Signals and Communication Technology

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Antenna Systems for Modern Wireless Devices

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To baby Norah Koul

—Shiban K. Koul

To readers of the book

—S. Swapna

To the eternal friendship with Priyanka K C

—G. S. Karthikeya

Preface

Ever since the discovery of radio waves by Hertz in 1886, wireless communication technologies have continuously evolved. The expansion is so remarkable that today wireless technology touches every aspect of our lives. Wireless Local Area Network (WLAN) is a disruptive technology that is replacing most of the wired LANs and wired WANs. WLAN technology is based on the IEEE 802.11 standard which is continually expanding and evolving to support higher throughput capabilities, low-latency, enhanced positioning and location capabilities, and vehicle-to-vehicle capabilities. Personal workspaces are getting transformed to wireless through Wireless Personal Area Network (WPAN). WPAN enables adhoc connectivity among portable communication devices at a short range. A vital component in the wireless communication technology is the antenna integrated with the transceivers. Highly efficient antennas are essential to maintain and improve the signal quality. Consequently, antenna designs for WLAN are also going through lot of innovation with different functionalities incorporated into state-of-the-art antenna designs.

This book is aimed not only to describe up-to-date WLAN antenna designs, but also to provide enough information to anyone who wants to design a WLAN antenna or a radiating system to be deployed for practical coverage. The book primarily focuses on pattern diversity antennas. Pattern diversity antennas are very vital in wireless communication. High correlation between multiple signals can result in low data throughput which can be solved by using antennas with pattern diversity. Beam scanning antennas and their different types are also described in detail. Pattern diversity antenna systems with multiport feeds are also comprehensively discussed in this book. For a multiport system to maintain a reasonable link budget, equal antenna gains are preferred for the required antenna coverage. The book further describes latest techniques to enhance and equalize the antenna gain within a compact radiating system. With increasing demand for faster connectivity with minimum path loss, the demand for high-gain antennas is rapidly increasing. Detailed discussion on gain enhancement with latest high-gain antenna designs is required while describing WLAN antennas. Some antenna designs discussed in the book use additive manufacturing for their design and fabrication. Additive manufacturing is a much sought-after technology today that allows rapid development of antennas at an affordable cost.

Recently reported WLAN antennas make use of this technology to develop versatile antenna designs. Finally, the book includes a section on wideband antenna designs. Antenna designs that reduce the scanning loss are also illustrated towards the end of the book.

As mentioned, this book delves into the world of WLAN, exploring its working principle, its evolution, and its potential to shape the future. Chapter 1 lays the foundation by introducing the fundamental concepts of WLANs, laying the groundwork for deeper exploration. Chapter 2 discusses the fascinating realm of pattern diversity antennas, showcasing how they enhance signal quality and combat fading. Delving into the topic of beam steering, Chap. 3 unveils the capabilities of electronic beam scanning antennas, capable of directing signals with precision. Beyond electronic scanning, Chap. 4 explores diverse beam scanning methods, including mechanical approaches and using innovative methods such as using metasurfaces. Chapter 5 tackles the challenge of achieving wide-angle beam scanning, expanding coverage possibilities for WLANs. To maximize signal strength and reach, Chap. 6 delves into various antenna gain enhancement techniques, utilizing metamaterials and sophisticated cavity designs. Chapter 7 builds upon this foundation, for enhancing gain and equalizing signals in WLAN antennas, leading to more robust communication. Chapter 8 presents the exciting potential of multiport antennas, enabling the creation of multiple data streams and catering to multiple users simultaneously. Finally, Chap. 9 explains the transformative power of 3D printing, revealing its potential to revolutionize antenna design with customized and intricate solutions.

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Contents

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He has successfully completed 38 major sponsored projects, 52 consultancy projects, and 61 technology development projects. He has authored/co-authored 615 research papers, 23 state-of-the art books, four book chapters, and two e-books. He holds 26 patents, six copyrights, and one trademark. He has guided 30 Ph.D. theses and more than 120 master's theses.

