Enabling Techniques for the Internet of Things

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An Information Processing Perspective

By

Indrakshi Dey, Anwar Ahmed Khan
and Shama Siddiqui

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Chapter 1

Introduction

1.1 Different Verticals of IoT

Mobile networks are rapidly emerging from communication hubs to advanced ecosystems with computational capabilities. These systems are bound to change the way we live, having a profound impact on our productivity at work and likewise, on our free time, through a number of real-time applications. This digital revolution is expected to be particularly relevant due to the increasing number of devices being connected together forming the Internet-of-Things (IoT); and this revolution of IoT is pervading every walk of life, being deployed in homes, cities, industries, all types of urban, suburban and rural environments.

IoT is a rapidly growing ecosystem that is changing the world around us, leaving no industry behind, through a network of innumerable number of smart devices, modules and network infrastructures. In future, it promises to deliver unmatched global coverage, Quality-of-Services (QoS), scalability, security and flexibility to handle different requirements for a comprehensive range of use

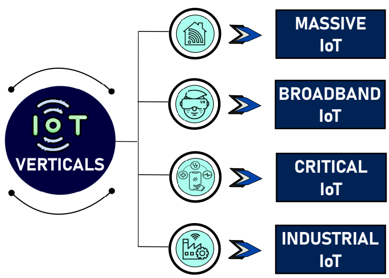

Figure 1.1: Different IoT Verticals.

cases. The growth in IoT connectivity is expected to accelerate, even more, owing to the push to digitize industries like manufacturing, automotive, utilities and the growing interest from network operators to expand their business beyond mobile broadband. By 2025, the number of devices connected by IoT networks are fore- casted to reach 5 billion worldwide.

Key players in global IoT markets like Cosco, ABB, Honeywell, Huawei, IBM, Ericsson, and Intel have now defined four different IoT segments, depending on the latency, reliability, throughput and coverage requirements of the use cases and applications:

☞ Massive IoT
☞ Broadband IoT
☞ Critical IoT
☞ Industrial IoT

An infographic representation of the IoT landscape is shown in Fig. 1.1.

1.1.1 Massive IoT

Massive IoT connectivity targets huge volumes of low-complexity, delay-tolerant devices, like sensors, meters, wearable and trackers, which are deployed in challenging radio conditions. Narrow-band-IoT (NB-IoT) [1,2] and Category-M (CAT-M) [3] have been recognized as the enabling standards for massive IoT. Massive IoT networks support delay-tolerant applications, through devices deployed in challenging radio conditions and implementing extended coverage. Therefore, one of the basic requirements of massive IoT is preservation of battery life of the devices at the cost of relaxed requirements of data rate and latency. A standard protocol that is currently leveraged is the Extended Discontinuous Reception (eDRX) and Power Saving Mode (PSM), which allows the devices to sleep for extended periods of time. Another way out is to resort to narrow bandwidths, half-duplex operation, and single-antenna design for both transmission and reception.

CAT-M and NB-IoT support complementary use cases, CAT-M is good for high-throughput, low-latency applications while NB-IoT can enable low throughput, delay-tolerant applications with highly reliable coverage and connectivity requirements. For example, NB-IoT supports up to 200 kHz bandwidth, while CAT-M can support up to 5 MHz bandwidth. CAT-M and NB-IoT are coexisting simultaneously with the advent of 5G New Radio (NR) specifically in the same spectrum while fulfilling all 5G massive machine-type communications (MTC) requirements, as per IMT-2020 [4] and 3GPP standards [5]. We present some of the major use cases for massive IoT next.

Smart Homes and Smart Cities

Smart homes and smart cities are the most common applications of massive IoT. A city is considered to be smart when it can run intelligently and autonomously by collection and analyzing mass quantities of data from a wide variety of industries, from urban planning to garbage collection, which can make better use of the public resources, increase the quality of the services offered to the citizens, as well as reduce the operational costs of the public administrations. Similarly, smart transportation/Internet of Vehicular Networks (IoV) is one of the major application areas of smart city, which has been deployed by urban hubs across the globe for reshaping their mass transit systems. IoV comprises of connected vehicles, transportation infrastructure (traffic signals and sign boards) and the devices of riders and pedestrians. These networks facilitate various purposes such as collision avoidance, route optimization, reduced fuel consumption, time management, etc.

