6th Generation: Communication, Signal Processing, Advanced Infrastructure, Emerging Technologies and Challenges

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***Abstract*— In the very initial stage of fifth-generation (5G) commercialization, researchers, scientists, and engineers are realizing the need for further enhancement in 5G parameters and more intelligent techniques to fulfill the expected future requirements. Due to advancement in infrastructure and rapid increment in wireless communication users, after few years, 5G parameters will not be sufficient to fulfill the requirements. The enhanced data rate, data security, ultra-low latency, low computation complexity, ultra-high spectrum efficiency, and power-efficient techniques are the main requirements. Thus sixth-generation (6G) wireless communication is becoming a research hot-spot. The key enablers techniques for 6G communication are auto-pilot unmanned aerial vehicle communication, high mobility communication, satellite communication, advanced device-to-device communication, accurate positioning system, GPS denied positioning, free-space optics, energy harvesting, wireless power transfer, internet of everything, massive internet of thing, intelligent reflecting surfaces, and artificial intelligence-enabled transceivers. In this review article, the role of these techniques for future wireless communication enhancement is discussed. We have also discussed enhancement in existing wireless technology such as pilot-based estimation to blind estimation, advanced error controlling techniques, advanced channel coding, millimeter waves, hybrid non-orthogonal multiple access techniques, orthogonal time-frequency, and space modulation.**

***Index Terms*— 5G, 6G, UAV Communication, Intelligent reflecting surfaces, Blind estimation, OTFS, NOMA, FSO, IoE.**

I. Introduction

Indeed, the fastest emerging sector of the communication industry is wireless communication. It has traveled through 1G, 2G, 3G, and 4G and the commercialization of fifth generation (5G) technology has started. At the same time research demands for the beyond 5G (B5G) or sixth generation (6G) is increasing day by day as researchers and scientists are understanding the need for new wireless communication techniques for future infrastructure and advancement. The rapid development of various emerging technologies like the internet of everything (IoE), artificial intelligence (AI), virtual reality (VR), smart homes, and the concept of smart cities led to the massive volume of traffic. Furthermore high mobility communication such as bullet trains, auto-pilot unmanned arial vehicle (UAV) communication, air taxies, air ambulance, driverless cars, etc. are also data-hungry. The volume of global mobile traffic was 7.46 exabytes/month in 2010 which has become 40.77 in 2020 and it is expected to become around 5016 till 2030 [1]. Looking at these statistics, it is obvious that the techniques and parameters that are used for 5G are not sufficient to fulfill the future applications. Thus researchers need to dig into new ways to overcome the existing challenges and meet future requirements.

The propagation environment for wireless signals transmission is tacitly random in nature, which is the main reason for signal degradation and fading. Measures that we take to enhance the signal quality are modification in the transceiver system which leads to highly complex transceiver design and power-hungry system. Furthermore, the technologies that being used till now are not sufficient to fulfill the future demands. Single carrier modulation (SCM) and multi-carrier modulation (MCM) like orthogonal frequency division multiplexing (OFDM) can not fulfill the demand of a highly varying channel environment or any other situation when frequency offset is high. To serve the huge number of users with limited availability of bandwidth, traditional multiple accessing techniques are not promising. Though the eye-catching technology of 5G, like massive multiple input multiple output (MIMO), is being used to serve a large number of subscribers simultaneously when the channel state information (CSI) is known at the transmitter side. However, problems like the need for multiple radio frequency (RF) chains and CSI overhead increase with increase in the number of transmitter and receiver antennas.

Time-division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), and OFDMA have been used as multiple accessing techniques till 5G which needs further modifications for the future requirements. Security issues are also need to be enhanced with the increment in data traffic users, existing techniques may fail to secure information. Error detection and correction techniques also have to be considered for further improvement for future high-speed communication. Since we are heading towards a future in which a massive number of devices would be connected and communicate with each other, we need technologies which can reduce the complexity of transceiver and also improve the quality of service (QoS).

A detailed discussion of 6G vision, requirements, network architecture, and other important aspects are given in [2]–[6]. Key applications and technologies for 6G are discussed in [7], [8]. Channel modeling for wireless communication is also a very important concern for B5G and 6G. New frequency bands and techniques are evolving for future wireless communication where the fading effect is different compared to the traditional one. Effects of channel impairments and their modeling for future wireless communication need to be analyzed and developed very precisely. The authors in [9] explained the 6G wireless channel, trends, challenges, and channel modeling. Antecedents of future 6G mobile ecosystems are discussed in [10]. 6G subnetworks for short-range and low power applications like brake control in intra-vehicle scenarios, or intra-body heart-rate control are discussed in [11]. The authors in [12] discussed intelligent mobile networks for future wireless mobile communication. The authors also discussed key enabling technologies to make wireless communication intelligent.

Sattelite communication is a key enabler for navigation, positioning, and even data transfer. Integration of satellite communication (SATCOM) with terrestrial mobile communication (TMC) can be a game-changer for B5G or 6G communication. The authors in [13] discussed the trends, challenges, and promising ways to integrate SATCOM with TMC.

Terahertz communication is also opening new ways to achieve estimated parameters for future wireless communication. Integration of traditional technologies along with terahertz communication can provide significant performance improvements. Performance evaluation, challenges, and open problems for hybrid precoding for 6G terahertz communications as future wireless communication enabling technology is discussed in [14]. Dynamic radio access technology (RAT) selection, opportunistic data transfer, and predictive caching are some of the key drivers for anticipatory mobile networking. The authors in [15] discussed cooperative data rate prediction for future mobile and vehicular 6G networks. The business model for the 6G ecosystem to develop products, services and applications are discussed in [16], [17]. The low data rate, low power, high range, and wide area network for beyond 5G is discussed in [18].

Wireless power transfer (WPT), computational complexity and efficient data transfer is a key enabler for 6G wireless communication. A combination of all these into a single design may create an outstanding platform for future wireless infrastructure. Integration of energy transfer, computation and data communication techniques for 6G communication is described in [19]. New 6G projects of Brazil with future applications and technologies are discussed in [20]. The frequency spectrum is one of the most important resources of wireless communication. In [21] the authors discussed traditional frequency spectrum management strategies and showed some promising strategies for future communication. Federated learning applications for 6G are discussed in [22]. Blockchain uses for 6G as new privacy and security risk reduction technique is described in [23], [24]. An OFDM-based bidirectional multi-relay simultaneous wireless information and power transfer (SWIPT) technique for high data rate, low latency, and efficient energy harvesting as a future wireless communication approach is proposed by the authors in [25]. Universal antenna design to support long term evolution (LTE), 5G, B5G and 6G communication is also a challenging task. Multiple researchers are working towards this issue. Antenna design issues and promising designs for integral LTE, 5G, and B5G are described in [26]. Cost-effective remedies for future wireless communication are discussed in [27].

Most of the survey papers and articles on B5G or 6G describes trends, challenges, latest wireless communication techniques directly. Furthermore, some papers explain the network architecture of 6G. In this review article, we first described the futuristic advanced infrastructure and the need for wireless connectivity for these. In Section II, we detailed about future infrastructure, which includes transportation, medical infrastructure advancements, security, surveillance, etc. In this section, we also described the challenges to achieve wireless connectivity to specified infrastructure. Difficulties with existing wireless techniques to serve future needs for different tasks and new promising techniques are specified in section III. Finally, we conclude the review article.