He is a Life Fellow of IEEE, Fellow of INAE and IETE, and Honorary Fellow of BES. He is the Chief Editor of *IETE Journal of Research* and Associate Editor of the *International Journal of Microwave and Wireless Technologies*, Cambridge University Press. From 2012 to 2014, he served as Distinguished Microwave Lecturer (DML) for IEEE MTT-S. Previously, he served as Speaker Bureau Lecturer for IEEE MTT-S. In addition to serving as an AdCom member of the IEEE MTT Society from 2010 to 2018, he is currently a member of the society's Awards, Nominations and Appointments and Education Committees. Prior to this, he served for over a decade as regional coordinator for R-10. He has recently been selected as the Distinguished Lecturer (DL) of the IEEE EMC Society for 2 years (2024–2025).

He is recipient of numerous awards including Institution of Engineers Kolkata Gold Medal (1977), Indian National Science Academy (INSA) Young Scientist Award (1986); Top Invention Award (1991) of the National Research Development Council (NRDC) for his contributions to the indigenous development of ferrite phase shifter technology; VASVIK Award (1994) for the development of Ka-band components and phase shifters; Ram Lal Wadhwa Gold Medal (1995) from IETE; Academic Excellence Award (1998) from Indian Government for his pioneering contributions to phase control module development for Rajendra Radar; Shri Om Prakash Bhasin Award (2009) in the field of Electronics and Information Technology; VASVIK Award (2012) for the contributions made to the area of Information, communication Technology (ICT); Teaching Excellence Award (2012) from IIT Delhi; Award for contributions made to the growth of smart materials technology (2012) by Institute of Smart Materials and Systems(ISSS) Bangalore; MN Saha Memorial Award (2013) from IETE, IEEE MTT Society Distinguished Educator Award (2014), Lifetime Achievement Award (2023) from the IETE, India; and Lifetime Achievement Award (2024) from the Broadcast Engineering Society (BES), India . His name has recently been included in the "Year 2021" category of Scopus Elsevier, recognising him as one of the top 2% of scientists.

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Abbreviations

0G	Zeroth Generation
1D	One-Dimensional
1G	First Generation
2D	Two-Dimensional
2G	Second Generation
2.5G	2.5 Generation
3D	Three-Dimensional
3G	Third Generation
3GPP	3G technology under Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation
ABS	Acrylonitrile Butadiene Styrene
ADS	Antenna Decoupling Surface
AFR	Array Feeding Region
AFSS	Active Frequency-Selective Surfaces
AM	Additive Manufacturing
AMC	Artificial Magnetic Conductors
AMPS	Advanced Mobile Phone System
AMS	Anisotropic Metasurface
AMTS	Advanced Mobile Telephone System
AoA	Angle of Arrival
AP	Access Point
AR	Augmented Reality
AT&T	American Telephone and Telegraph
ATSA	Antipodal Tapered Slot Antenna
AZIM	Anisotropic Zero-Index Metamaterials
BCR	Beam Coverage Range
BJ	Binder Jetting
BOM	Bill of Materials
BSS	Basic Service Set

BST	Barium Strontium Titanate
CBSA	Cavity-Backed Slot Antenna
CCK	Complementary Code Keying
CCLR	Cross-Circular Loop Resonator
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CMS	Cylindrical MS
CNC	Computer Numerical Control
COTS	Commercial Off-The-Shelf
CP	Circular Polarization
CPFRA	Circularly Polarized Folded Reflectarray Antenna
CPW	Coplanar Waveguide
CPWG	Coplanar Waveguide Ground
CRLH TL	Composite Right/Left-Handed Transmission Lines
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSIW	Corrugated Substrate-Integrated Waveguide
CSRR	Complementary Split-Ring Resonator
CTE	Coefficient of Thermal Expansion
DED	Directed Energy Deposition
DFS	Dynamic Frequency Selection
DL	Dielectric Lens
DMLS	Direct Metal Laser Sintering
DNG	Double-Negative Materials
DoS	Denial of Service
DP-CTS	Dual-Polarized Continuous Transverse Stub
DQDB	Distributed-Queue Dual-Bus
DS	Distribution System
DSS	Distribution System Service
DSSS	Direct Sequence Spread Spectrum
EBG	Electromagnetic Bandgap
EBM	Electron Beam Melting
ECC	Envelope Correlation Coefficient
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
EM	Electromagnetic
EMBB	Enhanced Mobile Broadband
ENG	Epsilon Negative
ENZ	Epsilon-Near-Zero
ERO	European Radiocommunications Office
ESS	Extended Service Set
ETSI	European Telecommunications Standards Institute
F/D	Focal-to-Diameter Ratio
FBR	Front-to-Back Ratio
FCC	Federal Communications Commission

FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication
FHSS	Frequency Hopping Spread Spectrum
FPC	Fabry–Perot Cavity
FPGA	Field Programmable Gate Array
FR2	Frequency Range 2
FRP	Flat Risley Prism
FSA	Frequency Scanning Antennas
FSS	Frequency-Selective Surface
GPR	Ground-Penetrating Radar
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRIN	Gradient Index
GSM	Global System for Mobile Communications
HART	Highway Addressable Remote Transducer
HDICP-CVD	High-Density Inductively Coupled Plasma Chemical Vapor Deposition
HIPERLAN	High-Performance Radio LAN
HPBW	Half-Power Beamwidth
HPRS	Hybrid Partially Reflecting Surface
HRI	High Refractive Index
HS	Hybrid Surface
HSDPA	High-Speed Downlink Packet Access
HSR	H-Shaped Resonator
HSUPA	High-Speed Uplink Packet Access
HWMP	Hybrid Wireless Mesh Protocol
IBSS	Independent BSS
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
IFA	Inverted-F Antenna
ILA	Integrated Lens Antennas
IMS	Impedance Modulation Surface
IMT 2000	International Mobile Telephone 2000
IMTS	Improved Mobile Telephone Service
IoNT	Internet of Nano Things
IP	Internet Protocol
IRS	Intelligent Reflecting Surface
IS-95	Interim Standard 95
ISLAN	Integrated Services LAN
ISM	Industrial, Scientific, and Medical
ITS	Intelligent Transportation Systems
ITU	International Telecommunication Union
LAN	Local Area Network
LC	Liquid Crystals
LCD	Liquid Crystal Display

LCRA	Liquid-Crystal Reflect Array
LEO	Low Earth Orbit
LHCP	Left-Hand Circular Polarization
LHMs	Left-Handed Materials
LIMs	Low-Index Materials
LLC	Logical Link Control
LMSC	LAN/MAN Standards Committee
LNA	Low-Noise Amplifier
LO	Local Oscillator
LOS	Line-of-Sight
LPWAN	Low-Power Wide Area Network
LSAP	Link Service Access Point
LTCC	Low-Temperature Co-fired Ceramic
LTE	Long-Term Evolution
LWA	Leaky-Wave Antenna
MAC	Medium Access Control
MBSA	Mechanical Beam Steering Array
MDCM	Metal-Dielectric Composite Metasurfaces
MEMS	Micro-Electro-Mechanical Systems
MEO	Medium Earth Orbit
MIMO	Multiple Input Multiple Output
MJ	Material Jetting
ML	Machine Learning
MMIC	Monolithic Microwave Integrated Circuit
MMS	Multimedia Messaging Service
MMTC	Massive Machine Type Communication
MNG	Mu-Negative
MNZ	Mu-Near-Zero
MPA	Microstrip Patch Antenna
MRC	Maximum Ratio Combining
MSAP	MAC Service Access point
MTM	Metamaterial
MTS	Mobile Telephone System
MUSA	Multiple-Unit Steerable Antenna
NFC	Near-Field Communication
NFMS	Near-Field Metasteering
NMT	Nordic Mobile Telephone
NPJ	Nanoparticle Jetting
NRI	Negative Refractive Index
NRI-TL	Refractive Index Transmission Line
NTT	Nippon Telephone and Telegraph
NZIM	Near Zero-Index Materials
OFDM	Orthogonal Frequency Division Multiplexing
OMT	Orthogonal-Mode Transducer
ORC	Orthogonal Radiating Choke

