Field Programmable Gate Array (FPGA) Based IoT for Smart City Applications

Anvit Negi, Sumit Raj, Surendrabikram Thapa, and S. Indu

Abstract In the present era of modernization, automation and intelligent systems have become an integral part of our lives. These intelligent systems extremely rely on parallel computing technology for computation. Field Programmable Gate Arrays (FPGAs) have recently become extremely popular because of its reconfigurability. FPGA, an integrated circuit designed to be configured by a customer or a designer after manufacturing, finds its application in almost every area where artificial intelligence and IoT is used. The benefits of FPGAs over Application-Specific Integrated Circuits (ASICs) and microcontrollers are emphasized in this chapter to justify our inclination towards more IoT-FPGA based applications. This Dynamic reconfigurability and in-field programming features of FPGAs as compared to fixed-function ASICs help in developing better IoT systems. Due to their remarkable features, they are being heavily explored in IoT application domains like IoT security, interfacing with other IoT devices for image processing, and so on. We would lay focus on areas which require high computational capabilities and the role of FPGAs or related System on-chip whichcan be used in such application resulting in low power designs and flexibility when compared to ASICs. We also provide our insights on how FPGAs in future will be like and what improvements need to be done.

Keywords Field programmable gate arrays (FPGAs) · Parallel computing · Internet of things (IoT) · Smart cities · Reconfigurable computing

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C. Chakraborty et al. (eds.), *Data-Driven Mining, Learning and Analytics for Secured Smart Cities*, Advanced Sciences and Technologies for Security Applications, https://doi.org/10.1007/978-3-030-72139-8_7

1 Introduction

Today's society has been moving towards modernization and innovation more than any time in the history. Technology has powered every aspect of human lives. It has influenced our daily mundane jobs, our healthcare facilities, transportation systems, and everything that we can think of. The tasks that used to take years can now be solved within a fraction of seconds. Every day, new things are being innovated. With this innovation, humanity has reached great heights. This unprecedented innovation is powered by machine learning and artificial intelligence. Machine learning, however, is not a new concept [1]. Researchers in the twentieth century had many interesting findings about how algorithms can learn themselves. On the grounds of the research of the twentieth century, modern-day machine learning is prospering. Earlier, the computational power was very limited which was one of the major impending factors. Today, with advancements in parallel computation and advanced computer architecture, we have very fast computers. Today's mobile phones have the ability to perform the tasks that the supercomputers in the twentieth century struggled to do. This power of computation has led the field of artificial intelligence to develop by multiple folds every year [2].

The electronics that we use today are becoming more and more intelligent. Such smart systems find its use in our daily lives. The electronics we use today are able to collect data through sensors. The appliances we use are smart with a lot of functionalities. We can control our appliances with the help of our mobile devices. This has been made possible with the help of IoT. Sensors used in physical devices in our daily lives collect data continuously. They are connected to a common IoT platform. Various sensors provide the data continuously which can be integrated to build more informative data. The data is then analyzed and valuable information is extracted. The results are shared across the devices and are used for various purposes like automation, improved user experience, etc. IoT has been used extensively in a lot of fields. For example, in a production line, the data of the devices that are being produced are stored in the database of a company. The sensors used in physical devices monitor the status of the device like the health of the device, issues of the device, etc. Such data collected using sensors can help the manufacturers to improve their customer service [3]. This is one of the multiple examples where IoT is used. The modern-day traffic systems, GPS, etc. use IoT extensively.

The technology is being infused in each and every part of our lives. The day-to-day problems like public transportation management, optimal power supply, waste management, etc. are being solved by technologies. The concept of smart cities enables us to use the concepts of big data and IoT to solve the real-world problems [4]. Governments can collect the data using various sensors to solve the problems of waste management, parking space management, etc. The data collected can be used to predict the consumption pattern of the electricity, drinking water, etc. A huge amount of money can be saved with smart sensors. For examples, using smart street lights which automatically turn off in case of no human can cut electricity usage by a huge percentage. The data collected using various sensors can even be used to solve very complex problems like predicting the spread of the disease, etc. [5]. IoT can thus be used to make cities smart, secure, and efficient.

2 Artificial Intelligence (AI) and Internet of Things (IoT) for Smart Cities

IoT has a wide range of applications in smart cities. Most of the works that used to require human intervention are now automated. Artificial intelligence is automating today's world and naturally, it also finds applications in urban planning and urban design accelerating the development of smart cities. Traffic systems, surveillance systems, air and pollution monitoring systems, etc. have become essential aspects of today's cities. Nallapermua et al. [6] have proposed a system named STMP (Smart Traffic management platform) that is able to harness the power of big data and AI algorithms. The system makes use of sensor networks in roadways, the Internet of Things (IoT) as well as social media data to make predictions on traffic flow as well as give solutions to traffic management problems. Detect concept drifts such as peak hours/non-peak hours as well as incidents in roadways such as accidents. This all happens in real-time. This system is implemented through an online incremental machine learning algorithm based on the Incremental Knowledge Acquisition and Self Learning (IKASL) algorithm. The sentiment and emotion of vehicle users are determined by using social media data in a non-recurrent traffic event such as an accident. The system uses real-time traffic data to provide optimal traffic control strategies using deep reinforcement learning. It predicts traffic flow and makes estimates on impact propagation using deep neural networks. Their system was run on a smart sensor network traffic data generated by hundreds of thousands of vehicles on the arterial road network in a state in Australia. Their system provided very good results and was also implementable in the real world. These days, intelligent systems make decisions based on multimodal data which has made the systems more robust and accurate [2]. Apart from the example given, there are use cases of IoT and AI in energy management, resource optimization, etc. These days IoT is also extensively used in precision medicine and healthcare [7]. Each and every problem of smart cities can be solved using AI and IoT. AI at the edge has become a new phenomenon. With new devices getting connected to the internet platform every day, it has become inexplicable to avoid the power of IoT. Even very small electronics are becoming more intelligent. The smartness of electronics is due to AI and for AI, we need strong computational power. FPGAs have become a powerful future prospect for deep learning because of the problem of parallelism it solves.