II. Future Infrastructure and Their Wireless Communication Challenges

A. Advance Transportation

1) Auto-pilot UAVs: UAVs that do not need human involvement to control are said to be auto-pilot UAVs. UAVs are the heart of future advanced infrastructure. Air taxies, air ambulance, package delivery, automated surveillance, site monitoring, 3-D mapping, artificial intelligence(AI)-enabled UAVs, etc. needs to be on auto-pilot. UAV can also be used as an intelligent surveillance option. Fig.1(b) illustrates the UAV assisted communication and survilliance for remote areas, country boarder areas and hilly areas.

2) Self-driving Electrical Vehicles: As fuel-based vehicles are becoming highly expensive and environmental threat transport system, electric vehicles (EVs) are emerging very fast as an alternative. Self-driving vehicles are also at the peak of research and development. Combined self-driving EVs are one of the main promising future transportation options. Electrical buses, taxies, bikes, cars, etc. are coming into existence and gaining popularity.

3) Fast Regional Trains: To overcome the high traffic issues, fast-running regional trains are coming into existence. These trains are mainly passing over the bridges or flyovers. These are not having very short distance stoppages like metro trains. These trains are used mainly to connect one city to its nearby cities.

4) Bullet and Maglev Trains: Bullet trains and maglevs trains are coming into existence in many countries. These are very fast running trains and capable of covering hundreds of kilometers in an hour.

For above mentioned advanced transportation options there are many challenge. Some of these are

- *Accurate Positioning and Navigation*: Both auto-pilot UAVs and self-driving vehicles need highly accurate positioning and navigation systems. Traditional GPS and global navigation satellite system (GNSS) based positioning are not sufficient as their accuracy is not satisfactory. If the positioning is not accurate then package delivery using auto-pilot UAV can be done in the wrong house. In UAV surveillance intruder location mismatch can create serious issues. Low positioning and navigation accuracy may create difficulty in advanced air traffic management.

For example, when the positioning is inaccurate, the probability of collision increases with increase in the number of air taxies and air ambulance. Due to the inaccurate positioning of self-driving vehicles, road accident can be increase to a large number. So centimeter accuracy is must for auto-pilot UAVs and self-driving vehicles. Furthermore, GPS or GNSS based positioning is not available at each and every location due to signal blockage or other envirnmental effects. Positioning accuracy also depends on channel fading behaviors, so it must be taken into consideration. Some accurate, universally available and cost-effective positioning techniques need to be developed.

- *High Endurance*: Small UAVs and EVs are generally battery operated. Batteries are having limited endurance which leads to the limited flight time and drives time for UAVs and EVs respectively. Achieving higher endurance for batteries is a challenging task. On the other hand, fuel-based vehicles and UAVs are very expensive. To overcome these issues new highly accurate, low loss electric resources need to be developed or some wireless power transfer techniques must be considered. Energy harvesting techniques along with power efficient communication may also be utilized to overcome endurance issues.
- *Seamless Connectivity and Data Security*: Enhanced wireless connectivity is required for advance UAV technology and rapid increase in the number of UAVs. For a network of UAVs, a very fast wireless connection is required to set synchronization among UAVs. Similarly, for self-driving vehicles and other advance transportations, seamless wireless connectivity is required. Furthermore, one UAV may be an eavesdropper for another UAV. This leads to insecure information transfer for UAVs. To ensure a liable link from UAV to ground or ground to UAV or UAV to UAV, enhanced physical layer or upper layer security techniques must be evolved. Information of self-driving vehicles and other transportations is also vulnerable from eavesdroppers, which need to be considered very carefully [28].
- *High Mobility Communication* : Vehicles with a speed of more than 150 kmph are considered to be high mobility vehicles. The transportation sector is becoming advanced day by day to create hassle-free and less time-consuming transportation options. Bullet trains, air taxies, air ambulance, high-speed regional trains, etc. are coming into existence to meet the requirements of future transportation. Most of these advanced transportation options are in the developing stage and are considered to be high mobility vehicles. Fig.1(c) shows a scenario of high mobilty vehicles for smart outdoor communication. Providing wireless connectivity to these high mobility future transportation options is one of the main concerns of researchers. Traditional wireless technologies may not fulfill the demands of these high mobility vehicles. High mobility leads to the Doppler shift which creates an offset in the frequency. Due to the frequency offset, frequency synchronization issue becomes very crucial even may lead to loss of information. In OFDM-based transmission, if there is frequency offset between the subcarriers then subcarriers lose their orthogonality which degrades the performance of the wireless system due to presence of inter-carrier interference (ICI). Apart from that traditional multiple accessing techniques, channel coding techniques, synchronization techniques, etc. may not be sufficient to serve high mobility communication. Traditional carrier frequency offset (CFO), symbol timing offset (STO), and channel estimation techniques may not suitable for high mobility communication, so new enhanced techniques need to be researched.
- *Sophisticated Obstacle Detection and Avoidance*: For auto-pilot UAVs, well-established algorithms for object detection and avoidance are must. Objects in the environment are diverse in dimension, so developing very accurate algorithms for these object detection and avoidance is very difficult. Sensors, hardware, and software algorithm integration is also a crucial challenge.

B. Underwater Wireless Communication

Underwater wireless communication (UWC) is a technique in which information signals are transmitted and received under the water using any wireless means. Two third of the surface of the earth is covered with ocean, which makes UWC an ideal for an uninterrupted communication system. It plays a significant role in scientific, industry, and military purposes [29]. It is used for other various purposes like oceanography research, naval vessel to vessel information transfer, climate change monitoring, pollution monitoring, oil control and maintenance, weather monitoring, etc. With the advancement of technologies like, autonomous and high mobility vehicles, researchers are now moving towards seamless possibilities of the water transportation system which can be above or underwater. In the future, we can expect a high mobility water transportation system equipped with modern technologies, which will be used as cargo or cruise. Measures are also being taken to develop autonomous underwater vehicles (AUV) which do not require any operator for its operation. AUVs can be used for commercial purposes for making maps and investigating seafloors before the actual operation. This will help a lot in setting up the pipelines and other infrastructures without harming the environment. Another very promising contribution of AUVs can be in the field of scientific exploration. It can be used for data collection of researches in marine archeology, marine biology, oceanography, etc. These explorations can certainly be very helpful in understanding the bio-diversity as well as terrain mapping under the water. It can also be used for finding crashed aircraft and lost vessels, and also to investigate the causes for their crash.

