



Chapter 1 : Introduction to IoT		1-1 to 1-56
1.1	Internet of Things (IoT).....	1-1
1.1.1	Characteristics of IoT.....	1-2
1.2	IoT Vision	1-3
1.3	Emerging Trends in IoT.....	1-9
1.4	Economic Significance of IoT (Societal Benefits of IoT).....	1-11
1.5	Technical Building Blocks (High-level Architecture of IoT)	1-13
1.6	Physical Design of IoT	1-14
1.6.1	Things in IoT	1-14
1.7	IoT Protocols (Interoperability of IoT Devices)..	1-16
1.7.1	Link Layer Protocols	1-17
1.7.2	Network Layer Protocols.....	1-18
1.7.3	Transport Layer Protocols.....	1-19
1.7.4	Application Layer Protocols.....	1-19
1.8	Logical Design of IoT.....	1-22
1.8.1	IoT Functional Blocks	1-22
1.8.2	IoT Communication Models	1-23
1.8.2(A)	Request - Response Communication Model.....	1-23
1.8.2(B)	Publish - Subscribe Communication Model.....	1-23
1.8.2(C)	Push - Pull Communication Model.....	1-24
1.8.2(D)	Exclusive Pair Communication Model.....	1-25
1.8.2(E)	Comparison between IoT Communication Models.....	1-26
1.9	IoT Communication APIs	1-26
1.9.1	REST-based Communication APIs.....	1-26
1.9.2	REST Architectural Constraints.....	1-27
1.9.3	WebSocket-based Communication APIs	1-29
1.9.4	Comparison between REST-based and WebSocket-based APIs	1-30
1.10	IoT Enabling Technologies.....	1-30
1.10.1	Embedded Systems	1-31
1.10.2	Communication Protocols.....	1-31
1.10.3	Wireless Sensor Networks (WSNs).....	1-31
1.10.4	Big Data Analytics	1-31
1.10.4(A)	The Five Vs (Characteristics) of Big Data	1-31
1.10.5	Cloud Computing.....	1-32
1.10.5(A)	Goals of Cloud Computing.....	1-33
1.11	UAV (Unmanned Aerial Vehicles).....	1-34
1.11.1	Applications of UAVs	1-34
1.12	IoT Levels and Deployment Templates.....	1-36
1.12.1	IoT Deployment Level 1.....	1-37
1.12.2	IoT Deployment Level 2.....	1-38
1.12.3	IoT Deployment Level 3.....	1-38
1.12.4	IoT Deployment Level 4.....	1-39
1.12.5	IoT Deployment Level 5.....	1-40
1.12.6	IoT Deployment Level 6.....	1-41
1.13	IoT Issues and Challenges	1-42
1.14	IoT and M2M.....	1-43
1.14.1	Introduction to M2M	1-43
1.14.1(A)	Applications of M2M.....	1-43
1.14.1(B)	General High-Level Architecture of M2M (Defined by ETSI)	1-44
1.14.1(C)	High-Level Architecture of M2M for IoT	1-45
1.14.1(D)	Difference between IoT and M2M.....	1-45
1.15	SDN and NFV for IoT.....	1-46
1.15.1	Software-Defined Networking (SDN).....	1-46
1.15.1(A)	Architecture of SDN.....	1-47
1.15.1(B)	Advantages of SDN	1-48
1.15.1(C)	Challenges with SDN.....	1-49
1.15.1(D)	Comparison between SDN and Traditional Networking	1-49
1.15.2	Network Function Virtualisation (NFV).....	1-50
1.15.2(A)	NFV Architecture	1-51
1.15.2(B)	Advantages of NFV.....	1-51
1.15.2(C)	Challenges with NFV	1-52
1.15.3	Role of SDN and NFV in IoT.....	1-53



Chapter 2 : Things in IoT		2-1 to 2-24	
2.1	Sensors, Actuators, and Smart Objects.....	2-1	
2.1.1	Sensors	2-1	