3 FPGA for Deep Learning

The early AI workloads depend heavily on parallelism, such as image recognition. Since the GPUs have been developed primarily to create video and graphics, they have been popular for machine learning and deep learning [8]. GPUs excellently execute a very vast combination of multiple arithmetic operations during continuous processing. In other words, in situations when the same workload needs to be completed several times in short succession, they will accelerate unbelievably. However, it has its limitations to run AI on GPUs. GPUs are not as powerful as an ASIC, a chip optimized for a certain amount of deep learning [9].

FPGAs may be configured in order to execute GPU-like or ASIC-like activities with integrated AI. The FPGA's reprogrammable, a restructured character is ideally tailored to a rapidly shifting AI scene, enabling programmers to quickly validate algorithms and sell quickly [10]. For deep learning implementations and other AI workloads FPGAs provides many advantages:

- **Fast output with low flow rate and low latency**: By explicitly entering video through the FPGA, FPGAs may have lower latency as well as deterministic latency for real-time applications such as video playback, transcript, and operation recognition. Designers should create from the ground up a neural network to build the FPGA to fit the model better.
- **Outstanding value and cost**: FPGAs for various features and data types can be retrofitted to make them one of the cost-effective hardware choices. FPGAs have extended product lives, so FPGA-based hardware models can be calculated in years or decades. This function makes them suitable for automotive, security, health, and industrial applications.
- **Low power consumption**: Engineers may adapt the hardware to their application using FPGAs, thereby satisfying the criteria for energy efficiency. FPGAs can also handle many functions to improve chip energy usage. A part of the FPGA should be used for a function instead of the whole chip such that the FPGA can host several functions in parallel.

3.1 AI and Deep Learning Applications on FPGAs

Where the program needs low latency and low load sizes, FPGAs will deliver efficiency benefits over GPUs—for example with voice recognition and other operating loads for natural language processing (NLP). Because of their very scalable I/O interface, FPGAs are often suitable for the following tasks:

- **FPGAs are used where I/O inefficiencies to be solved**: FPGAs are also used where data must travel across several various low latency networks. They are highly helpful in removing memory buffering and solving I/O bottlenecks, one of the most restricted variables in the efficiency of AI systems. FPGAs will speed up the whole AI workflow by speeding data intake [11].

- **Including AI in workloads**: Designers can apply AI capabilities to current workloads using FPGAs, including deep product inspection or financial fraud identification.
- **Activating fusion sensor**: When processing multiple sensor data, such as cameras, LIDAR, and audio sensors, FPGAs are excellent in managing multi-sensory input data, such as cameras, LIDAR, and audio sensors. The ability to build autonomous vehicles, robots, and manufacturing devices can be highly useful.
- **Enabling high-performance clusters (HPC) to be accelerated**: By operating as programmable speeders for inferences, FPGAs can help to promote convergence of AI and HPC. They have additional features outside AI. FPGAs make it possible, without needing an additional processor, to incorporate protections, I/O, networking, or pre/post-processing capability.

FPGAs merit a role in big data and machine learning between GPU and CPU based AI chips. In specific, they demonstrate significant potential for accelerating AI-related workloads. The key benefits of using an FPGA for speeding computers and profound learning processes are stability, custom parallelism, and multifunction programming [10]. However, further development is needed in the conception of AI-driven by FPGAs. Just two big IT businesses, Alibaba and Microsoft, sell their customers FPGA-based cloud acceleration. This idea also avoids the shortage of vendors that sell circuits capable of handling such high-level workloads.

4 What Exactly is Field Programmable Gate Array (FPGA)?

FPGA is an integrated circuit which consists of logical blocks bound to each other by modular links. The logic blocks consist of LUTs, which have a specific number of inputs and are structured over basic memories, SRAM, or Flash. In addition to supporting sequential circuits, every LUT has been combined with a multiplexer as well as a flip-flop register. Often, several LUTs for the implementation of complex functions may be mixed. Today's FPGAs are strong systems of I/O specifications such as I2C, SPI, CAN, or PCIe that support hundreds of standards. The FPGA I/Os are divided into banks under which each Bank can support various I/O requirements separately. FPGAs may be reconfigured according to the desired feature or features. FPGAs can be reprogrammed or reconfigured and this makes them different from application-specific integrated circuits (ASICs), custom-designed for unique design projects [12].

A prototype can be carried out using the basic logic feature of each cell and the interconnecting matrix switches can be selectively closed. An FPGA's building block consists of the collection of logic cells and the network of the connecting wires. The programming of these fundamental elements can be used to incorporate complex designs. Over other deployments such as ASIC and off-the-shelf DSP and microcontroller chips, FPGAs have various advantages.

FPGAs are different from processors; FPGAs use logic-processing hardware and has no operating system. Due to the concurrent processing routes, separate processes do not have to compete for the same processing capacity. This causes speeds to be very high and multiple control loops to operate at various frequencies on one FPGA system. A Simple Model of an FPGA Squares represent configurable processing elements, and circles represent configurable switches to control routing. As high parallelism is utilized on circuits in the reconfigurable fabric, FPGA can accommodate incredibly high data throughput speeds. For some uses, FPGA reconfigurability provides a versatility that also renders them superior to GPU. Parallelism and optimal energy usage (performance/watt) are core features of FPGA that can inspire massive data analytics. A key element of FPGA is its parallelism with a design in the hierarchical form which can be ideal for applications in the data processing. Many of the more complex and common data operations on FPGA can be introduced by hardware programming (Fig. 1).