Smart home is an interesting futuristic application of smart city. A smart home is equipped with smart devices to help people manage and monitor a range of appliances and systems from mobile phones, but also an intelligent entity with instantaneous and distributed decision-making capabilities. Various advances in the domain of smart homes have been proposed, in addition to the typical sensing and reporting. For example, machine learning algorithms can keep track of the activity levels and habits of the residents and in turn, adapt the home environment (e.g light, temperature, pressure) as per their need.

Smart Agricultural and Environment Monitoring

Massive IoT has a huge potential for revolutionizing the domains of agriculture and environmental monitoring as it connects and manages a vast number of heterogenous devices. Precision farming is one such evolving field where farmers deploy sensors across fields to collect data about various parameters such as soil moisture, temperature and humidity; these data assist the farmers and farm-owners to take informed decisions about crop management, fertilization and irrigation. Moreover, massive IoT also plays a pivotal role in livestock management through facilitating the continuous remote monitoring of the farm animals. By using smart RFID tags and relevant IoT protocols, real-time insights into animal behavior and health are generated.

Massive IoT also collects and reports data about the crucial environmental parameters like air and water quality, temperature, pressure, weather, etc. Such data is used for maintaining smart eco-system as it becomes possible to predict the environmental threats and promotes resource conservation for a diverse range of applications. For example, in natural habitats, the sensors help to assess the impact of bio-diversity through assessing wildlife movements and poaching activities. On the other hand, the massive IoT is often designed to facilitate the assessment of pollutants which in turn contributes to timely alerting residents. Thus, massive IoT offers an opportunity to develop proactive strategies for environment preservation.

Healthcare and Remote Patient Monitoring

Massive IoT facilitates creating a seamless network for healthcare and remote patient monitoring that extends beyond the conventional clinical settings. Various wearable devices and hospital equipment continuously collect health data and report it to remote healthcare providers, enabling proactive health management. The major role of real-time health tracking is for the patients residing at remote locations as they may avail virtual consultations and other telemedicine solutions. The IoT deployments not only improve the healthcare access to the patients, but at the same time, also reduce the burden on the state by offering preventive healthcare measures.

In addition to customized wearable devices and hospital equipment, the smart phone applications also promise to revolutionize the preventive healthcare services. A wide variety of smart phone applications are available today that deal with fitness tracking, anxiety and depression management, chronic disease management, nutrition and diet management and sleep tracking. It is worth noting here that the applications keep on emerging every day, and novel applications have been introduced, such as baby monitoring, or ambient assisted living for elderly. Often, these apps integrate with the wearable devices and keep collecting and reporting data through the sensors embedded within the wearables or smartphone itself. Millions of consumers are relying on such apps as they are low-cost, customized, easy to access and helpful for improving their quality of life.

1.1.2 Broadband IoT

Broadband IoT provides superior performance in terms of lower latency and higher throughput than massive IoT. Typical applications are advanced wearables, ariel and ground vehicles, augmented reality (AR)/ virtual reality (VR) enabled devices and sensors. Therefore, in this case, long-term evolution (LTE) [6,7] has to be the enabling standard for the broadband IoT. Multi-gbps throughput can be enabled through LTE using multi-antenna capabilities and carrier aggregation functionalities. LTE can also offer added advantages in terms of low latency, fast connection and extended coverage.

Extended coverage can be enabled at the cost of low throughput. This can be made possible through switching between normal and extended coverage depending on the environmental condition, such that a user can experience high data-rate in areas with excellent coverage and can switch to low data-rate in areas with low signal strength and weak coverage. For example, a connected car can support high throughput applications, such as in-car infotainment, gaming, in a location that has normal coverage. But when it is parked underground, such high throughput application may be difficult to run. However, Broadband IoT can also coexist with 5G NR enabling larger throughput and reduced latency. Some more use cases for this emerging vertical of IoT are described next:

Augmented reality (AR) and Virtual Reality (VR)
An emerging application of broadband IoT is holographic communications capable of capturing images of people and objects in reality and transferring those images and related ambience to the receiver. Very high throughput in the range of terabits per second can materialize transmission of rich details of people and object images and offer close to reality like experience along with AR/VR. Together with tactile transmission and holographic communications, it is also possible to bring about immersive five-sense or five-dimension communications. So now the real surroundings will embed sights, hearing, touch, smell and taste and any other sensations using the neurological processes.