However, limited bandwidth, the effect of noise, etc. limits the efficiency of underwater communication. The speed and quality of EM-waves depend on various parameters like conductivity, permittivity, permeability, etc,. which depend on the underwater conditions and frequency being used for the communication [30]. However, measures are being taken by the researchers to eradicate these limitations. RF, optical and

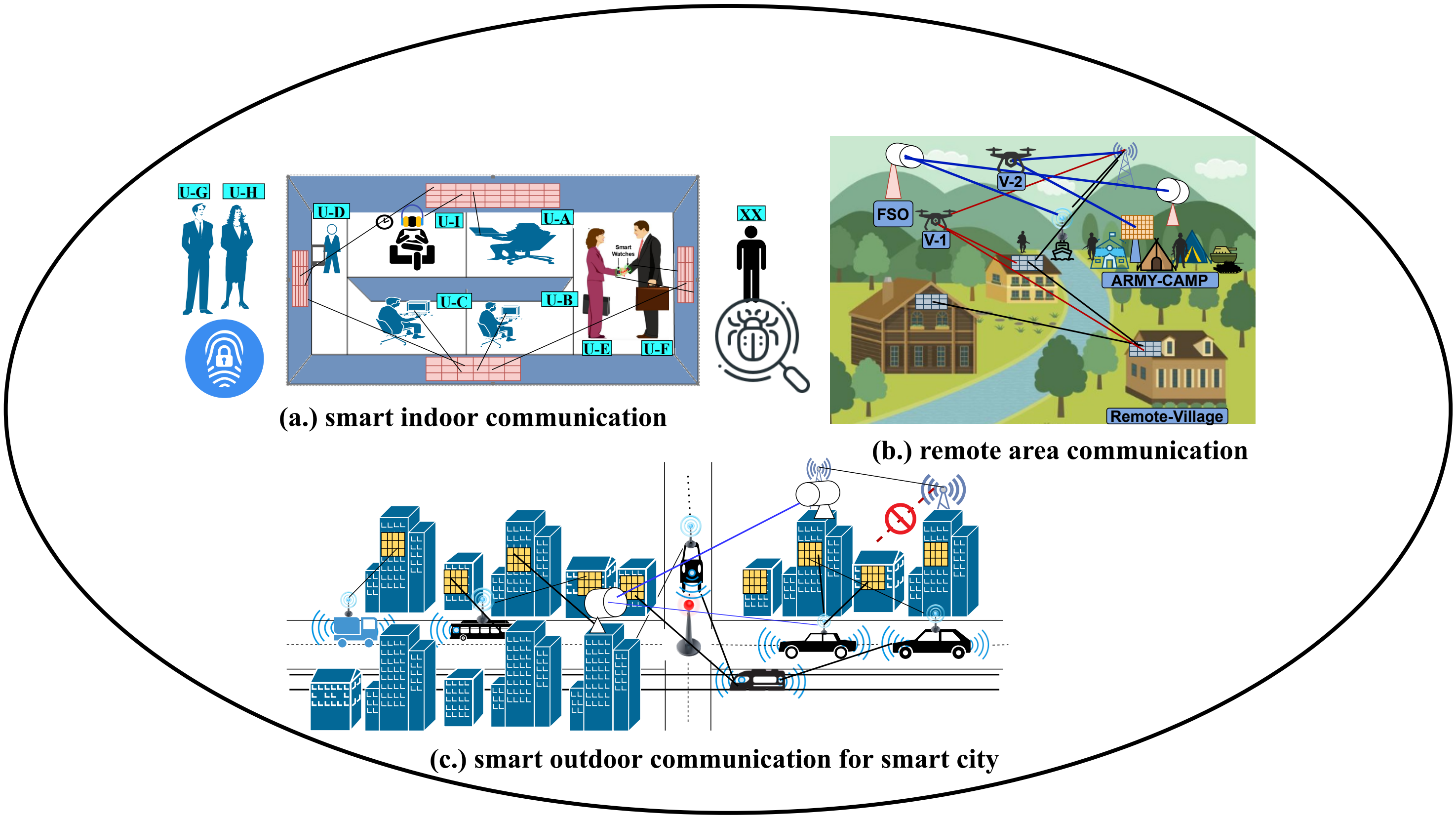

Fig. 1: Future infrastructure with supporting wireless technologies

acoustic waves are the different techniques that are used for the transmission of signals. Due to electromagnetic interference and attenuation, RF waves are suffered a lot and thus its range is limited for smaller distance communication [31]. Optical communication plays an important role in terms of data rate but it is limited by line of sight (LoS) communication between transmitter and receiver, for acoustic it offers the longest range among the three up to 20 km [32]. Wavelenth selection for optical link setting is one of the important measure [33].

C. Global Artificial Intelligence Environment

The complexity and the dynamic behavior which 6G offers, traditional network management methods will prove to be untenable. Intelligent network management is required to fulfill the demands. AI is becoming an integral part of 6G internet of things (IoT) due to the availability of massive actionable data and advances in computation capability. AI can make complex 6G networks more intelligent and enable network management, flexible network operation, proactive configuring, dynamic optimizing, self-healing, etc. [34], [35]. Over the years various machine learning algorithms have been deployed for intelligent resource allocation, network optimization, network design, etc. In a 6G network, AI can be integrated at various levels like network orchestration, signal processing, coding, and data mining [36]. AI-based networks learn from their environment and have the ability to adapt, make decisions and predict. Multilevel distributed AI can be deployed for global monitoring of 6G networks. AI can be deployed at various levels, global AI center can be deployed in the core network, local AI can be part of mobile edge computing (MEC) servers. Device can be incorporated on user equipment like smartphone [35].

D. Communication for Blind Zones

In the present infrastructure such as remote areas, hilly areas, country border, natural disaster areas, coastal terrain, etc. have limited connectivity or no connectivity. Locations which do not have wireless connectivity are considered to be blind zone. In these areas, it is very difficult to establish wireless connectivity infrastructure like base station (BS). In the blind zone areas, UAVs may be used as BS to serve wireless connectivity. Fig.1(b) depicted this scenario. Again to control these UAVs wireless connectivity is required or UAVs need to be fully auto-pilot. In the disaster management, the auto-pilot UAV can be served as a BS, when all other communication link get destroyed.

E. Hybrid Environment

Situations, where different type of objects with different characteristics are involved, considered as the hybrid environment. The characteristics may be their speed, location and their weight, for an example, in a city, some people in a static situation with a mobile phone, others are in a car with medium speed and some are in high-speed trains or other high-speed vehicles. The combination of all these is a hybrid in the sense of their speeds. Location-wise, the combination of road vehicles, air vehicles, and water vehicles, etc. makes a hybrid situation. There may be a huge number of situations where a hybrid type of scenario is involved. To serve these hybrid scenarios, traditional wireless technologies are not capable. For example in the case of hybrid mobility with static, medium, and high mobility vehicle, OFDM can not serve with the same performance to all since subcarriers orthogonality may lose for high mobility case which degrades the performance. So some new techniques must be evolved to serve hybrid scenarios with the same performance or desired performance.

F. Fast Delivery for Advance E-commerce and Postal Services

Electronic commerce or e-commerce denotes the online purchasing or selling of goods or articles. With the advent of $21st$ century, online ordering has conquered the market. The e-commerce companies like Amazon, Flipkart, Alibaba, Myntra, Nykaa, etc. have dominated the market. With the help of e-commerce, we get our desired items, at our doorstep by a single click. The only problem with these kinds of services is the long delivery times. Also during the pandemic time, the services were affected a lot due to the requirement of a delivery person to deliver the items of the order to door. Thus there is a need to reduce the time taken as well as human involvement in these kinds of delivery services to make them more useful and serviceable with no contact deliveries.

A solution can be the advancement in autonomous road vehicles and UAVs which can be used to deliver the consignments to the customer's door without any involvement of the delivery person and within a short span of time. Also, there is a need for change in the traditional postal system. Sometimes, we need some documents urgently, but the time taken by the normal postal system is very long, even the speed post services take several days to deliver the posts within the same city or state. In these situations, we always go for a fast delivery system which can deliver posts as soon as possible. UAVs may become a perfect match for these kinds of services. We can hope in future these kinds of services will boom and make our lives easier as well as save time. Again, to provide package delivery using UAVs or other self-driving vehicles, multiple challenges arise. These vehicles need to have accurate positioning and navigation. Furthermore, these must have very accurate object detection and avoidance algorithms. Seamless wireless connectivity is also a requirement for these delivery options.