OSB	Open-stop Band
OSI	Open Systems Interconnection
P2MP	Point-to-Multipoint
P2P	Point-to-Point
PA	Power Amplifier
PAA	Phased-Array Antennas
PC	Polycarbonate
PDC	Personal Digital Cellular Telecommunication System
PEC	Perfect Electric Conductor
PECVD	Plasma Enhanced Chemical Vapor Deposition
PhSAP	Physical Service Access Point
PHY	Physical Specification
PIFA	Planar Inverted-F Antenna
PLA	Polylactic Acid
PLPDA	Printed Log-Periodic Dipole Array Antenna
PLYDA	Printed Log-Yagi Dipole Array Antenna
PMC	Perfect Magnetic Conductor
PMM	Phase Matching Method
PPW	Parallel-Plate Waveguide
PR	Polarization Rotator
PRS	Partially Reflecting Surface
PS	Portable Stations
PSS	Phase-Shifting Surface
PTT	Push to Talk
QoS	Quality of Service
RA	Reflect Array
RCA	Resonant Cavity Antenna
RF	Radio Frequency
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
RHCP	Right-Hand Circular Polarization
RP	Rapid Prototyping
RPA	Risley-Prism Antenna
RS	Reflective Surface
RSN	Robust Security Network
SATCOM	Satellite Communication
SFF	Solid-Freeform
SIW	Substrate-Integrated Waveguide
SIW-SA	Substrate-Integrated Waveguide Fed-Slot Antenna
SLA	Stereolithography
SLL	Sidelobe Level
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
SMS	Short Message Service
SNIR	Signal-to-Noise Plus Interference Ratio

SNR	Signal-to-Noise Ratio
SPDT	Single-Pole Double-Throw
SRR	Split-Ring Resonator
SS	Station Service
SSPP	Spoof Surface Plasmon Polariton
STA	Stations
SW	Surface Waves
SWL	Surface-Wave Launchers
TA	Transmit Array
TACS	Total Access Communications Systems
TDMA	Time Division Multiple Access
TE	Transverse Electric
TM	Transverse Magnetic
TPC	Transmit Power Control
TRAI	Telecom Regulatory Authority of India
UAV	Unmanned Aerial Vehicle
UC	Unit Cell
UHF	Ultra-High Frequency
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra Reliable Low Latency Communications
UV	Ultraviolet
UWB	Ultra-Wideband
VGA	Variable Gain Amplifier
VICTS	Variable Inclination Continuous Transverse Stub
VLE	Very Large Epsilon
VLF	Very Low Frequency
VoIP	Voice Over Internet Protocol
VP	Vertically Polarized
VR	Virtual Reality
VSRR	Vertical Split-Ring Resonator
WABS	Wide-Angle Beam Scanning
WAIM	Wide-Angle Impedance Matching
WAP	Wireless Application Protocol
WCDMA	Wideband Code Division Multiple Access
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan-Area Network
WPA	Wi-Fi Protected Access
WPAN	Wireless Personal-Area Network
WPT	Wireless Power Transfer
WWAN	Wireless Wide-Area Network
XR	Extended Reality
ZIM	Zero-Index Material

Chapter 1
Introduction to Wireless Local Area Network

1.1 Introduction

We are in an era where everyone and everything is interconnected. Along with people using wireless networks to talk to one another, all possible electronic devices also talk to one another. The traditional wired networks are now becoming more and more obsolete with the onset of wireless networks. If users must be connected to a network by physical cables, their movement would be dramatically limited, which is inconceivable in today's fast-paced life. Wireless connectivity, however, poses no such restriction and allows a great deal of free movement on the part of the user. There are many benefits to wireless communication like lower maintenance costs, more flexibility, and better adaptability for challenging remote environments like isolated deserts and steep valleys where wired networks cannot be installed [1]. As a result, wireless technologies are becoming ubiquitous, replacing wired networks. The use of Wireless Local Area Network (WLAN) systems is rapidly growing in the communications industry. A WLAN enables devices to connect and communicate based on radio transmission rather than wired connections. WLANs transmit data using high-frequency radio waves and often include an access point to the Internet.