The 5-sense communications along with AR/VR is, therefore, another rising application of broadband IoT.

Connected Vehicles and Intelligent Transportation Systems
With broadband IoT capabilities, the vehicles are provided with real-time communication capabilities; the vehicles can now communicate with each other, with the pedestrians passing by and with the infrastructure. Vehicles can share crucial traffic information such as road conditions, their location, speed etc. Connected vehicles promise to assist drivers through technologies of advanced driver assistance systems (ADAS) and collision avoidance. The vehicles may communicate with each other, adapt to the traffic patterns dynamically throughout the day, avoid collisions, choose routes in real-time and optimize the energy/fuel consumption. Furthermore, the emergency response can also be improved in case of accidents through timely delivery of information.

In addition to connected vehicles, entire smart transportation system is governed by broadband IoT solutions. Here, the advanced communication protocols are used for applications such as reduced traffic congestion, optimized traffic flow, and improved transportation services to the people. All the critical traffic infrastructure, including traffic lights are road signs are integrated with IoT sensors and actuators enabling real-time monitoring and communication of traffic status. For example, with the help of connected infrastructure, the signals can be remotely managed in the event of accidents/emergencies. Another example of IoT in smart transportation is smart parking, where the drivers/vehicles may get real-time information about the available parking spaces in the nearby areas.

1.1.3 Critical IoT

Critical IoT pushes the boundaries of IoT networks even further enabling extremely low latencies of about 1 ms and ultra-high reliability of about 99.9999% at a variety of data-rates. It is to be noted that the requirements significantly differ for each vertical, as shown in figure 1.2. The segment addresses extreme connectivity requirements in applications like intelligent transportation systems (ITS), remote healthcare and fully immersive AR/VR. Such applications have to be powered by innovative capabilities and functionalities beyond LTE for enabling ultra- reliable-low-latency communications (URLLC) [8]. Let's look at some common use cases of the critical IoT.

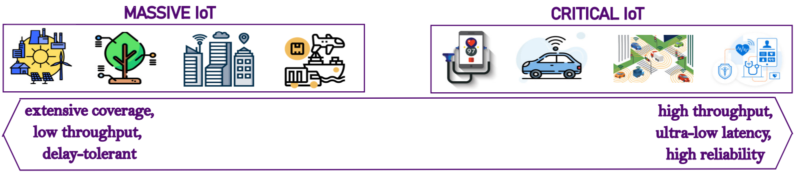

Figure 1.2: Different verticals have different requirements.

Healthcare Applications (e.g., real-time monitoring, remote surgeries)

Smart healthcare systems enabling reliable remote monitoring of body vitals, remote diagnosis, remote consultancy and even remote surgery is one of the promising applications of critical IoT. Huge volumes of medical data are needed to be transported quickly and reliably to facilitate quality care. This data can be further analyzed to estimate and predict impending health conditions using different Artificial Intelligence (AI) techniques.

Remote surgeries have become possible as the emerging 5G/6G communication technologies enable transmissions of high-quality video feeds in real-time; hence, surgeons have become able to perform intricate surgeries from a distance. The robotic surgical systems integrated with IoT sensors & actuators ensure precise movements, which provides high degree of similarity with the physical surgical procedures. Again, patients dealing with emergency situations at remote locations can benefit the most through critical IoT infrastructure as access to specialized surgical expertise is often not possible at such locations.

Another emerging healthcare application in critical IoT is the wireless brain- computer interface (WBCI). WBCI will enable functions like emotion- driven devices through tactile internet, haptic communications and related ideas. WBCI can formulate a communication pathway between the human brain and peripherals so that appliances can be controlled daily in smart homes and healthcare systems in an elegant way.