IoT is a big catalyst for creative technologies, new business structures will be encouraged, and global culture will be improved in an unimaginable way. With inherent device and hardware programmability, FPGA provides real simplicity and scalability to address IoT requirements. This effective mix helps you to work independently and to customize the approach to the individual requirements of your

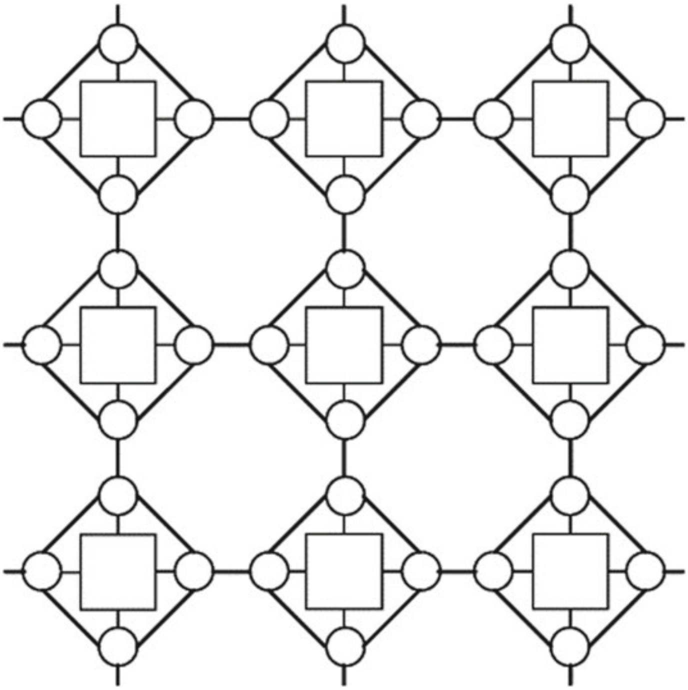

Fig. 1 A simple model of an FPGA squares represent configurable processing elements, and circles represent configurable switches to control routing

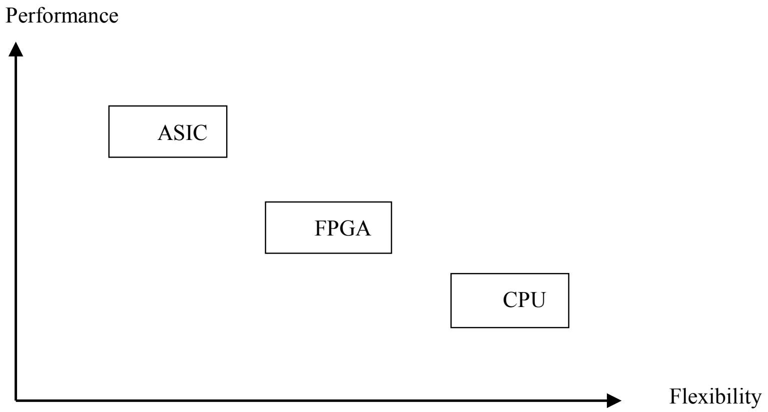

Fig. 2 Comparison of FPGA, ASIC, and CPU on basis of performance and efficiency

consumers and to scale solutions to satisfy fragmented and changing business demands. FPGAs democratize IoT creativity, from intelligent houses and connected automobiles to intelligent electrical grids and public networks. Their solutions allow anybody to build any application from a single concept unit to 100 000 units in volume. This elegantly imitates the wide spectrum of IoT implementations and not a limited number of high-volume applications [13] (Fig. 2).

4.1 Benefits of FPGAs

There are a lot of benefits that FPGAs offer for accelerating deep learning problems. Some of the benefits of FPGAs are as enlisted below:

- **Productivity**: FPGAs include conceptual frameworks to integrate parallelism into designs and thereby improve processing speed dramatically over processor-based platforms.
- **Efficiency**: Processor-driven architectures are based on instructions on common hardware resources to execute a specified operation. FPGA-based architectures consist of dedicated tools to carry out those activities with predictable delays. Therefore, real-time solutions are more accurate.
- **Maintenance**: In the event that an architecture is modified over time, FPGAs provide versatility in updating the design. The time it takes to redesign/improve an FPGA-based system is much less than that of ASIC design.
- **Expense**: The cost of developing the custom ASIC is immense relative to the costs of non-recurring manufacturing for FPGA. Cost: Backend architecture, manufacturing, and shipping costs are also circumvented by FPGAs.

- **Market time**: FPGA technology offers versatility for rapid product prototyping by preventing manufacturing and many other processing delays, thereby allowing faster time to market.

4.2 FPGAs and Artificial Intelligence

Machine learning (ML) was possible due to the Graphics Processing Unit (GPU). It delivered even more processing capacity and had quicker memory access than that of the CPU. Data centers have implemented them easily into their technologies and GPU vendors have built tools to make efficient use of their hardware. GPUs are power-hungry machines, though, and they are just as critical as edge devices for data centers. The scale and complexity of AI algorithms have increased, and the development of a GPU cannot be kept pace. The FPGA, which is fundamentally parallel and hardware programmable, is a substitute, and they are excellent for specialized workloads requiring massive parallelism in computational operations [14].

Because of benefits, such as fast processing time, user-created ability, and low production costs, FPGAs have been the chosen option for integrating glue logic, experimental systems, and hardware prototypes. There are therefore overheads of space and time to provide tunable logic, customizable storage, and configurable routing tools. Designers are completely conscious that it is necessary to completely use the versatility of FPGAs, particularly those which can be swiftly reconfigured in the moment, to mitigate the consequences of these expenses [15]. For the term runtime reconfigurability, we shall follow a limited interpretation: it covers devices that only accept the full user configuration and those which can be partly reconfigured at runtime.