2.1.1(A)	Types of Sensors	2-4	
2.2	Light Sensor.....	2-7	
2.2.1	Voltage Sensor	2-7	
2.2.2	Humidity Sensor	2-7	
2.3	Wireless Sensor Networks.....	2-8	
2.3.1(A)	WSN Topologies.....	2-8	
2.4	Level Sensors.....	2-9	
2.4.1	USB Sensors.....	2-10	
2.4.2	Embedded Sensors	2-11	
2.4.3	Motion Detection Sensors	2-12	
2.4.4	Distance Measurement with Ultrasonic Sensor.....	2-12	
2.4.5	Actuators	2-12	
2.4.5(A)	Types of Actuators	2-13	
2.5	Connecting LED	2-13	
2.6	Buzzer Controlling	2-13	
2.7	AC Power Devices.....	2-13	
2.8	Servo Motor.....	2-13	
2.9	Speed DC Motor.....	2-13	
2.10	Smart Objects	2-13	
2.10.1	Common Smart Objects (IoT Devices)	2-14	
2.10.1(A)	Home Automation.....	2-15	
2.10.1(B)	Industrial IoT.....	2-15	
2.10.1(C)	Personal and Health Care	2-16	
2.10.1(D)	Other Uses.....	2-17	
2.11	Electronic Communication Protocols (Device Interfacing) Protocols.....	2-18	
2.11.1	I2C (Inter-Integrated Circuit).....	2-18	
2.11.2	SPI (Serial Peripheral Interface).....	2-18	
2.11.3	UART (Universal Asynchronous Receiver Transmitter).....	2-19	
2.11.4	USART (Universal Synchronous Asynchronous Receiver Transmitter).....	2-20	
2.11.5	CAN (Controller Area Network).....	2-20	
2.11.6	Comparison between I2C, SPI, UART, USRT, and CAN.....	2-23	
Chapter 3 : Communication Protocols and IoT Challenges		3-1 to 3-44	
3.1	Connecting Smart Objects	3-1	
3.1.1	Communications Criteria.....	3-2	
3.1.2	Comparison between Various Wireless Technologies based on Communication Criteria..	3-6	
3.2	Introduction to Non IP based Protocol.....	3-7	
3.2.1	IEEE 802.11.....	3-7	
3.2.1(A)	WLAN Architecture	3-7	
3.2.2(B)	Wi-Fi Alliance	3-8	
3.2.2	IEEE 802.15.4.....	3-9	
3.2.2(A)	IEEE 802.15.4 - Device Types.....	3-9	
3.2.2(B)	IEEE 802.15.4 - Network Components.....	3-10	
3.2.2(C)	IEEE 802.15.4 - Network Topologies.....	3-10	
3.2.2(D)	IEEE 802.15.4 - High-level Architecture	3-10	
3.2.2(E)	IEEE 802.15.4 - Frame Structure	3-11	
3.2.3	Bluetooth.....	3-12	
3.2.4	ZigBee	3-14	
3.2.4(A)	Benefits of ZigBee	3-14	
3.2.4(B)	ZigBee Technical Specifications.....	3-15	
3.2.4(C)	ZigBee Architecture.....	3-15	
3.2.4(D)	ZigBee Devices.....	3-16	
3.2.4(E)	ZigBee Network Topology	3-16	
3.2.4(F)	ZigBee Application Profiles.....	3-17	
3.2.5	Wireless Medium Access Issues.....	3-17	
3.3	IP Based Protocol	3-19	
3.3.1	IPv4 Protocol Overview	3-19	



3.3.2	IPv6 Protocol Overview	3-21	3.8.1(C)	The Hierarchy of Edge, Fog and Cloud.....	3-40
3.3.3	Transmission (Addressing) Modes.....	3-22	3.8.1(D)	Comparison between Edge, Fog, and Cloud Computing.....	3-40
3.3.3(A)	Availability of Addressing Modes in IPv4 and IPv6.....	3-22	3.8.2	Data Aggregation Approaches	3-40
3.3.4	Comparison between IPv4 and IPv6.....	3-23	3.8.3	Data Dissemination Approaches.....	3-41
3.3.5	IPv6 Over Low-Power WPAN (6LoWPAN).....	3-23	<hr/>		