G. Intelligent Surveillance

Using traditional closed-circuit television (CCTV) cameras and manual security personal it is not feasible to cover a large area and the probabilty to miss the anomaly is also high. AI-enabled advanced cameras for surveillance are emerging rapidly. These cameras along with the intelligent circuitry attached can detect anomaly by own and inform the corresponding authority. Along with prons challenging problems also arises. As these are fully automated cameras with intelligence attached, they need to have sophisticated algorithms for anomaly detection. Furthermore, to inform the corresponding authority of any mishap, these cameras must have accurate coordinates of the location. Areas, where security is a major issue like politicians, lecture gathering, government administrative blocks, etc. UAV with intelligent cameras are also coming into existence for surveillance. Wireless connectivity for live streaming from these high definition intelligent cameras is one of the most challenging tasks.

H. Massive IoT and IoE Environment

Massive IoT refers to applications that are less latency sensitive and have relatively low throughput requirements but require a huge volume of low-cost, low-energy consumption devices on a network with excellent coverage. There is a huge demand for IoT applications that rely on connectivity over wide areas and deploying a huge number of devices like wearable (e-health), asset tracking (logistics), smart city, environmental monitoring, and smart manufacturing. Issues with massive IoT include a large volume of devices, their presence over a wide area and management of these devices over their life cycle. Wireless standards capable of handling such a large number of devices deployed over a wide area and their effective monitoring and management is necessary.

IoE is an intelligent connection of people, processes, data, and things. IoE comprises communication between machine to machine (M2M), machine-to-people (M2P), and people-to-people (P2P) interactions. Humans can participate in this state of total connectivity, both as generators and consumers of data. One of the defining features of the IoT is that devices talk to other devices – but not necessarily to a human operator. IoE can cover everything, it can be everywhere along with intelligence. 5G may have launched the era of the IoT, but the IoE is not yet appeared until 6G.

III. Promising Solutions

A. Modulation Techniques

Till 3G, single carrier modulation techniques were used. MCM schemes like OFDM came into existence after 3G. With the advancement of technology, expectation of data rate increases which introduce frequency selective fading channel. MCM schemes are very useful to mitigate the effect of multipath. With the enhancement in the future infrastructure like vehicles with very high speed, self-driving vehicles, etc., existing MCM schemes are not sufficient to serve wireless connectivity. Due to high mobility, Doppler shift leads to frequency offset in OFDM subcarriers and degrades the overall performance of the system.

Orthogonal time frequency and space (OTFS) is emerging as alternative solution of OFDM for high mobility communication. OTFS works in delay-Doppler domain instead of time-frequency domain. In OTFS, signals are in 2D grid where one dimension denotes delay and other denotes Doppler. Basic block diagram of OTFS based tranceiver is shown in Fig.2. Channel estimation and other parameters estimation are easy for OTFS. A single pilot pulse surrounded by zeros is sufficient to estimate the channel very accurately. A total number of significant paths and their delay spread and Doppler shift may also be extracted easily. OTFS needs non-linear decoders for

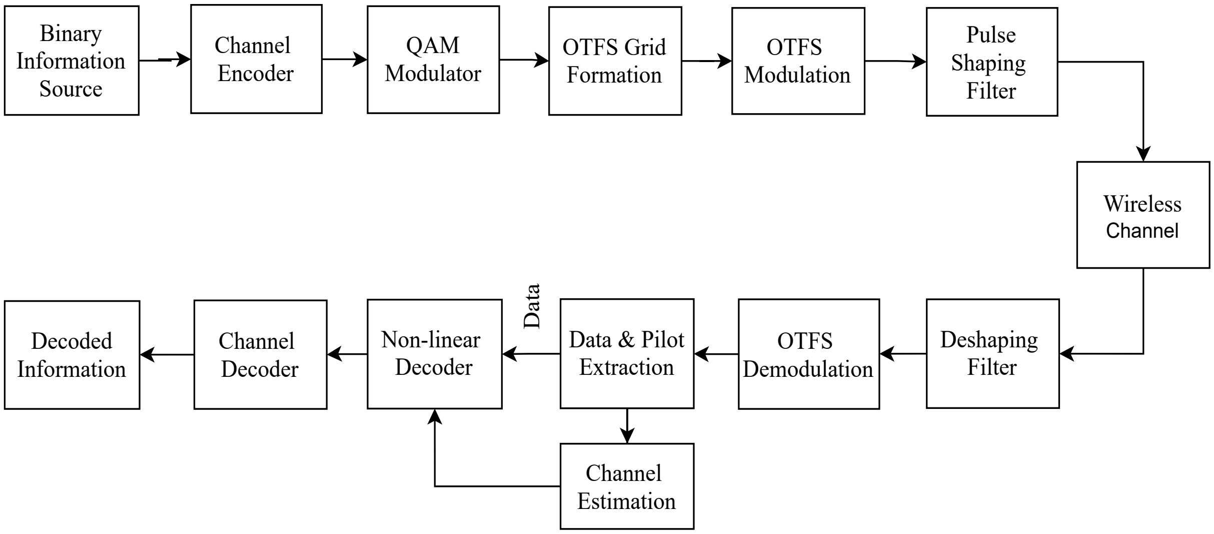

Fig. 2: OTFS Basic Transceiver Block Diagram

good performance. Generally, non-linear decoders are complex and have high convergence times. This leads to high system complexity and overall high latency. So along with multiple prons, some cons are also there using OTFS. Researchers are looking to minimize the complexity of non-linear decoders to be used for OTFS and also trying linear decoders to provide up-to-mark performance. Apart from that, one can think of deep learning-based decoders as well. The deep learning model can be learned using a high-performance non-linear decoder. Then non-linear decoder can be replaced by a deep-learning-based decoder. This will reduce the complexity and convergence times.

B. *Multiple Access Techniques*

Serving more than one user wirelessly is called multiple accessing in the wireless communication domain. TDMA, FDMA, CDMA, and OFDMA are the main traditional multiple access (MA) techniques. Resources like bandwidth, power, and time are limited. With the available resources, it is impossible to serve a large number of users using existing techniques. So to achieve future wireless connectivity goal to serve a huge number of users new MA techniques needs to be developed. Some new emerging MA techniques for future wireless communication are described below:

1) Non-Orthogonal Multiple Access: Non-orthogonal multiple access (NOMA) is getting attention to serve wireless connectivity for multiple users using the same resources. Resources like frequency band and time are the same for users only power level or code are different for users. So NOMA can be classified as power domain NOMA and code domain NOMA. With the limited available BW, traditional multiple accessing techniques are not capable to serve a large number of users. In the application of IoT, UAV communication networks and cell phone communication. huge number of users need connectivity. The allocation of power for users can be done on behalf of channel conditions and distance of the user from BS, Fig.3 illustrates the basic idea behind NOMA. Two users namely, near user (NU) and far user (FU) are a large distance