The number of parallel computing components that can be placed in more optimal configurations is improved dramatically by FPGAs. They have tiny quantities of memories in the cloth that put the processing near to the memory [14]. Recently, research was released in which two Intel FPGAs were compared to an NVIDIA GPU. The primary purpose of the experiment was to see whether FPGAs would compete with GPUs to accelerate AI implementations in the future century.

5 FPGA Based IoT Architecture and Applications for Secured Smart Cities

In developing cities today, cyber-physical networks provide smart sensing and control hardware and software. In Smart cities collecting and analysis of urban road data using highly defined images, videos, and background information have now become a necessity. The Field Programmable Gate Array makes data centers and processing reveals that their simulations have an immense potential. The class of applications from the Smart city class involves the gathering and analysis of urban information, remote sensing, the identification of objects and pedestrians, water, and electricity. These potential Smart City technologies are helping City Infrastructures, real estate developers, architecture and technology companies, and scientists via the use of high-resolution photographs, videos, and background details. Running those complex algorithms on standardized processors or graphic processors with low energy consumption can be difficult to accelerate, to use as sensor boxes to build urban information systems. To ensure an effective mapping of the algorithm to reconfigurable hardware, it is important to explore these architecture areas early in the day. In the Internet of Things (IoT) systems, safety and security is an integral necessity in smart cities, which have integrated structures with limited processing capacities and energy limits in the most underlying computing platforms. The FPGA scalable low-area hardware architecture works as a component to speed costly and complicated computation and provides the necessary tools for development in order to reconfigure them.

5.1 FPGA Based IoT for Smart Homes

The Internet of Things (IoT) is found its application in several domains, it even enters smart houses. IoT devices can be easily controlled and tracked with Android apps via smartphones. Home automation is one of the deepest applications of daily life. Wireless Fidelity (Wi-Fi) is groundbreaking, as compared to wired LAN connectivity, as a result of hasty technical developments [16]. There is just a short distance between current wireless networking devices like Bluetooth, ZigBee, NRF24L01, etc. For wireless data sharing over long distances through the Internet, IoT uses Wi-Fi. The IoT module (ESP8266) is used in distant parts of the world for monitoring of domestic industrial equipment. Serial communication shares knowledge between the IoT module and the FPGA. Home devices are managed by an FPGA system that receives commands from the IoT Module via the smartphone application in serial communication. IoT home automation can update system status via email and also on the Internet with IP address, which can be password protection relative to current house automation. IoT based home automation serves effectively to physically disabled and elderly citizens due to high precision and compatibility on smartphone technologies.

IoT can be connected and accessed via the Internet via IP address and accessible worldwide, which are very cheap in the marketplace. The next big thing is IoT and this will be the future. Many Bluetooth modules on the market are available, but in contrast, IoT modules are reliable and cheaper and have various uses, including smart shopping systems for home automation, etc. With the aid of IoT technology, home automation can be accomplished easily. Home appliances can be tracked and operated by IoT modules. The internet of things is the system of physical objects or things built using hardware, programming, sensors, and system networks which allow these objects to collect and trade information. Each progress contributes to the numerous IoT applications overview [17].

Currently with IoT, during office hours, we can control the electronic gadgets that have been put in our homes. When we go to the shower in the morning, our water will be warm. The credit goes to the best devices that make up the smart house. Above all, we need to worry about certain problems such as the consumer should be able to connect this IoT module from whatever gadget they want (Android/iOS devices). He should be able to move the host from one gadget to another and this module should function the same way. If there are any flaws, it should be possible to evaluate them and the system to function efficiently if there is a path for the improvement of distant innovation. The FPGA board is used here because it gives our system high security. For any feature, FPGA offers high versatility to re-configure to any additional functionality. Furthermore, FPGA makes adaptive compromise for programs that do not completely use the on-board resources, either to concurrently perform many small (heterogeneous) tasks or customize a single task for low latency or high precision with more onboard resources [18].

5.2 FPGA Based IoT for Data Encryption, Storage, and Security

The Internet of Things (IoT) has been commonly used for the storage and processing of data in the industry. Data protection is one of the most serious safety concerns of the manufacturing system during storage and contact. Although the existing embedded platform's single security approach and low data throughput are difficult to meet the growing requirements, particularly in the high specification edge computing system, such as FPGA based on the embedded system [19]. A fast hybrid FPGA encryption process improves data protection and data transfer via the integrated Advanced Encryption Standard (AES) Encoding with a highly customized high-parallel message digest (MD5) encryption. Experimental findings in a heterogeneous FPGA with the National Info-Science and Technology Lab demonstrate that the hybrid encryption implementation will achieve high-performance data encryption for edge-computing security applications. It is difficult to achieve high performance without the assistance of hardware for such security systems such as public encryption systems. The complexities of algorithms and hardware specifications have tested the strengths of standard processors and current hardware with the introduction of machine learning and artificial intelligence [20].

5.3 FPGA Based IoT for Safety and Surveillance Applications

The recent substantial growth in electronics, mobile devices, and urban civilization has contributed to the formation of a smart city with intelligent autonomous systems. The use of smart devices in a wide variety from human–computer experiences to robotics has been a major use of computer vision. In comparison, these systems must be extremely reliable in all cases. The automatic video surveillance, commonly used in real-time monitoring today, is one of the essential applications of these systems; it can analyze traffic patterns, follow/track cars, video-cameral recognition, and detection of accidents. Completely automated systems that need minimal processing time and storage space are the major challenges; they often require no personalized thresholds or tunings. These problems underline the significance of algorithms that are computationally efficient, task-based, operator-independent, and threshold-independent in tracing and finding activities [21].

