthogonal sequences have been used as a time varying multiplied by constant part to generate RIS phase profile. Also, the RIS phase design is used to extract channel parameters related to each UE. The estimations results showed good accuracy in the area around the transmitter.

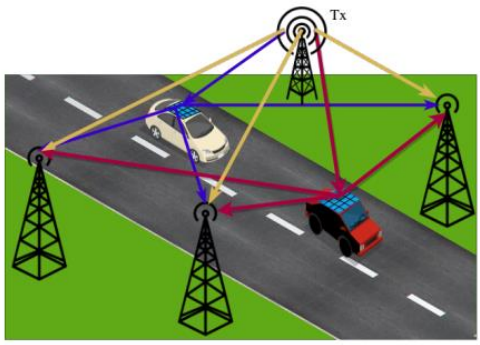

Figure 17 The proposed system with two UEs and three Rxs [77],

A multi target mmWave RIS aided localization MIMO radar system (Figure 18) is proposed in [78]. The authors tend to use adaptive positioning algorithm employing the topic of designing hierarchical codebook to attain good accuracy. In particular, the use of traditional direction-of-arrival (DoA) for UE estimation in NLoS is a challenge that the authors try to get a solution using RIS, with adaptive algorithm. The simulation results and theoretical bounds are showed that accurate estimation of multiple targets locations in NLoS case could be achieved at low SNR regimes.

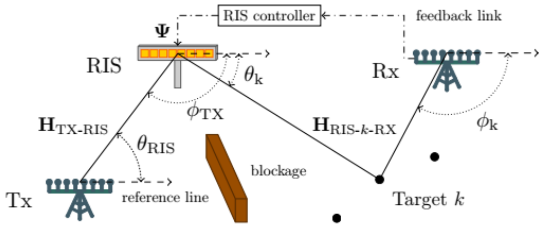

Figure 18 Multi-target radar system with RIS-aided [78].

The wireless fingerprinting positioning (in Figure 19) has been investigated in [79] to support 6G applications. The authors suggest and show how to use the diversity that RISs provide to generate and select easily differentiable radio maps for fingerprinting localization. Also; machine learning feature is used to limit the space of the RIS, that to improve the positioning accuracy and estimation execution time The simulation of the radio propagation in [106] is used because it suitable for RIS-enabled settings. The proposed approach is evaluated and obtained sub-meter localization accuracy without the need of multiple access points and large numbers of fingerprint-grid sample points.

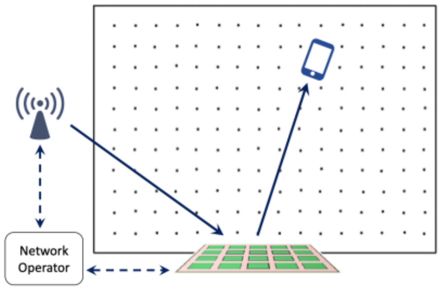

Figure 19 System model for RIS-aided localization [79].

The localization of multi-IoT devices assisted by RIS Figure 20 is proposed in [80]. The triangulation-based positioning method is considered. The orthogonality between the transmitted signals between users is utilized hence facilitating the computation of the propagation delay through the direct path and the reflection from the RIS. The cross correlation of the received signals is used to estimate the localization parameters in addition to minimizing the total power of the transmission via semidefinite relaxation of the non-convert problem. The non-orthogonal scenario is also considered where the interference between the users signals is eliminated via zero forcing detectors.

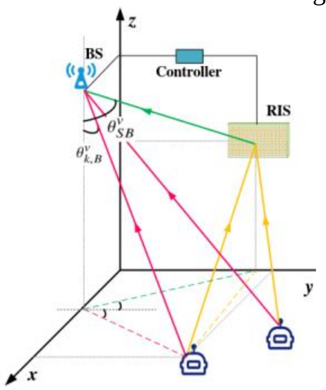

Figure 20 Multi-user localization with the aid of RISs [80]

A design gathers the passive beamforming (PBF) and active beamforming (ABF) at RIS and UE is used in RIS-assisted mmWave positioning system to achieve accurate positioning and minimize the worst-case of positioning estimation error at the selected area is investigated in [81]. It is assumed that there is a blockage between the anchor and the UE as in Figure 21. The optimization of this algorithm lead to non-convex problem with respect to ABF and PBF and non-concave problem with respect to position. So, to solve diverge of this optimization, the authors propose algorithm with two steps joint array gain and path loss search which get good convergence and improve the worst positioning performance. Simulation results emphasize that proposed algorithm can provide good performance results over the benchmark.

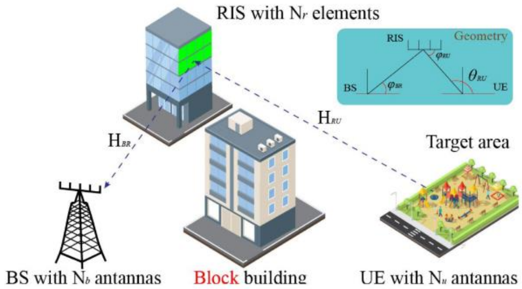

Figure 21 System scenario for localization with RIS in [81]

5. Conclusion

This comprehensive survey has delved into the transformative field of RIS and their profound impact on wireless localization technologies. Through an in-depth exploration of the current state-of-the-art, we have witnessed the evolution of localization systems from conventional methods to the integration of RIS. This paper highlighted the fundamental principles of localization algorithms in general then of RIS aided localization emphasizing the RIS role in dynamically manipulating EM to enhance signal propagation and localization precision. We reviewed a spectrum of localization techniques, examining their scenarios and limitations, laying the foundation for the necessity of the RISs in addressing existing challenges. Our focus on algorithms, deployments, propagation regimes, channels, and applications, provided valuable insights for researchers aiming to harness the potential of RIS-aided localization. The survey covered diverse domains, including indoor localization, outdoor localization, vehicular localization, and IoT applications, demonstrating the adaptability and scalability of RIS technology. While this survey provides a comprehensive overview of the current landscape, the evolving nature of technology presents opportunities for future research and development in the field of RIS-aided localization. Several avenues for future exploration include for example: optimization techniques, integration with emerging technologies, security and privacy considerations.

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