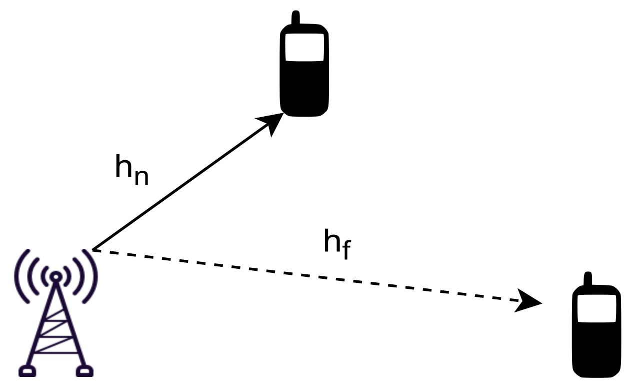

Fig. 3: Non-Orthogonal Multiple Access

apart from each other. BS assigns less power to the near user and high power to the far user as its signal needs to travel more distance. At the FU receiver the interference by NU signal is be negligible as its power allocated is very less and it travels a large distance. So FU information can be decoded directly without using any interference cancellation technique. Conversely, at NU an interference cancellation technique needs to be implemented to remove out interference by FU. It is very easy to allocate power for two users but when the number of users increases difficulties to allocate optimum power also becomes challenging. With the increase in number of users, the resolution to extract each user decreases. Power allocation strategy for large number of users is still an open problem. Similarly, for code domain NOMA for a large number of users, it is difficult to get orthogonal codes with good correlation properties.

2) OTFS-Multiple Access: OTFS is a very useful technique to serve high mobility communication. OTFS-multiple access (OTFS-MA) is a technique to serve multiple users with high mobility. Fig.4 illustrates the one basic way to serve multiple users using OTFS-MA, where k_p, k_v and k' are pilot, integer Doppler and fractional Doppler index respectively. l_p and l_T are pilot and maximum delay indexes respectively. Different arrangement of OTFS-MA is described in [37]–[40].

M-1	*	*	*	*	*	*	x	x	x	x	x
	*	*	*	*	*	*	x	x	x	x	x
k_p+2k_v+2k'	*	*	o	o	o	o	o	o	o	x	x
	*	*	o	o	o	o	o	o	o	x	x
k_P	*	*	o	P_1	o	P_2	o	P_3	o	x	x
	+	+	o	o	o	o	o	o	o	+	+
k_p-k_v-2k'	+	+	o	o	o	o	o	o	o	+	+
	+	+	+	+	+	+	+	+	+	+	+
0	+	+	+	+	+	+	+	+	+	+	+
	0		l_p-l_T	l_p		l_p+l_T+1		l_p+l_T+2			N-1

Fig. 4: OTFS-MA: (*: user1), (+: usre2), (x: user3), (o: zero pads), (Pi: Pilots impulse) .

3) Sparse Code Multiple Acces: Sparse code multiple acces (SCMA) is a non-orthogonal multiple access techniques, which is one of the promising techniques for future wireless communication. SCMA enhances the spectrum efficiency as it in non-orthonal in resourse sense. Generally, SCMA is considered as combination of CDMA and OFDMA [41]. Users are having different codes with same other resource blocks. Inter-user interference is very less in SCMA since it uses sparse codebook. SCMA is also being used with MIMO to get higher data rate, low inter-user interference and higher spectrum efficiency [42]. Message passing algorithm will converge faster for SCMA since it uses sparse codes [43]. OTFS-SCMA is also coming into lime-light as high speed vehicles also rapidly increasing [44].

C. Intelligent Reflecting Surface

Intelligent reflecting surface (IRS) is composed of a large number of scattering elements which are made up of metallic or dielectric particles. These elements are capable of transforming the incident EM-waves in various ways [45]. The thickness of each element is to less that it is considered a 2D surface. The response of the coming incident waves, i.e., either it can be reflected, absorbed or the amount of phase change and the strength of the reflected waves depends on the size, material, and the inter-cellular distance of the unit cells. The propagated EM-waves follow the Snell's law and Fresnel's equatios [46]. The size of each unit cell and their intercellular distance are generally half the wavelength or can be even smaller of the order of 5-10 times the wavelength [47]. All the elements are connected to each other with positive intrinsic negative (PIN) or varactor diodes (VD) to get the real-time reconfigurability of the IRS. The phase of the incident signals can be reconfigured by varying the bias voltage of the VD or switching the PIN diode on or off. Similarly, the amplitude of the reflected signals can be modified by changing the variable resistance of the unit cells . As in practice, we need an independent control over phase and amplitude the circuit must be integrated effectively. Typically the IRS is made up of three layers, the outer surface which consist of the meta-material units which interact with the incoming signals, then a metallic layer generally made of copper is used to avoid the leakage of the signal energy, and then a layer of control circuitry which is responsible for adjusting the phase and amplitude. In practice controllers like field programmable gate arrays (FPGAs) are used to act as gateways between other network elements like access providers (AP) or BS for data exchange. An schematic diagram of the IRS surface is shown in the Fig.5.

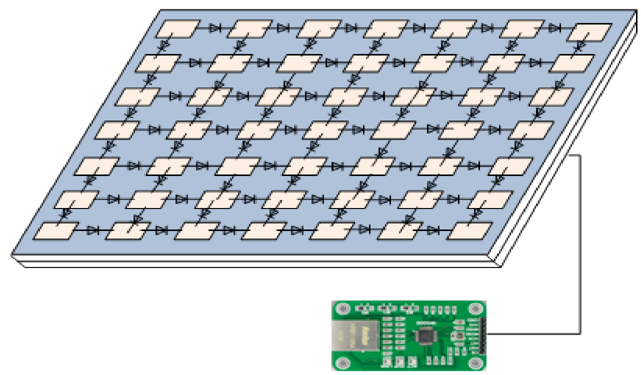

Fig. 5: Intelligent Reflecting Surfaces

In addition to this, IRS provides various attractive advantages from the implementation point of view. As IRS is made up of low-cost metamaterials and its structure is very thin and light in weight, it can be easily deployed or removed from any surface, buildings, walls, or ceilings. It is nearly passive in nature, i.e., no power amplification is required, no active components like amplifiers are used while signal processing which is the most power-consuming element. Very minimal power is used during the surface configuration by the switching elements used like diodes makes it unique. The minimal power requirement can be provided by energy harvesting methods. It also does not require any changes in the standards and hardware of the existing wireless communication system which makes it flexible and compatible with the traditional communication system. Few necessary modifications in the wireless data transmission protocol are sufficient. These qualities of IRS make it a unique and practical approach that can be used to integrate with the existing networks at a low cost.

1) How IRS is Different: When we talk about IRS, some related existing technologies like active-relay, MIMO-based large-scale active surfaces, etc. also come to our mind. The basic difference between relay and IRS is that IRS does not use active components like amplifiers but only integrates the incoming signals and beam-form towards the destination. Also, relay-aided communication functions in half duplex mode while IRS is capable of full duplex mode Communication [48]. In order to achieve a full duplex communication in relay-aided networks, it causes complexity, power consumption, self-interference, and a hike in price for installation while in contrast, IRS is secure, passive, noise-free, and cheap solution for the same. As relays simply amplify the incoming signals, the noise of the received signal also gets amplify, it is also more prone to error propagation while IRS is not. The passive nature of the IRS is the main reason which makes it different from MIMO-based large-scale active surfaces.