1.1.1 Radio Spectrum: A Key Resource of Wireless Networks

Audio frequencies extend from 3 to 20 kHz in the very low-frequency (VLF) band, whereas radio frequency (RF) occupies a very wide range of spectrum (20 kHz–300 GHz). Depending on the nature and requirement of the application, suitable RF frequency can be selected [2].

The spectrum is divided into different frequency bands as shown in Fig. 1.1 and each band has a specific application. This spectrum would be typically allocated to companies or organizations depending on the state policies. For most countries,

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the RF (Radio Frequency) spectrum is a national resource, like water, land, gas, and minerals [3]. The use of radio spectrum is rigorously controlled by regulatory authorities through licensing processes. In the USA, regulation is done by the Federal Communications Commission (FCC). European allocation is performed by the European Radiocommunications Office (ERO) of the European Conference of Postal and Telecommunications Administrations (CEPT). In India, the spectrum allocation is performed by the Telecom Regulatory Authority of India (TRAI). Different national bodies are coordinated by an international body, the International Telecommunication Union (ITU) for the purpose of standardization of global telecommunications. Table 1.1 lists some common frequency bands used.

In this book, the focus is more on the Industrial Scientific and Medical (ISM) bands as these are popular for numerous commercial applications. ISM bands are

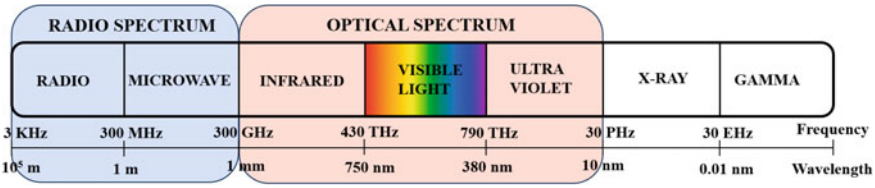

Fig. 1.1 Electromagnetic spectrum

Table 1.1 Common frequency bands [4]

Band	Frequency range	Typical applications
HF	3–30 MHz	Short wave broadcasting
VHF	30–300 MHz	Mobile radio communication
UHF	300–1000 MHz	TV broadcasting
UHF ISM	902–928 MHz	GSM
L	1–2 GHz	GPS
S	2–4 GHz	4G LTE
S Band ISM	2.4–2.5 GHz	Wi-Fi/Bluetooth
C	4–8 GHz	Satellite communication
C Band ISM	5.725–5.875 GHz	Wi-Fi
X	8–12 GHz	Defense
Ku	12–18 GHz	Satellite communication
K	18–26.5 GHz	Satellite communication
Ka	26.5–40 GHz	5G (FR2)
Q	32–50 GHz	Radio astronomy
U	40–60 GHz	Band currently unused
V	50–75 GHz	Millimeter wave radar
W	75–100 GHz	Military radar

set aside for equipment related to industrial, scientific, or medical areas and can be operated without requiring any licenses.

1.1.2 Types of Wireless Networks

Wireless networks are categorized into four types according to the geographic area where a signal and its services are available [5]. A complete wireless illustration is shown in Fig. 1.2.

1.1.2.1 Wireless Personal-Area Network (WPAN)

WPAN uses low-power transmitters to create a short-range network, typically 20–30 feet (7–10 m). It is used to communicate among a group of private devices such as wireless mouse, wearable devices, USB flash drives, digital cameras, thermostats, lighting controls, and motion sensors. It has no connection to the outside world and is only among the selected devices. This includes technologies like Bluetooth®, Zigbee®. The unlicensed 2.4 GHz ISM band frequencies between 2.402 GHz and 2.480 GHz are used for the protocols.