Analyzing large camera network video streams requires immense bandwidth and processing power. Edge computing has been suggested to reduce the strain by the accessibility of resources in the proximity of data. However, there is a continuing rise in the amount of video feed and the related computer resources will become shortened once again [22]. An FPGA-based, smart camera architecture, allowing optimal in situ stream-processing, in order to satisfy the stringent low-latency, energy-efficient, low power conditions for cutting edge vision applications, to essentially solve resource shortage and to make real-time video feed analyses scalable. Together, we maximize energy effectively the allotment of computing capital and plan assignments for heterogeneous tasks. We can achieve a 49× improvement over the CPU and a 64× improvement in energy consumption over the GPU with the background subtraction algorithm by exploiting FFGA's intrinsic design efficiency characteristics by using its hardware support for parallelism [23].

6 FPGA Based IoT Architecture and Applications for Healthcare Analytics

Because of an incredible rise in population growth, conventional health care is not serving the demands of everybody [24]. Despite getting modern, smart, and costly medical services, everybody is unable to access or afford them [25]. The medical system should be more intelligent and accessible for all to solve this problem. Proper use of tools and emerging innovations such as cutting edge, IoT, wearable systems, wireless brain sensors, etc. [26] will accomplish this. The Internet of Things (IoT) is becoming an important connectivity mechanism for control applications for healthcare. Doctors recommend that individuals use multiple kinds of IoT-based items that are effective in preserving and presenting various sorts of disease-related pathological data [27, 28]. Hence, IoT based architectures are being developed for generic and e-health purposes.

The overall medical care market is impacted by various segment patterns, including the accompanying:

- Developing and Aging Population: The U.S. Census Bureau predicts that most of the U.S. "Baby Boom" populace (28% of the all-out U.S. populace) will start to turn 65 somewhere in the range of 2010 and 2020
- Buyer desires for improved medical care are expanding in both created and non-industrial nations.
- Insurance providers and employers are declining payment and compensation for medical costs. Customers/patients would pay more funds.
- Innovation is offering to ascend to new clinical treatments, which thus are tending to an ever-increasing number of clinical illnesses and helping in prior analysis and counteraction of sicknesses [29].

The per capita medical services spending has increased exponentially worldwide. In the U.S., it rose from $144 per person in 1960 to nearly $4,400 per person in 1999 and is estimated to rise further in coming years [30]. Manufacturing companies recognize that they must concentrate and thrive in the United States to succeed in the medical industry.

Within the next two decades, early identification, multimedia details that can be viewed from several places, and the "total solution" revenues will be the key focus of the healthcare industry. In [31, 32], an exhaustive survey of IoT-based health technologies, confidentiality features, including hazard models, attack taxonomies, and healthcare security specifications, was published. Power, security, scalability, wireless communications, etc. were discussed in the key parameters for IoT-driven healthcare systems [32].

6.1 Advantages of Programmable Logic

Almost all medical products contain some kind of semiconductor. Indeed, the content of the silicon chip in these diverse items continues to grow. The rate of acceptance tends to be significantly greater than that of other semiconductor groups. In the production of medical instruments, Programmable Logic Devices provide a feasible and efficient replacement to ASICs PLDs remove costs incurred in non-recurring engineering (NRE) and a minimum order number connected with ASICs, as well as the expensive risks presented by several silicon iterations by being able to reprogram during the design process as required. PLDs offer design versatility and board alignment options in competition with ASICs, which distinguish themselves from rival suppliers of medical equipment. In addition, as specifications improve or criteria change, PLDs may be updated in the sector [33].

Furthermore, it is possible for designers to reuse a basic electronic platform to build differentiated systems that promote a number of functional sets with a single basic design, leading to reduced production cost. If designing a CT computer or a patient tracking unit, programmable logic is a scalable low-risk road to effectively designing a system that provides maximum economic effectiveness while having sufficient capability for distinction relative to other manufacturers of medical devices. PLDs have a long life-cycle, which is highly crucial in the medical sector due to the long product periods and defend consumers from obsolescence.

The programmable logic is a versatile, low-risk route towards the efficient design of devices, offering maximum performance while providing value-added differentiation capacities of long-life cycles, including diagnostics, electromedicine, therapeutics, and life science and hospital equipment for medical applications.

6.2 Medical Applications for Programmable Logic

In order to economically build state-of-the-art devices for many applications like a medical room by using programmable logic includes:

Diagnostic imaging systems

For centuries, medical imaging techniques such as X-ray and ultrasound are in operation. Newer are additional systems such as Computed Tomography, MRI, and Nuclear or Positron Emission Tomography (PET). These modern imaging diagnostic systems are intensive and costly image processing, causing companies to constantly incorporate innovations and performance enhancement [29].

The development of these sophisticated imaging diagnostic systems plays a significant role in semiconductors. The programmable logic today enables Device on Chip (SoC) to power imaging systems of the next generation, with improved density, versatility, and reliability.

As seen above, three types are part of a standard diagnostic imaging system:

- data collection
- data aggregation
- image/data processing cards.

The most cost-sensitive device card is the data acquisition card that filters data received. Normally there are several data acquisition cards in a diagnostic imaging system. Until the data is paid and sorted, it is forwarded to the buffer and data alignment data consolidation card. After extracting the data, it is provided to the processing card for pictures/data processing. These chips filter extensively and reconstruct images with the most algorithms. The FPGAs and the SOCs possess a vital feature necessary for the implementation of these semiconductor devices and that is reconfigurability. The methods of dynamic partial reconfiguration enable a designer to collect and filter data using the same semiconductor setup and this feature makes the system flexible for the development of several medical features [34].