2) Emerging Possible Contributions of IRS: It is envisioned that an IRS-assisted network can revolutionize the way, concept, and structure of the current wireless communication system [49]. By using it we can be capable of controlling the path of data flow which is considered random in literature. It not only enhance the energy and spectrum efficiencies but also plays a major role in data security, power requirement and management. Some of the possible direction in which the IRS is going to play a major role is being discussed below:

- *Wireless Power Transmission*: IRS can be used for performance enhancement of the wireless networks. By smartly adjusting the phase of the incoming signals and adding the reflected signals costructively for passive beamforming it can provide SWIPT [50].
- *Cell Edge Communication*: Users at the cell edge get highly attenuated signals from their base station. Co-channel interference caused by the nearby BS is also very high at the edges of the cell. IRS is being considered to solve these problems by effectively designing the beamforming pattern at the cell edge.
- *Physical Layer Security*: IRS can be tuned to cancel or absorb the signals towards illegitimate users thus provide. a secure communication.
- *Solution for users in the Blind Zone*: If there is a user, who is unable to get LoS signals from the BS due to any obstacles or blockage, IRS can serve by creating a virtual LoS communication between the BS and the user.

Fig.1(a),(b) and (c) illustrate the IRS assisted indoor communication, IRS assisted remote area communication (including blind zones) and smart high mobilty outdoor communication respectively.

D. Index Modulation

Index modulation (IM) is a modulation technique in which either some physical resources of the communication system like, antenna, subcarrier, frequency carrier or virtual resources like, signal constellation, time-slot and space matrix are being activated to modulate the information bits. These indices information are embedded into the transmitted signals or the received signals. These indices carry additional information regarding the antenna activation order, subcarrier deactivation pattern, virtual parallel channel information, etc. but consume very little or no power. This feature, make it possible to achieve higher spectral and as well as energy efficiencies. IM like spatial modulation (SM) can be very beneficial to reduce inter-channel interference and to limit the inter-antenna synchronization (IAS) [51], [52]. Furthermore, deactivating certain subcarriers of OFDM for IM effectively reduces peak average power ratio and ICI problems. In general, IM can be categorized in the space domain, space-time domain, and frequency domain.

- *IM in Space Domain*: The concept of IM started with the SM which can be considered as the MIMO family but it has its unique characteristics. As compared to MIMO, SM only uses a single RF chain. As we know most of the power consumption in communication systems takes place in these kinds of RF chains consist of power amplifiers and other circuitry, thus SM provides energy efficiency. Also, some other examples of SM like quadrature spatial modulation (QSM), use one RF chain to transmit in-phase and quadrature components of the signal, activating a single or two antennas to transmit two independent bit-streams. Thus the index bits contribute to double the spectral efficiency [53]. The IM can be applied to both the transmitter side or the receiver side. Technique like pre-coding spatial modulation (PSM), it activates one receive antenna at a given time slot and provides added information through its index bits [54].
- *IM in Space-Time Domain*: IM utilizes space as well as time domain. Differential SM (DSM), trellis-coded SM (TCSM) and space-time block code SM (STBC-SM) come under this category. In SM, we need CSI at the transmitter and receiver side and as we use an ML detector for signal detection it suffers from high search complexities. A solution is to use STBC-SM which gives the joint advantage of SM and space-time coding [55]. Like SM, DSM information bits also consist of two parts. The first part includes the activation information of the antenna which is selected from the space-time matrix and the second part gives the modulated symbols. As compared to SM, it does not require CSI at the transmitter or receiver [56]. To improve the coding and diversity gain, gray coding is used for the activation pattern of the antenna [57].
- *IM in Frequency Domain*: IM in the frequency domain extends the concept of SM to the subcarriers of OFDM. In this modulation scheme, certain subcarriers of OFDM are activated or deactivated according to the subcarrier activation ratio. By doing so, we save spectrum, also these deactivated subcarriers or null subcarriers help us to transmit more information bits in the form of index bits. The selection of these deactivated sub-carriers is done using nature binary code [58] and combinatorial number theory [59]. OFDM-IM gives the maximum benefits when the subcarrier of each group experiences independent fading, which can be achieved by interleaved grouping. OFDM-IM can be proved very beneficial for high mobility vehicle communication [60], [61].

IM can play a significant role in the 5G technologies like massive MIMO, co-operative communication, etc. It can provide possible solutions for high mobility transportation like high-speed railways, UAVs and driverless vehicles. Though IM is a promising technique that is being used in 5G, but there are a lot of other open challenges which still need to be achieved. The various emerging scenarios like SWIPT, WPT, NOMA, and many more still need to be achieved using IM.

E. CFO and STO Estimation Techniques

To achieve the increasing demand of high data rate, we are shifting to advance techniques like OFDM, MIMO, MIMO-OFDM and OTFS. These techniques are very sensitive to synchronization parameters. These parameter consists of two major parts: CFO and STO [62], which leads to the ICI [63] and ISI respectively. Synchronization is one of the most important steps which has to be done at the receiver to enhance the performance of the systems.

CFO is caused by the frequency mismatching between the transmitter and receiver oscillators or Doppler shift due to the relative motion between the transmitter and receiver. Integral CFO (ICFO) and fractional CFO (FCFO) are the two components of the normalised CFO. A cyclic shift is caused by ICFO to the corresponding subcarrier on the receiver side [64], [65]. The orthogonality between the subcarriers is not destroyed by ICFO but destroyed by FCFO.

Estimation of CFO is necessary to preserve the orthogonality properties of the subcarrier and enhance the system performance. In general, estimation algorithms are classified into two categories: training symbol based estimation algorithm and blind estimation algorithm. In training symbol based estimation algorithm, some pilot symbols are used to estimate the CFO. The cyclic prefix (CP) based CFO estimation methods can only approximate the CFO within a certain range (less than or equal to 0.5) and cannot estimate ICFO. By reducing the difference between two blocks of samples for correlation, the range of CFO estimation can be increased. This is accomplished by employing training symbols that are repetitive over a span of time. Training symbol based algorithm uses pilot symbols for estimation which leads to loss in the spectrum efficiency. Traditional techniques for CFO and STO estimation are mentioned in Table I.

In 6G, blind/automated estimation methods are preferred to improve the spectrum efficiency and to provide intelligence to the communications. The blind estimation has equal importance in high speed communication systems where training sequence lose their correlation properties owing to a severe channel condition. Designing a blind wireless receiver (BWR) and blindly estimating from the undefined signal parameters is the most successful ways to overcome the bandwidth efficiency problem. The BWR is designed using sequential blind estimation algorithms, which include CFO estimation, STO estimation, symbol rate estimation (SRE), and modulation classification (MC). Various technologies like OFDM, MIMO-OFDM are extremely vulnerable to synchronization errors, which result in inter-symbol interference (ISI) and ICI [80], [81], and severely degrade the performance efficiency. Thus numerous blind estimators have attracted huge attention because wastage of spectrum is reduced by using the blind estimation. It not only improves the spectrum efficiency but also makes the transceiver adaptive and intelligent in the physical layer. In [82], the proposed BWR is reconstructed for estimating the parameter such as STO, CFO, SRE, and modulation mode without knowledge of transmitted signal for single carrier system. The authors investigated estimation of the SRE of BWR for quaternary phase-shift keying (QPSK) under different conditions. In [83], the efficiency of the sequential blind estimation method is demonstrated by measurement set-up and experimental validation of the proposed BWR. CFO estimation, SRE, STO estimation, and MC are all included in the proposed BWR.