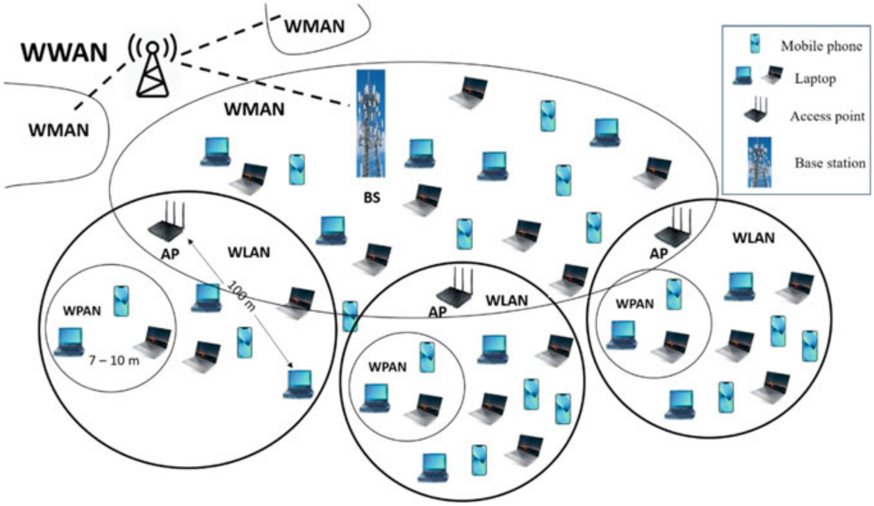

Fig. 1.2 Wireless network illustration

1.1.2.2 Wireless Local-Area Network (WLAN)

WLAN is a wireless service that connects multiple devices over a medium-sized range up to 100 m. It eliminates the need for an access point by enabling users in a small area to create a temporary network. However, through the usage of an access point, it can be used to gain access to the Internet. The unlicensed 2.4 GHz and 5 GHz ISM band frequencies with frequency bandwidth of 5.15–5.85 GHz are used.

1.1.2.3 Wireless Metropolitan-Area Network (WMAN)

WMAN is a wireless service over a large geographic area of more than 100 m but smaller than a Wireless Wide-Area Network (WWAN). Licensed frequencies are commonly used, and these spectra would be allocated by the state.

1.1.2.4 Wireless Wide-Area Network (WWAN)

WWAN is a wireless data service for mobile phones that is offered over a very large geographic area (regional, national, and even global) by telecommunications carriers. Only licensed frequencies are used here.

1.1.3 Commercial Wireless Technologies

Wireless connectivity technology like Bluetooth®, Wi-Fi, ZigBee® [6], RFID, NFC, and Z-wave® [7] are used in short-range communication, while Cellular communication (2G and beyond) [8, 9], and LPWAN [10] are used for large-range communication. Bluetooth® uses radio signals to connect nearby devices like wireless speakers and smartphones and share information between them. As a result, Bluetooth® can be used in both Wireless LANs and Wireless PANs. ZigBee® and Z-Wave® specifications are also used to create wireless PANs primarily for smart home devices like programmable light bulbs and security sensors.

Bluetooth®

The Bluetooth technology operates in the ISM band at 2.4 GHz. The Bluetooth devices will connect and communicate through short-range networks known as piconets. A piconet consists of a minimum of two and a maximum of eight peer devices. The piconets are dynamically established as and when a Bluetooth device enters and leaves a network. Bluetooth range is around 5–10 m and it consumes very low power.

Wi-Fi

Wi-Fi is a wireless technology that allows computers, mobile phones, and other devices to interface with the Internet. The wireless access point allows the wireless device to connect to Wi-Fi and it has a range of 20–100 m which could be extended with repeaters. The ISM spectrum of 2.4 GHz and 5 GHz is used in the Wi-Fi. The protocols that enable Wi-Fi communication are defined in the IEEE 802.11 standard, which will be discussed in a later section.