3.3.5(A)	6LoWPAN - Overview.....	3-23	Chapter 4 : IoT Platforms and its Programming		
3.3.5(B)	6LoWPAN - Goals	3-23	4-1 to 4-84		
3.3.5(C)	6LoWPAN - Frame Types	3-24	<hr/>		
3.3.5(D)	6LoWPAN – Maximum Transmission Unit (MTU).....	3-24	4.1	System on a Chip (SoC).....	4-1
3.3.5(E)	LoWPAN Adaptation Layer and Frame Format...	3-25	4.1.1	Architecture of SoC.....	4-1
3.3.5(F)	6LoWPAN - Routing Requirements.....	3-25	4.1.2	Applications of SoC.....	4-2
3.4	Application Layer Protocols.....	3-28	4.1.3	Comparison between SoC and a Traditional System.....	4-4
3.5	MAC (Media Access Control) Protocols.....	3-28	4.2	Single Board Computer (SBC)	4-4
3.5.1	Classification of MAC Protocols.....	3-29	4.2.1	Block Diagram.....	4-6
3.5.1(A)	Contention-based	3-29	4.3	Types, Specifications and Comparison of SBC Models.....	4-6
3.5.1(B)	Poll-based.....	3-30	4.3.1	Raspberry Pi	4-6
3.5.1(C)	Schedule-based.....	3-30	4.3.1(A)	Features and Characteristics of Raspberry Pi.....	4-7
3.5.1(D)	Hybrid	3-32	4.3.1(B)	Raspberry Pi Models.....	4-9
3.6	Routing Protocols.....	3-32	4.4	I/O and Network Access Devices.....	4-10
3.6.1	Functions of Routing Protocols	3-32	4.4.1	Raspberry Pi Interfaces.....	4-13
3.6.2	Interior and Exterior Routing Protocols	3-33	4.5	Overview of Raspberry Pi OS	4-16
3.7	Sensor Deployment and Node Discovery	3-34	4.5.1	Different Types of OS.....	4-16
3.7.1	Constrained RESTful Environments (CoRE) Link Format.....	3-34	4.5.2	Installation.....	4-17
3.7.2	Resource Directory (RD)	3-35	4.5.2(A)	Using Raspberry Pi Imager.....	4-17
3.7.2(A)	Architecture of Resource Directory.....	3-35	4.5.2(B)	Using NOOBS (New Out of Box Software).....	4-21
3.7.2(B)	Resource Directory (RD) Content Model.....	3-35	4.6	Basic Python Programming.....	4-23
3.8	Data Aggregation & Dissemination.....	3-36	4.6.1	Installation.....	4-23
3.8.1	IoT Data Management and Compute Stack.....	3-37	4.6.2	Interactive Python	4-24
3.8.1(A)	Fog Computing.....	3-37	4.7	Variables and Data Types.....	4-27
3.8.1(B)	Edge Computing.....	3-39	4.7.1	Writing Comments in Your Python Programs	4-28
			4.7.2	Python Indentation	4-29
			4.8	Flow Control Structures.....	4-29



4.8.1	Conditional Statements	4-29	4.14.1(A)	Hardware Specification.....	4-52
4.8.2	Loops	4-31	4.14.1(B)	Software Features	4-53
4.8.2(A)	While Loop	4-31	4.14.1(C)	Camera Module Installation.....	4-53
4.8.2(B)	for Loop	4-32	4.14.1(D)	Camera Module Configuration.....	4-54
4.9	Functions	4-33	4.14.1(E)	Using Camera	4-54
4.9.1	Defining a Function	4-34	4.14.2	Serial Communication GSM.....	4-55
4.9.2	Python Modules (Importing a Function)	4-34	4.14.2(A)	GSM Module	4-55
4.9.3	Time Functions	4-36	4.14.2(B)	GSM Module Installation.....	4-56
4.9.4	Library Functions	4-37	4.14.2(C)	Enable UART Serial Ports on Raspberry Pi Device.....	4-57
4.10	Basic Arithmetic Programs	4-38	4.14.2(D)	Communicating through GSM Module	4-58