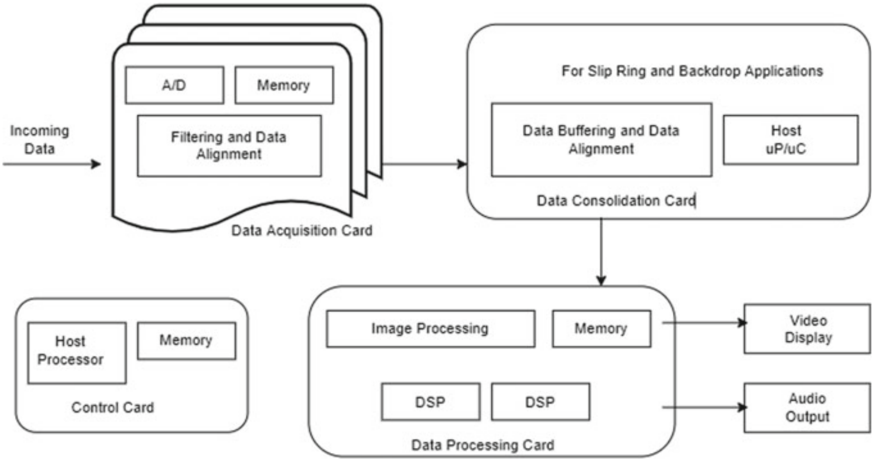

Fig. 3 Example of IoT diagnostic imaging equipment based on FPGA

Electromedical Applications

Patient monitoring

Health tracking systems record and interpret the vital clinical decision-maker knowledge of a patient. Hospital monitoring developments provide a new type of factors enabling the transport of patients [29] (Fig. 3).

Life support

Another critical field of the medical industry is oxygen and life support. This equipment consists mainly of fans and supply systems and is closely connected with the central surveillance system.

Anaesthesia equipment

The use of anaesthesia is essential and demands the finest human treatment, particularly when the patient is administered. Innovation plays a significant role in the provision of anaesthesia by supplying the patient with the same dose.

7 IoT Architecture and Its Applications for Urban Planning Based on FPGA

Increased cost and demand of diverse resources have driven many organizations to find intelligent ways to track, manage, and save their money and resources. A smart management system will help to reduce costs while also satisfying the need for energy. In order to control energy consumption effectively in domestic, commercial, and industrial fields, the evolving Internet of Things (IoT) and big data technologies can be utilized. Not only energy management but also networking for the next generation uses uniform protocols, interdependent architectures, and innovative technology to establish widespread and secure connectivity. Not only can this advancement of connectivity enhance the efficiency of the current networks, but also facilitate different implementations in other areas when incorporating various heterogeneous systems. This huge escalation of mobile connectivity requires increased operational bandwidth. By delivering relatively low latency and a high bandwidth for data transfer, 5G offers a robust solution. FPGA should be used for constructing components of 5G networks because it has the ability to be energy/cost effective. It will ramp up network performance without spending significantly on new hardware. Compared to fixed-function ASICs, dynamic reconfigurability and in-field FPGAs programming capabilities help to build improved wireless systems. This presents multiple FPGA technology fields for the next 5G network preparation [35]. The following factors make an FPGA based 5G system, electricity storage, and the smart grid feasible.

- **Flexibility**: Platform reconfiguration and changing device functionality.
- **Performance**: Accelerate the hardware phase of complex DSP-optimized control-algorithms.
- **Design integration**: Mixed device fabric design convergence supports both the design and embedded processing requirements of FPGA.
- **Reduced costs**: lower costs, lower power usage, and improved device efficiency with enclosed devices with fewer parts.
- **Lifespan**: endorse a product life cycle of more than 15 years on average.

7.1 FPGA Based IoT for 5G and Beyond

5G is more than just a generation jump, contrary to its predecessors, it is the basis for a globally linked digital age [36]. This requires a set of superlatives: 100 times the normal end-user data rate; 100 times the number of wireless devices; and 1,000 times the amount of smartphone data—all with more diverse end-user apps connected to them. 5G plans to use current and likely new RATs to fulfill these criteria, to use new technology, including Massive MIMO, along with new distribution scenarios, such as cloud-based RANs, but remains a cost-effective option for realistic execution [37]. Possible potential for 5G is a cloud-based radio access network called C-RAN, which uses a centralized datacentre infrastructure to process a wider range of nodes. FPGAs, since they can be used for hardware acceleration and virtualized features in Xeon processors, are essential to this approach.

However, while 5G demand is likely to be gigantic, there is also ambiguity in the systems used to satisfy these needs [38]. Programmable FPGA provides the flexibility and efficiency required to fulfill ambitious and ever-changing 5G wireless networking criteria.

5G Connectivity Obstacles

With the Internet of Things rolling in, the number of wireless devices is bound to escalate, and with considerably more diverse implementations, a multitude of networking types are required. Therefore, 5G is going to need:

- Reliable data transfer from 1 Gb/s up to 20 Gb/s
- The near-zero-time delay for applications including connectivity between vehicles
- Assistance for the reliable mass potential of hundreds of billions of wireless devices
- Data rates and tariffs versatility for multiple applications
- There are now various ideas and innovations introduced to solve the problems of 5G, not only to enable a world that is universally interconnected but also to accomplish them using cost-efficient solutions. In other words:
- Radio access networks or virtualized RANs focused on the cloud-based computing
- More advanced multi-access and software/development solutions
- The modern architecture of the RF and baseband
- New methods for beam formation
- Effective and scalable spectrum utilization in Specialized RF domain processing.

7.2 FPGA Based IoT for Energy Management

Energy Management is a way of selectively switching off the priority system to lower electronic device's power consumption. The effective and reliable supply of energy to the rising global population is one of the great challenges of the next decade. The evolution of the Smart Grid, which has emerged as a consequence of the need for a more advanced electricity supply mechanism, poses many opportunities [39]. The conventional network was the production of energy from fossil fuels like coal or nuclear energy at a power plant. The electricity generated from centralized power stations has been distributed through a variety of transmission and distribution lines (T&D) to the consumer at the end of the day. In the twenty-first century, this unidirectional distribution of energy is difficult because electricity is not concentrated, it is dispersed with more worldwide energy from alternative energies such as solar and wind power.