ZigBee®

ZigBee is a wireless technology for low-power and low-data rate applications because its focus is on wireless monitoring and control. The frequency range supported in ZigBee is 2.4 GHz and it has a range of 10–30 m. When a device using ZigBee finds another active device in its vicinity, it initiates communication without any interruptions. ZigBee is used in smart home applications, healthcare devices, and sensors.

Radio Frequency Identification (RFID)

RFID is a wireless technology that can identify, locate, track, and monitor people and objects without a clear line of sight between the tag and the reader. The main frequencies used by passive RFID tags are 125 kHz, 134 kHz, 13.56 MHz, and 860–956 MHz and active tags use 433 MHz and 2.45 GHz. The read range of an RFID tag varies from 1 to 10 m based on the frequency and tag type used. RFID technology has the potential to replace bar codes in the future.

Near-Field Communication (NFC)

NFC is a short-range, high-frequency, low-bandwidth wireless technology between two NFC-enabled devices. It integrates RFID technology and a contactless smartcard interface with mobile phones. The communication between NFC devices occurs at 13.56 MHz as in RFID but at a very close range of 4 cm or less. In the case of contactless smart cards, the communication is performed when the devices are in close proximity, and for contact smart cards, the communication is performed when the devices are in contact with each other.

Z-wave

Z-wave is a wireless communication technology for home automation. It interconnects lighting, heating, security, and safety devices with devices from different vendors able to work together. Z-wave uses the sub-1 GHz frequency with a range of 30–40 m. A Z-Wave mesh network can have interconnections of up to 232 devices. The devices can be controlled via a Z-Wave remote control, a cell phone, or a PC. Z-Wave devices can also be programmed to turn up the heater or turn off all lights with one button.

Cellular Communication

Cellular communication is a wireless technology that enables users to use voice and data communication through mobile phones. Mobile communication technology has continuously evolved in the past four decades, from the second generation to the fifth generation. The 2G is designed to operate at the 900/1800 MHz frequency band, 3G at 2100 MHz and 1920–2170 MHz, 4G at 700–800 MHz and 1710–2700 MHz, and 5G at 26/39 GHz band. Cellular communication is facilitated through various base stations installed at fixed locations at various geographic locations by various service providers.

Low-Power Wide-Area Network (LPWAN)

LPWAN is a wireless communication technology designed to allow long-range communications with low-power consumption, low-cost interface, low transmission data rates due to small packet sizes, and a long battery life. LPWAN-based applications are expected to be one-third of all IoT applications. LPWAN can provide long-range communication up to 10–40 km in rural/desert zones and 1–5 km in urban zones. LPWANs use sub-GHz band to achieve robust and reliable communication as the sub-GHz frequencies have better propagation characteristics.

1.1.4 Benefits of Wireless Networks

Mobility: The most obvious advantage of wireless networking is mobility. WLAN allows users to move around the coverage area, often a home or small office while maintaining a network connection. A mobile telephone user can drive miles during a single conversation because the phone connects the user through cell towers. The access to the network is not bounded by the length of the cables.

Device adaptability: Wireless networks typically have a great deal of adaptability, which can translate into rapid deployment. It supports the use of a wide range of devices, such as computers, phones, tablets, gaming systems, and IoT devices.

Easier installation: The back-end infrastructure side of a wireless network is qualitatively the same whether you are connecting one user or a million users. A WLAN requires less physical equipment than a wired network, which saves money, reduces installation time, and takes up a lesser footprint in typical office settings.

Economical: The equipment and setup costs are reduced. To offer service in an area, you need base stations and mobile terminals in place. Adding a device to the network is a matter of configuring the infrastructure, and does not involve running cables, punching down terminals, and patching in a new jack.

Scalability: Wireless networks are scalable in nature. Once the initial infrastructure is built, adding a user to a wireless network is mostly a matter of authorization, which does not require additional infrastructure.