4.11	Basic Interfacing	4-39	4.14.2(E)	Making a call from Raspberry Pi.....	4-59
4.11.1	Breadboard.....	4-39	4.14.2(F)	Receiving a call on Raspberry Pi.....	4-59
4.11.1(A)	Programming Raspberry Pi with Python.....	4-40	4.14.2(G)	Configuring GSM Module for SMS Messaging.....	4-59
4.11.2	LED	4-40	4.14.2(H)	Sending an SMS from Raspberry Pi.....	4-60
4.11.2(A)	Blinking LED Program	4-40	4.14.2(I)	Receiving an SMS on Raspberry Pi.....	4-60
4.11.2(B)	LED with Variable Brightness	4-41	4.14.3	Ultrasonic Sensor	4-61
4.11.2(C)	Traffic Lights.....	4-41	4.14.3(A)	HC-SR04 Ultrasonic Sensor	4-61
4.11.2(D)	Light Sensor.....	4-41	4.14.3(B)	How Does an Ultrasonic Sensor Work?.....	4-61
4.11.3	Switch (Button/Buzzer)	4-41	4.14.3(C)	Interfacing Ultrasonic Sensor with Raspberry Pi.....	4-62
4.11.3(A)	Button Controlled LED.....	4-42	4.14.4	Passive Infrared (PIR) Motion Sensor	4-63
4.11.3(B)	Motors.....	4-43	4.14.4(A)	Interfacing PIR Sensor with Raspberry Pi	4-63
4.12	Servo Motors.....	4-43	4.14.5	Fingerprint Reader.....	4-64
4.12.1	Robot	4-44	4.14.5(A)	Enrolment	4-65
4.12.2	LCD	4-45	4.14.5(B)	Verification.....	4-65
4.12.3	Installing RPi.GPIO Package	4-45	4.14.5(C)	Interfacing a Fingerprint Sensor with Raspberry Pi.....	4-66
4.12.4	Basic Structure of a 16 × 2 LCD	4-45	4.14.6	AC Power Devices	4-68
4.13	Internal Advanced.....	4-48	4.15	Introduction to Arduino.....	4-69
4.13.1	Bluetooth	4-48	4.15.1	Interfacing of the Sensors and Actuators with Arduino.....	4-70
4.13.2	Wi-Fi	4-49	4.15.2	Programming and Application	4-71
4.13.3	Ethernet	4-50	4.15.3	Writing Programs.....	4-73
4.13.3(A)	Configuring Static IP Address.....	4-51			
4.14	External Advanced.....	4-51			
4.14.1	Camera.....	4-51			



4.16	Signals Storage and its Analysis Using Arduino.....	4-76	5.4.2(A)	How Ubidots Works?.....	5-14
4.17	Design of a Minor Project Based on Arduino.....	4-77	5.5	Python Web Application Framework-Django.....	5-14
4.17.1	Adjustable Countdown Timer	4-78	5.6	Designing RESTful Web Service.....	5-15
4.17.1(A)	Project Description.....	4-78	5.7	IoT Security	5-15
4.17.1(B)	Required Components	4-78	5.7.1	Concept Building - Security Basics	5-15
4.17.1(C)	Circuit Diagram	4-78	5.7.2	Information Security Concepts.....	5-17
4.17.1(D)	Program	4-78	5.7.2(A)	Confidentiality	5-17
<hr/>			5.7.2(B)	Integrity	5-17
Chapter 5 : IoT Physical Servers and Cloud Offerings			5.7.2(C)	Availability.....	5-17
5-1 to 5-52			5.7.3	Security Threats and Vulnerabilities	5-18
<hr/>			5.7.3(A)	Security Threats.....	5-18
5.1	Introduction to Cloud Storage Models and Communication API.....	5-1	5.7.3(B)	Security Vulnerabilities.....	5-19
5.2	WAMP (Web Application Messaging Protocol) (Web Server for IoT).....	5-3	5.7.4	Access Control and Attacks	5-20
5.2.1	WAMP Concepts.....	5-3	5.7.4(A)	Identification	5-20