Public safety (e.g., Smart Grids, Disaster Response Systems)

Critical IoT has also been used in public safety applications, through integration with emerging technologies such as smart grids. IoT solutions ensure secure delivery of electricity while optimizing energy consumption of smart grids. IoT sensors embedded within smart electricity infrastructure monitor various critical parameters like equipment health, demand of electricity, and potential faults. Preventive actions are possible due to the real-time monitoring; for example, in case any disruption occurs, the critical IoT can quickly reroute the power which reduces the downtime and also enhances smart grid's resilience. Thus, the impact of power outage significantly reduces due to the integration of critical IoT infrastructure with the smart grid, ensuring public safety.

Similarly, critical IoT also improves the conventional disaster monitoring systems. Large number of heterogenous IoT sensors are deployed in different regions, that collect data about seismic activity, air quality, weather patterns etc. With the help of this data, the prediction of natural disaster becomes more accurate, which helps the disaster management teams to be prepared timely. Moreover, the IoT solutions are often deployed at disaster prone areas, such as those frequently affected by floods, fire or earthquakes; these solutions provide timely alerts and assist in evacuation procedures. Typical IoT architecture deployed for disaster monitoring and response is shown in the figure 1.3.

Moreover, Unmanned Aeiral Vehicles (UAVs) are also used with critical IoT to execute the disaster management. UAVs participate in surveying the disaster affected regions, to assess the damages and relay the critical information about the presence of people that may have stuck in the debris.

Autonomous Driving

Fully autonomous driving is a major application of critical IoT which involves perception, planning and control. These core functionalities are enabled by image sensors and cameras, high-resolution radar, light detection and ranging and millions of sensors. With the help of different enabling techniques like AI, network graph theory and data analysis and mining techniques, it is possible to meet stringent safety

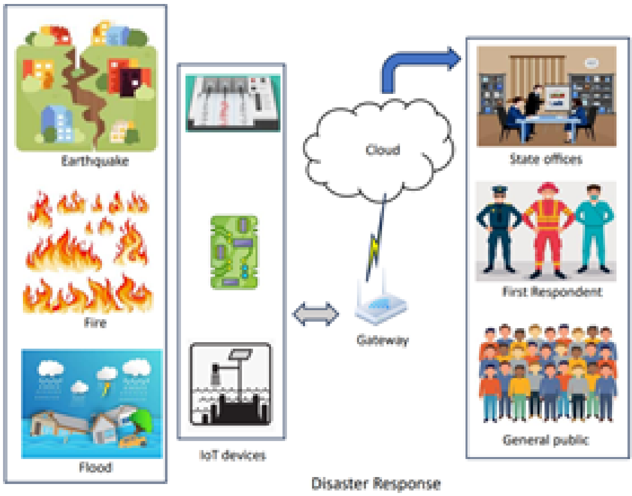

Figure 1.3: Critical IoT Architecture for Disaster Response

demands under different vehicular scenarios. With fully implemented autonomous driving, it is possible to empower disabled people with new mobility prospects.

1.1.4 Industrial IoT

Industrial IoT as a segment covers solutions primarily for a manufacturing setup but also others that show common requirements for an industrial network, perspective such as control systems for railways as well as power generation and distribution. It uses a non-public network at factory premises to address the range of connectivity requirements from environmental sensors and trackers for inventory and supply management to more demanding connectivity for Automated Guided Vehicles (AGV), to the most demanding real-time sensors and robotics on the assembly line which are typically wired. This means that industrial IoT combines all the demanding requirements for critical, broadband and massive IoT, i.e., high throughput, ultra-low-latency, ultra-high-reliability and extensive coverage in favorable to harsh radio conditions. Let's look at some common use cases of this IoT vertical:

Predictive Maintenance
Connected machines in the industrial environment help to communicate the issues early as compared to the conventional troubleshooting practices. Early detection of problems does not help to efficiently plan the maintenance activities leading to time and cost savings but also supports the domains of business intelligence. For various industrial processes, industrial IoT plays a vital role to manage quality of processes, ensure green and sustain- able processes, track assets, manage energy, trace supply chain and parameters, such as temperature, pressure etc.

Supply Chain Optimization
Using IIoT, entire supply chain can be monitored, starting from the manufacturing plants and ending at the retail centers. With the help of sensing and communication technologies, the movement of inventory and delivery timelines for each supply chain agent can be identified, which leads to subsequent assessment of the bottlenecks. Also, due to the availability of real-time data, quick insights can be developed into changing demands or possible disruptions, which helps in timely decision-making.