The blind modulation classification also play an important role in adaptive transceiver system. In [84], [85] for different modulated signals such as binary phase shift keying (BPSK), QPSK, offset-QPSK (OQPSK), minimum shift keying (MSK), and 16-quadrature amolitude modulation (16-QAM), a new blind modulation classification (BMC) has been proposed for classifying the modulation format. The proposed approach is based on the combination of elementary cumulant (EC) and cyclic cumulant in combination. The output of the proposed method derived from the feature-based hierarchical hypothesis test is compared with maximum likelihood (ML) and EC methods and also implemented on a NI testbed. The measurement results are verified using simuation. In [86], blind MC for single and multiple antenna has been proposed for single and multiple antenna systems and measured it performance over frequency selective fading channel by including seven class of modulation format. The properties of the second-order correlation function, second-order cyclic cumulant, fourth-order correlation, and fourth-order cumulant are used in the proposed algorithm.

In [87], a blind STO estimation method is proposed for OQPSK. In this method, a collection of near and approximate offset is used to compensate the offset between the in-phase and quadrature components of the received OQPSK signal. In [88], [89], a BMC algorithm for linearly modulated signals of OFDM systems has been proposed. In [89], Using discrete Fourier transform (DFT) and normalised fourth order cumulant, a blind MC algorithm for linearly modulated signals of OFDM systems has been proposed and implemented on a NI testbed setup. The proposed MC algorithm operates in the presence of synchronization errors, such as frequency, timing, and phase offsets, and without knowing the signal parameters or channel statistics beforehand. After implementing uniformly distributed random timing offsets in each of the OFDM symbols, a statistical average was taken over OFDM symbols to nullify the effect of timing offset in the feature extraction process. In [90], a deep neural network (DNN) is proposed to estimate symbol rate without having any knowledge of CSI for a single carrier system over frequency selective fading channel. The normalised mean square error (NMSE) measures the performance of the SRE.

In [91], a blind synchronization algorithm is proposed to estimate the CFO and STO for SC-FDMA. The parameters are calculated using the correlation attribute of the samples of the obtained signal. Over the entire delay spread of the fading channel, the Cramer-Rao lower bound (CRLB) of the CFO estimator has been derived. In [92], authors estimated CFO with the help of CFO incorporated frequency domain received signals. Over frequency-selective fading channels, a blind CFO estimator for an orthogonal space-time block coding (OSTBC) MIMO-OFDM system with a constant modulus constellation has been proposed. Under the assumption of a slowly varying channel, a cost function was formulated using

TABLE I: List of Various Method for Parameter Estimation

Category	Method	Parameter estimation	Reference
Training symbol based	Extension of Schmidl & Cox method only one training symbol is used	Frequency offset estimation	[66]
Training symbol based	Scattered pilots-based algorithm	Integral and fractional CFO estimation	[67]
Training symbol based	-	CFO estimation	[68]
Training symbol based	Maximum likelihood algorithm	CFO estimation	[69]
Training symbol based	Cramer rao lower bound based	STO estimation	[70]
Training symbol based	-	Timing offset	[71]
Training symbol based	Constant amplitude zaro autocorrelation sequence with PN as weighted factor	Frequency and timing offset	[72]
Semi blind based	Subspace based algorithm	Frequency offset	[73]
Semi blind based	-	channel and CFO estimation	[74]
Blind algorithm	Maximum likelihood estimation of time and carrierfrequency offsets	Frequency and time offset	[75]
Blind algorithm	Based on over sampling	CFO estimation	[76]
Blind algorithm	Music algorithm	Integral and fractional CFO estimation	[77]
Blind algorithm	Cyclic prefix based algorithm	CFO estimation	[78]
Blind algorithm	Covariance power fitting criterion and phase information algorithm	Frequency offset	[79]

frequency domain sum and difference signals. In [93], an oversampling-based blind CFOs estimation algorithm for single carrier-FDMA (SC-FDMA) uplink systems in the presence of frequency selective fading channels. CFO is estimated by formulating the cost function which minimizes the strength of the off-diagonal elements of a signal covariance matrix. In [94], the authors proposed a blind multiple CFOs estimation method for all carrier mapping scheme (CMS) of SC-FDMA and implement on a testbed. The proposed method needs only one SC-FDMA symbol to achieve accurate estimation even in a high mobility environment, such as a double selective fading channel. It estimates CFOs by using the phase difference between even and odd samples of the obtained oversampled signal.

F. Wireless Power Transfer Techniques

Transfer of power without any physical link between a power source and load is known as WPT [95], [96]. This technology has many wide range applications from low power toothbrushes to high power applications such as fuel-free EV, airplanes, and rockets. Many leading smartphone manufacturers are giving a built-in wireless charging capability. As shown in Fig.6, WPT technology is classified into two

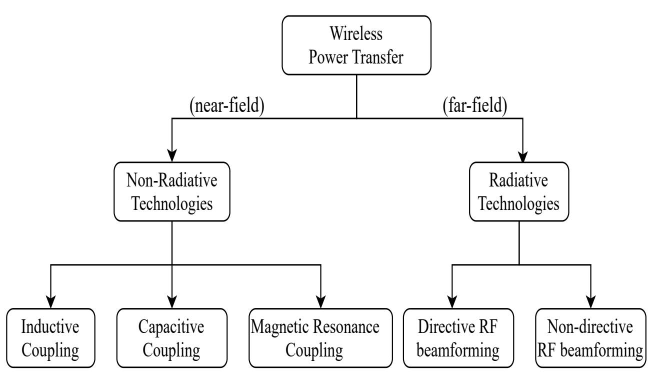

Fig. 6: Classification of Wireless Power Transfer Technologies

broad categories, i.e., non-radiative coupling-based charging (near-field charging) and radiative RF-based charging (far-field charging). The first category consists of three techniques, as inductive coupling [97], capacitive coupling [98] and magnetic resonance coupling [99], and the second category is divided into two techniques, i.e., directive RF beamforming and non-directive RF beamforming [100]. The achievable amount of coupling capacitance in capacitive coupling is dependent on the available area of the system. However, it is difficult to produce enough power density for charging for a typical-size portable electronic device, which imposes a daunting design constraint. As with the RF power beamforming directive, the restriction lies in the need for the charger to know the exact position of the energy receiver. Table II shows the comparison among different WPT techniques. The gain, the drawback, and the efficient charging distance are summarized in the tavle. The major applications of near-field charging are induction generator [116], induction motor [117], [118], automated underwater [119], [120], roadway powered electric vehicle [121], wireless powered sensors [122], wearable device [123], [124], implantable system [125], and power line communication [126]. Daily use of household devices such as inductive toothbrushes, TV, lighting is the application of near-field charging. The most widely adopted application of far-field charging is in low-power wireless systems like radio frequency identification (RFID) [127] and wireless rechargeable sensor networks (WRSNs) [128]. These rechargeable sensors are used in other applications or we can say other environments like wireless body area networks (WBANs) [129], [130] for health monitoring. RF powered sensors has been used in M2M communication systems [131], IoT [132] , smart city system [133], [134] etc.