Besides, developments in wired and wireless networking technologies are being integrated into the modern grid. Yet hurdles are impeded by the introduction of the smart grid. These hurdles include emerging requirements, long-lasting durability, safety, low-cost deployment, and two-way real-time communications. Smart grid control equipment and clean renewable energy ecosystem such as smart solar inverters are far from straightforward [40]. You can increase the efficiency and scalability criteria of task-specific system functionality, such as control loop, grid communications, network redundant, and defense, with a single FPGA or SoC following, changed architecture specifications. An FPGA-based control system in a smart home for monitoring the load energy supplied by the form and amount of loads attached to the power grid. FPGA makes it possible for the intelligent home energy management system to integrate multiple loads without raising the scale of the installed hardware. It can also be used to perform on-site modifications, minimizing repair costs. Since its competing nature guarantees high-speed processing power, FPGAs are most suitable for real-time applications.

8 Further Applications of FPGA Based IoT for Smart Cities

There are a lot of areas beyond the topics discussed above where FPGA finds its applications in use-cases relating to smart cities.

8.1 FPGA Based Neuroscience and Its IoT Applications

Neuroscience is a field of science that focuses on the nervous system structural and functional aspects, which includes neurological and computer sciences, interactive neurosciences, evolution, growth, biochemical and tissue biology, physiology, anatomies, and pharmacology of the nervous system. FPGAs are potentially going to be much larger than programmable read-only (PROM) chips in theory. Internet of things (IoT) is an interconnected part of the future internet, including the emerging and current internet and network creation, and can be designated as a complex global network system with standard and interoperable protocol-configuring capability for connectivity with physical and virtual "things" having names, physical and virtual characteristics [41].

8.2 FPGA Implementation of Automatic Monitoring Systems for Industrial Applications

The automated monitoring system in the industrial field using IoT (Internet of Things) could be thought for the further application. In this technique, the industrial device is automatically controlled, which includes the main FPGA controller, the analog sensor like gas sensor, optical sensor, and the particle sensor like the Pir Motion Sensor. Different sensors and a voltage spectrum of 4.4 V are often used to track manufacturing devices, confirming a safer control device. This is created by the crystal oscillator with an input frequency is 50 MHz. The ADC and GSM module are VHDL-coded. The output will eventually be calculated by a cell network and the current state of the LCD. The use of proximity sensors and various other sensors based on the requirements of the industry will further enhance its functionality [42].

FPGAs can even be used for optimized routing algorithms which are phenomenal in industrial applications [43]. It can also be used in multiple healthcare applications [44].

8.3 Reconfigurable Embedded Web Services Based on FPGA

This approach offers a concept for optimizing the use of spare FPGA resources by employing them to perform separate computational tasks. They use this technique for FPGA-based online applications that conform with the SOA model and that are environmentally safe. For each operation, different segment modules must be given and architectural standards must be followed. You aim to achieve the lowest possible extra hardware expenses [45]. The idea introduced to previously developed FPGA software framework for the application of different Web services was initially implemented by them. Future priorities for growth include:

- Advertising automatic service (related to the issue of service repository)
- Develop or modify existing algorithms that will enable us to transfer computations seamlessly between FPGA-based systems and the service management subsystem to facilitate the uninterrupted operation of the web services.

8.4 Smart Sensor Based on SoCs for Incorporation in Industrial Internet of Things

The Smart Sensor integrated spatial includes real-time operational functionality, local data processing capability, highly accessible communication interfaces, including HD-Seamless Redundancy (HSR) and Parallel Redundancy Protocol (PRP), interoperability (Industrial Protocols), and cyber protection [46].

8.5 FPGA Based Health Monitoring System

The device is used for monitoring body temperature, pulse rate, and breathing rate by using wearable sensors. A health tracking system developed by FGPA would receive the information from various sensors and evaluate the data in order to reduce human participation and react accordingly. If requested, they will include the health summary, state of health, and warnings [47].

9 Futuristic Applications and Challenges of FPGA Based IoT for Smart Cities

In the future for potential cars with a growing number of self-sufficient capacities, we should expect increased communication of the users of the system. Intelligent vehicles and cognitive grids are the culmination of a changing world that makes formerly isolated computers, networks, and services online. This exemplifies the advent of IoT based technologies and the complexity of the domain, with increasing uses we would require convoluted algorithms and better computational processors and this is where SOCs come into the picture. In simple terms, SOC is just a single chip combination of an FPGA that is the programmable logic with an Arm-based processor the programmable software. The convergence of both PL and PS makes the device versatile and ready for tremendous computation with intelligent programming of software while the dedicated hardware solving the intricate computations in the field of medicine, Space Exploration, and data mining. The Flexibility and durability these boards provide make them ideal for Big data applications in the coming time. With software designers exhausting the GPU/ASIC capabilities the SOC or the FPGA is the upcoming option [48].

The convergence of different IoT devices and networks would eventually contribute to the growth of intelligent cities around the world and the use of the modern infrastructure that allows for all-round connection and the ever-rising bandwidth. It is also necessary to remember that it doesn't mean it's secure or will stay safe, only because a system is incorporated. The Big IT companies namely Amazon, Nvidia, and Google have identified the role of FPGAs in IoT applications and have set up data centers using these SOCs. Now the future of complex computation lies in the design and development of these FPGAs and therefore, protection should be treated as hardware rather than software patches, with a variety of potentially severe threats including data violations, falsified components, and IP Property (IP) theft regularly imposed on chip manufacturers. In addition to the fundamental safety of the chip during development, the incorporation of the right IP security core into an SoC will allow producers to build devices, platforms, and systems, which remain protected during their respective lives.

Examples of hardware-enabled products include equipment provisioning, Subscription Management, safe payments, RMA/test support. Integrated SoC/FPGA can serve as the essential medium for authenticating services and Keys. SoC Security Core will control debug modes to counterfeit reverse engineering when authenticating chips. SoC-based protection will handle on-board resource management with methods such as partial reconfiguration. The Safety Provided by the FPGAs is incomparable to the operating system-based hardware modules, lack of operating system makes FPGA secure from cyber-attack since we have dedicated hardware for every operation, we would expect the client or the user to provoke [49].