The parameters of interest including inventory levels, production rates, and environmental conditions are continuously monitored using the sensors embedded within the machinery, vehicles and equipment. For example, for inventory tracking, the real-time information is collected through RFID tags, GPS modules and sensors on products and storage facilities; this information helps the industrial setups to prevent over or understocking. Similarly, IIoT plays a crucial role in maintaining the quality of products. The temperature, humidity and pressure sensors are used throughout the manufacturing and transportation processes, to ensure the desired level of environmental parameters is maintained. In this context, cold chain management which is vital for pharmaceutical products is highly benefited by IIoT.

In addition to helping the industrial processes, the IIoT also brings indirect benefits to the operating environment. The sensors embedded within various industrial equipment/departments can be configured to monitor their carbon footprint (energy consumption). Based on this data, energy-saving strategies can be developed, to reduce the operating cost and also to ensure a sustainable environment.

Industrial Automation and Robotics
In the era of IIoT or industry 4.0, the equipment and machinery are inter-connected and communicate with each other. The sensors embedded with the machinery engage in real-time data collection to identify issues such as abnormal vibration, rusting etc.; this data helps to identify any potential maintenance issues and the equipment not only convey these to the human workers, but also to the alternative equipment so they may continue the operations to reduce the downtime.

Industrial robots are also introduced at the smart factories where they work with the human workforce to improve the efficiency, reduce the errors and improve the overall productivity. Particularly, these robots are used for areas and tasks which may not be safe for the humans. Advanced machine learning algorithms are being developed for optimizing the performance of industrial robots and to ensure that they continue collaborative working (cobots) without colliding. Moreover, robots are often trained by making to observe their human counterparts instead of programming. The recent trends of industrial robotics are highlighted in figure 1.4.

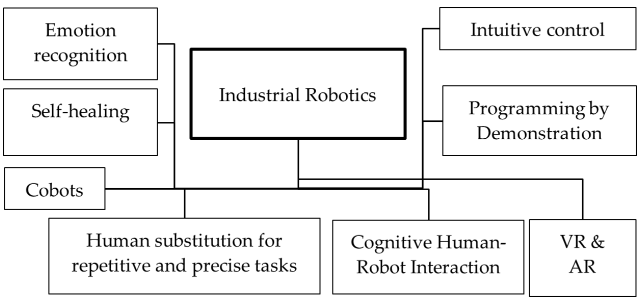

Figure 1.4: Emerging trends for Industrial Robots integrated with IoT.

1.2 Key Enabling Technologies

Different verticals have different technical and commercial requirements and different functional ecosystems. The technical key performance indicators (KPIs) are coverage (determines where the devices can be deployed and connected), energy efficiency (affects battery life and maintenance cycle), latency (determines whether time-sensitive services can be provided) and throughput (maximum amount of data transmitted at a given time). While the principal commercial requirements include QoS (ensures the value of the IoT service that can be delivered), security (protects privacy and integrity of IoT users), cost (decides the business viability of implementing and operating the IoT services) and scalability (determines the flexibility for managing growth). For example, massive IoT requires long battery life, strong cover- age, low cost and low-to-moderate requirements on throughput and latency. Critical IoT applications, on the other hand, require very low latency levels with ultra-high reliability combined with very high throughput.

Based on the requirements of the application and the IoT vertical it belongs to; we need different enabling technologies to bring out the full functionality of the application and fulfil the KPIs defined. Some of such technologies are described briefly in this section.

1.2.1 Data Processing and Fusion

As established in the previous sections, data collection and analysis are the key processes governing the efficiency of any IoT solution. A series of operations and algorithms are implemented in order to convert the data collected from the sensor nodes into a meaningful information. The tasks that are often required during data processing include data cleaning, validating, aggregating/summarizing, calculating and analyzing. Machine learning algorithms are often used for this stage of data processing as the data collected through IoT devices may exhibit certain trends, which could easily be identified through ML [9]. In addition to processing data collected through each IoT device, in various scenarios, the data also needs to be fused from multiple devices. Data fused from diverse sensors or equipment helps to assess the environment. The major goal of information fusion is to reduce the chances of errors and improve reliability.