5.2.2	Routed Remote Procedure Calls in WAMP	5-4	5.7.4(B)	Authentication	5-20
5.2.3	Publish and Subscribe in WAMP	5-5	5.7.4(C)	Authorisation	5-20
5.2.4	WAMP Transport and Session Lifetime.....	5-6	5.7.4(D)	Accountability	5-21
5.2.5	Comparison between WAMP and Other Protocols.....	5-7	5.7.4(E)	Non-repudiation	5-21
5.2.6	WAMP Application Components.....	5-8	5.7.5	STRIDE Model.....	5-21
5.2.7	WAMP Implementations.....	5-8	5.7.6	Types of Security Attacks.....	5-22
5.3	Autobahn for IoT.....	5-11	5.7.6(A)	Active Attacks.....	5-22
5.3.1	Installing Autobahn Python	5-11	5.7.6(B)	Passive Attacks	5-23
5.3.2	Creating WAMP Application Components	5-11	5.7.7	Encryption and Decryption.....	5-24
5.3.3	Running WAMP Application Components	5-12	5.7.8	Hashing.....	5-25
5.3.4	Registering Procedures	5-12	5.7.9	Digital Signature	5-26
5.3.5	Calling Procedures	5-12	5.7.9(A)	How does this work?	5-26
5.3.6	Subscribing to Topics	5-12	5.7.9(B)	Application and use of Digital Signature	5-27
5.3.7	Publishing Events.....	5-13	5.7.9(C)	Properties of Digital Signature	5-27
5.4	Cloud for IoT	5-13	5.7.10	X.509 Certificate	5-27
5.4.1	ThingSpeak.....	5-13	5.8	Lifecycle of an IoT Device.....	5-28
5.4.1(A)	Key Features of ThingSpeak.....	5-13	5.8.1	Vulnerabilities of IoT.....	5-29
5.4.2	Ubidots.....	5-14	5.8.2	Security Requirements for IoT Systems.....	5-31
			5.8.3	Challenges of Securing IoT.....	5-32



5.8.4	Comparison between IoT System Security and Traditional IT System Security.....	5-34	6.2.3	Structural Health Monitoring	6-7
5.8.5	Threat Modelling	5-35	6.2.4	Surveillance Applications.....	6-7
5.8.6	Threat Modelling in IoT.....	5-35	6.3	Health.....	6-8
5.9	Key Elements of IoT Security.....	5-36	6.3.1	Fitness and Health Monitoring	6-8
5.9.1	Identity Establishment and Access Control in IoT	5-43	6.3.2	Wearable Electronics	6-8
5.9.2	Data and Message Security in IoT	5-44	6.4	Agriculture.....	6-9
5.9.3	Non-Repudiation and Availability.....	5-45	6.4.1	Smart Irrigation	6-9
5.9.4	Security Model for IoT	5-45	6.4.2	Greenhouse Control	6-10
5.10	Challenges In Designing IoT Applications.....	5-47	6.5	Environment.....	6-10
5.11	Lightweight Cryptography	5-49	6.5.1	Weather Monitoring	6-10
<hr/>			6.5.2	Noise Pollution Monitoring.....	6-11
Chapter 6 : Domain Specific Applications of IoT			6.6	Logistics	6-11
6-1 to 6-20			6.6.1	Route Generation and Scheduling.....	6-11
<hr/>			6.6.2	Shipment Monitoring	6-12
6.1	Home Automation.....	6-2	6.7	Retail Management.....	6-13
6.1.1	Smart Appliances.....	6-2	6.7.1	Inventory Management.....	6-15
6.1.2	Intrusion Detection.....	6-3	6.7.2	Smart Payments.....	6-16
6.1.3	Smoke / Gas Detector.....	6-4	6.8	Industry Applications.....	6-17
6.2	Smart City.....	6-5	6.8.1	Machine Diagnosis and Prognosis	6-18
6.2.1	Smart Parking.....	6-6	6.8.2	Indoor Air Quality Monitoring.....	6-19
6.2.2	Smart Road	6-6			