Protection, privacy, security breaches, unauthorized control, and denial of service include IoT challenges. For completely safeguarding platforms and devices including FPGAs, wearables, phones, notebooks, and other smart devices, a hardware-first approach to the safety and implementation of the required functionality is important in the chip (SoC) area on systems [50]. In reality, a single interface (UI) across the worksite, real-time consistency in operations, and cloud-based function activation are available on the hardware platform. IoT products have a long service life, but manufacturers will probably cease designing and carrying out patches for a product until it has become obsolete and the reconfigurability the FPGA provides come into the picture. We can actually model the new design by just reprogramming the board with a new bitstream. IoT systems can also utilize hardware-based security and insulation devices that provide robust protection from different modes of attack [51]. The external layer of this network consists of physical devices that touch or nearly touch the real world, including optical, thermal, mechanical, and other sensors, which measure building, computer, or human physical states. Certain controls such as thermostats, smart sensors, or drone helicopters are available. The existence of these dynamic devices leads to a mixture of sensors and actuators or entire frameworks for the IoT [52].

Take the home thermostat for example. If we install a smartphone app such that the temperature can be read, faults can be checked and set-point can be modified, the interface is running automatically. This strategy aims to pass power over the Internet, preferably onto a cloud device, and to spread micro, cheap sensors everywhere if possible. Here we totally eradicate the thermostat and place sensors around the building, inside and outside instead. When we are there, our control boards are disconnected from the oven and the air conditioner, their inputs and outputs are linked to the Internet and a cloud program will read their conditions and control their devices directly. Operating on very low steady current, long stretches of sleep, and short operation, these wireless interfaces typically match characteristics such as low power and efficiency to sleep [53]. However, the interfaces still carry luggage. These are incompatible with one another, have limited ranges, and use simpler package formats for the non-internet protocol (IP). These features include a new computer for the intermediation of a local IoT concentrator between the capillary network and the next layer of the IoT [48].

In its immediate proximity, the concentrator acts as a gateway for short-range RF links, handles and transfers data between interfaces. As it is doubtful that these concentrators have a direct link to an Internet connection router, Wi-Fi or Long-Term Evolutions (LTE) would usually be used as a backhaul network and becomes the second layer of the IoT. It is then the duty of the hub to do regular network bridgework as well as to bundle and unpack the traffic and convert it between headers used for backhaul networks and headers used in the short-range RFs.

Not just a revamped design is required for a safer FPGA based IoT smart city but also a remodeled method is required and is one of the biggest challenges for a designer. FPGA uses a relatively low-level language namely Verilog/VHDL and this creates a challenge for a designer to incorporate every complex feature that various other tools provide. For example, training of neural networks on an FPGA board is nearly impossible and the implementation after training is still possible but the process and time to market is really huge when compared to Neural net implementation in a python-based environment. Intel and Xilinx have provided solutions like Vitis, Sdaccel, and HLS that is a high-level synthesis for designing the FPGA boards but the potential of these solution is still not remarkable and we are left with complicated versions of C++/System C and hence this does not provide an acceptable solution and is still a challenge for the designer.

10 Conclusion

The internet has been established in our lives, from offline experiences to social connections. By allowing contact of objects and human beings, IoT has brought fresh potential into the Internet, rendering the world clever and knowledgeable. This has led the vision of connectivity "anytime, anywhere, anyway" truly possible.

Despite the fact that presently FPGAs fall short in several aspects when compared to present IoT rendering devices such as microcontrollers. Parallel computing offers them a rim over microcontrollers in making IoT applications more rapid and effective in complex processes, for example, image processing. Because of these remarkable characteristics, they are extensively explored in various IoT domains such as privacy protection, cryptographic systems, algorithmic acceleration, and many more. Moreover, the unison of independent processors with an FPGA fabric on a single SoC has inspired engineers to upgrade the current device with its deployment in them.

There will be more uses for smart cities in the future, such as intelligent building energy sensors. An IoT machine, which connects several heterogeneous devices via the internet, should be able to communicate and compute results as soon as possible for an efficient real-time process that will make the core of smart cities. This is where FPGA comes into the picture, with the present trend if we are able to enervate our design using the capabilities of FPGA, we would build a computationally advanced IoT architecture for the future.

Challenges in developing a smart healthcare system, such as increasing the complexity of the system, resulting in higher energy usage and cost of design can be reduced by an implementation based on FPGAs. FPGAs can be used in real-time analysis and provide medical feedback that can be crucial to reaching greater levels of data interfacing directly and the computational capacity of these devices will improve the medical performance ratios of electronic-based diagnosis.

SoC FPGA's existing 'do something' set of 'must be good' options are surely all too crowded to customize the data center program of unused features. And, with eFPGA (embedded FPGA IP) technologies increasing lately, more businesses will opt out of the regulation (and massive margins) of stand-alone FPGAs to design data center-class neural network accelerators. Application-specific circuits (ASIC), chips made for one very particular AI role are being replaced by FPGAs as A SICs lack the flexibility that is they cannot be reprogrammed and the cost to market in dedicated hardware for operation-based requirements. This dedicated hardware reprogrammability which has been discussed in detail makes FPGAs ideal for IoT applications that will discard ASICs due to prolonged time to market and design constraints. We envision a world with Xilinx FPGAs and Intel's AI (ML/DL) toolchains, where digital signal processing with field programmable gate arrays is a common alternative to deploy AI applications. Applications that thrive from quick implementation capacities in any digital signals processing with field programmable gate array-based AI systems include Machine View, autonomous driving, driver assistance, and data center.

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