In the context of IoT verticals, various techniques are being used for data processing and fusion. Compressed distributed detection is an approach where the data streams generated by various sensors or equipment are processed. Due to the real-time monitoring requirement of almost all the IoT verticals, massive amount of data is generated; if all this data is transmitted over the network, there will be enormous bandwidth requirement, leading to resource wastage. Therefore, the compressed detection technique is often used to compress the transmission right at the source node; to maintain the goal of optimal transmissions, the data is intelligently summarized/processed at the source node before being forwarded for the central processing. Hence, the resource usage is optimized.

Similarly, there are a large number of other novel techniques also used for transmitting only essential information such as clustering and collision-aware distributed detection, channel-aware decision fusion, robust and distributed estimation space-time-frequency spreading, and heterogenous data fusion.

1.2.2 Signal Denoising

Signal denoising refers to removing noise from the signals. For IoT, since massive data is generated, it is crucial to denoise the signals received from sensors and equipment in order to infer the accurate values [10]. Techniques used for signal denoising in IoT often include time-domain filtering, wavelet transform, wavelet packet division multiplexing, dual-tree complex wavelet transform, data-driven decomposition, and variational-mode decomposition.

Time-domain filtering applies mathematical filters to a signal in its original time domain, such that the unwanted signal may be attenuated selectively, and at the same time, the required signal components can be enhanced. Wavelet transform, on the other hand, signal into different frequency components. This technique provides time and frequency localization both; hence, a detailed analysis of signal characteristics may be conducted.

Wavelet Packet Division Multiplexing is an advanced technique, which divides a signal into packets. This technique results in precise denoising as it allows processing of specific frequency bands. Another wavelet-based technique is referred as Dual-Tree Complex Wavelet Transform which uses a pair of wavelet trees for capturing magnitude and phase information; it is often used for developing simpler representation of complex signals. Data-driven decomposition deals with identifying patterns and meaningful trends in the data signals. Thus, a more flexible approach of denoising is offered due to adaptive analysis of data. Finally, Variational-mode decomposition decomposes a signal into intrinsic mode functions. This technique achieves the separation of different variation modes and specific signal components are isolated to perform the denoising.

1.2.3 Forms of Learning

Various forms of learning are involved in analyzing the trends and patterns depicted by the IoT data. Diverse set of equipment and IoT network elements may participate in the process of learning to enable optimization of resources and data analysis processes. For example, a leading type is multi-agent networks where agents (nodes) collaborate and share their data to improve the overall network efficiency. On the other hand, the sparsity-aware learning is based on the sparsity of the data that is produced by various nodes; these nodes share the datasets to make decisions such as future schedules, data aggregation frequency/routes and so on.

Similarly, learning is also crucial for maintaining the security and integrity of IoT networks. In this context, anomaly detection is performed through learning where the nodes monitor the network to identify the potential threats and irregularities. Moreover, Learning for real-time estimation and prediction refers to quick analysis of the data that is received during the real-time which enables taking proactive approaches towards reaching the overall goal of IoT network. The real-time estimation learning often employs machine learning algorithms to dynamically assess the current and past data to further improve the decision-making.

Data classification and clustering deals with managing diverse data received through heterogenous sensor nodes and IoT equipment. The process facilitates efficient information retrieval and resource consumption. Moreover, data-space reduction also deals with streamlining data that ensures minimal transmission, without compromising the efficiency of IoT application.

1.2.4 Graph Signal Processing

The technique of Graph Signal Processing (GSP) is applied for IoT solutions, due to the interconnected nature of IoT nodes. Graph theory is used in this signal processing technique for the analysis and manipulation of signals transmitting across the graph structure formed by IoT devices (where the devices represent the node and connectivity between those nodes is illustrated by the link between nodes) [10].

In addition to just collecting signals from the IoT devices, the use of graph theory ensures that the interconnection and interdependencies between the nodes are also taken into account. Advanced machine learning algorithms are used today to identify the patterns of device interactions. Some of the techniques used for studying the spatial characteristics of IoT networks include signal transformation, filtering, and reconstruction. The flow of information is widely optimized through IoT network by using GSP approach.