G. Energy Harvesting Techniques

We know that 6G is moving towards the battery-less device and these devices can be remotely and intelligently powered by the network itself by using energy harvesting technology. One of the most creative innovations in 6G would be wireless information energy transfer (WIET) in communication. By using wireless power transfer during communication, sensors

TABLE II: Comparison of Wireless Power Transfer Techniques

Wireless power transfer technique	Advantage	Disadvantage	Distance	Multicasting
Inductive coupling [101]–[103]	Safe for human, simple implementation, high power efficiency in centimeter range	Short charging distance, needs strong connection between charger and charging device, produce more heating, not applicable for mobile application	Few mm to few cm	No
Capacitive coupling [104]–[107]	Simple structure, low standing power loss, achieve high power efficiency within several cm range	Need large coupling area, not suitable for portable electronic device(due to small coupling capacitance)	Up to several cm	No
Magnetic resonance [108]–[111] coupling	Non-line-of-sight charging	Implementation complex, not applicable for mobile application, charge some limited distance	Few cm to several m	Yes
RF radiation [112]–[115]	Suitable for mobile application, charging is possible up to many km	Line-of-sight charging, dangerous when RF exposure is high, applicable for mobile device	Up to several km	Yes

and smartphones are charged. WIET is a promising technology to prolong the lifespan of wireless battery-charging systems. Therefore, on 6G connections, devices without batteries will be enabled. Also, near-field clothing offers the ability for continuous physiological tracking in the medical sector with battery-free sensors. There are many ways to harvest energy from external sources [135].

There are two protocols generally used in WPT one is SWIPT and harvest-then-transmit protocol. In SWIPT both wireless power and information can be transmitted simultaneously in one packet, i.e., sensor nodes use the wireless power to transmit the information to another node. However in harvest-then-transmit protocol mode, first harvest the energy from the power transmitter and then further use this power to transmit the information bits to the other information receiver node.

In the 6G era, the most important technology, IoT needs rechargeable wireless sensor networks. For these networks, several open research issues are addressed in this energy harvesting [136], [137]:

- *Energy Storage*: The main objective of energy harvesting is to replace storage with a harvested energy from the ambient environment. Energy harvesters have become an important research area as they can harvest energy from different sources to power the sensor nodes. These harvesters overcome the energy storage in wireless sensor networks.
- *Power Management*: The harvested energy is properly routed to the sensor nodes. This requires proper routing protocols and energy-efficient prediction algorithms.
- *Simulation Environment*: There is no existing simulation environment that can evaluate energy harvesting systems.
- *Energy-Efficient Reliable Systems*: The sensor nodes have to be chosen to minimize energy consumption and size of the system. Thus, miniaturization becomes an open research area.
- *Channel Capacity*: The energy harvesting channel capacity for finite battery capacity is an open research challenge.
- *Multiple Antenna Techniques*: The use of multiple antennas in energy harvesting systems is a new research issue and provides various energy optimization problems.
- *Security*: Signal security becomes the most challenging issue while transmission and reception.
- *Conversion Efficiency*: The power conversion efficiency of an energy harvester and the overall system is always an issue of interest.

Therefore, energy harvesting itself is a great effort to address energy constraints in wireless networks. By properly addressing the above issues, energy-efficient and reliable wireless network systems can be designed for future communications.

H. Positioning and Navigation Techniques

GPS is the most popular positioning and navigation technique. GPS availability is not possible at every location due to a limited number of satellites, i.e., limited coverage area. By including most of the positioning systems like GPS, GLONASS, Galileo, Beidou, and other regional systems, a system called global navigation sattelite system (GNSS) is developed. Details of each navigation system are provided in Table. III. The coverage of GNSS is much wider than GPS alone and accuracy is also high. Still these sattelite based navigation systems combinely are not capabale to provide naviagtion at each and every location. So researchers are working towards new emerging navigation techniques for higher accuracy and wide coverage area. Some of emerging navigation techniques are as follow:

TABLE III: List of Country-wise navigation system

Navigation System	Associated Country	Operational Sattelites
GPS	United States	30
GLONASS	Russia	24
BeiDou	China	28
Galileo	European union	24
NavIC	India	7
QZSS	Japan	4

1) Real Time Kinematics based Postioning: GPS or GNSS alone is not capable to provide centimeter accuracy which is required in current and future applications. Integration of real time kinematics (RTK) with GPS or GNSS can provide highly accurate positioning and navigation. In [138], the author has discussed RTK based positioning for UAVs. GPS and RTK based android application for precise geotagging is proposed in [139]. RTK-GNSS based navigation performance for different landscapes is described in [140]. Precise positioning is required in advanced applications like robotic manufacturing, IoT applications, etc. A study on RTK-GPS based positioning for an indoor environment is done in [141]. RTK based positioning is highly expensive and requires GPS or GNSS as its basic reference to improve accuracy. In situations where any satellite signal of GNSS is not available or degraded its challenging to navigate or position the object. Researchers are working toward making RTK a cost-effective technique and improving its accuracy further in diverse situations.

2) GPS denied Positioning and Navigation: There are several situation when GPS/GNSS signal is not available. These are called GPS denied environment. New positioning and navigation techniques need to be develop which do not require GPS or GNSS signal. Some important work of literature are described in Table.IV.

IV. Summary

Advanced infrastructure in different sectors like transportation, surveillance, and package delivery, etc. are discussed in this review article. UAVs, EVs, and high-speed trains are futuristic transportation options, a brief overview is provided for these. Use cases of UAVs are discussed for multiple applications. Significant wireless connectivity challenges for these advanced infrastructures are also discussed. Challenges to achieving seamless connectivity at every location, to serve a huge number of mobile users, communication for very high mobility vehicles, wireless connectivity for hybrid scenarios, accurate positioning, and navigation are discussed in detail. The promising solutions to overcome these challenges are also addressed. OTFS as a new modulation technique, NOMA to serve multiple users by using the same resources, and other techniques are discussed in detail. The beauty of blind parameter estimation techniques for different modulation is discussed and the enhancement in spectrum efficiency using these techniques is also detailed. We tried to convey the concept of all the techniques in the easiest possible way. We showed pictorial representation and tabular representation whenever possible to make this article precise and easy to understand.

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TABLE IV: Different emerging techniques for positioning in GPS/GNSS denied environment

Method Used	Location	**Sensors Used**	**Reference**
Single camera and Lidar based	Indoor and Outdoor	Camera, LiDAR,IMU, barometer and wheel odometer	[142]
Nonlinear Autoregressive Exogenous(NARX)	Indoor and Outdoor	IMU	[143]
adaptive continuum shape constraint analysis (ACSCA)	Indoor and Outdoor	NA	[144]
Pose estimation based on laser range finder	Indoor and Outdoor	miniature attitude heading reference system (AHRS) unit	[145]
Cooperatively Applied Positioning Techniques Utilizing Range Extension	Indoor	Bluetooth radios on mobile devices	[146]
Direction-of-Arrival Measurements based	Indoor and Outdoor	flight data and MLE	[147]
Fusion Positioning Strategyr	Indoor and Outdoor	microelectromechanical-based IMU, sliding-mode observer (SMO), federated Kalman filter (FKF)	[148]
IEEE 802.11p-Based Cooperative Positioning	Indoor	Bayesian filters	[148]
FAST detection and optical flow	Indoo and Outdoorr	Optical camera, IMU	[149]

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