There are various features offered by GSP for IoT networks such as designing optimal data flows, extraction of optimal network topology, recovering missing data and learning for device management and anomaly detection. Since the communication patterns between nodes is known, GSP easily identifies the most optimal topology such that data flow, communication latency, reliability and overall efficiency improves. The reliability is also enhanced as the knowledge about interaction between nodes helps to identify the missing or corrupt data.

The device management using GSP is one of the interesting features. Here, the historical data is fed into machine learning algorithms to identify the optimal device configurations, communication links and protocols. For example, the role of devices such as cluster head selection can be governed by deploying GSP instead of just devices making the decision. Some of the approaches of automated device management include reduced burden on the processor of each node, load balancing throughout the network, energy optimization etc.

Similarly, GSP also facilitates the process of anomaly detection by identifying the irregular patterns of transmission between the nodes. Since GSP keeps track of all the communication paths and data transmitted, it quicky identifies any change in these patterns, leading to efficient intrusion and malicious node identification. Thus, the risk of unauthorized access, data breach and device malfunction significantly reduce.

1.2.5 Game Theoretic Algorithms

Game theory refers to a mathematical model focused on studying interaction between various entities. Various game theoretic algorithms offer a great opportunity for complex decision-making in complex IoT scenarios [12]. First, static games serve as the foundation for modeling interactions where information provided to entities may be complete or incomplete. Second, distributed decision-making is often served by potential and nash-bargaining games, which is a a crucial requirement for decentralized IoT systems. These approaches assist IoT entities to make either competitive or collaborative decisions. Finally, cooperative and non-cooperative games are deployed in IoT networks for resource allocation problems. As discussed previously, the interconnections between the IoT nodes and their past communication history is readily available; based on this information, the nodes use cooperative games to allocate resources in a collective manner. On the other hand, non-cooperative games utilize competitive scenarios for independent resource allocation by nodes.

1.2.6 Full Duplex Techniques

These techniques are used in IoT solutions for enabling simultaneous communication on the channels. Conventionally, the connections between nodes used to be half-duplex, where nodes had to wait for their turn to transmit. Using full duplex mode, the devices may communicate bi-directionally without the need of having dedicated time slots. There are various benefits of having full-duplex technique, some of them are discussed below:

Coverage Extension
The coverage of IoT nodes enhances significantly by using full duplex transmission mode. The circuit for these networks is designed in a way that self-interference issues are well-catered; the techniques of antenna configuration and advanced signal processing algorithms also contribute to the goal.

Optimal Design for Diverse IoT Verticals
The customized full duplex techniques are deployed to various IoT solutions for meeting their application requirements. For example, in the smart city applications which require seamless and efficient communication, the full duplex algorithm will optimize the communication efficiency; whereas, for the industrial IoT environment where interference and latency are major challenges, the full duplex technique will be optimized accordingly. The optimization for multiple criteria is achieved through configuring power levels, modulation schemes and antenna parameters.

Latency Minimization
The major objective of full duplex transmission is to reduce the latency for critical applications such as healthcare and industrial automation. For these applications, the techniques of interference cancellation, dynamic spectrum allocation, antenna design (e.g. MIMO), and advanced signal processing (e.g. beamforming) are used.

Throughput Maximization
Finally, the network throughput is optimized through full duplex techniques as the bi-directional communication takes place over the link. This results in increased overall data rate for the network. The methods adopted for adaptive modulation and beamforming contribute to achieving optimized spectral efficiency.

1.3 Overview of the Book

We have dedicated the upcoming chapters in this book to the discussion of various enabling technologies required to implement each IoT vertical to its full potential. For example, data processing and fusion with multi-device in- formation processing and multi-antenna fusion center offers promising results in terms of combating signal loss and error due to channel impairments, fading and shadowing over multi-access wireless channels (refer to Chapter 2). Signal denoising techniques offers performance improvement in large-scale industrial IoT networks which suffers from impulsive and background noise owing to the large dimensions and presence of noisy instruments and machines (refer to Chapter 3). On the other hand, deploying full-duplex relays in a massive IoT network extensively manifests coverage along with high throughput and ultra- low latency (refer to Chapter 7). Consequently, the following each chapter of this book from the second one is dedicated to each enabling technology and how they can solve concomitant challenges and contribute towards satisfying requirements of different IoT verticals and applications.

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