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IoT Evolution: Revolutionary Developments in Recent Years

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Article Info	ABSTRACT
	The term "Internet of Things," or IoT, comes from blending the words "Internet" and "things." It refers to a network made up of everyday objects like cars, appliances, and more. These items come with sensors, software, and the ability to connect to the internet, allowing them to collect and share data [1]. Recently, IoT has woven itself into various parts of our lives, from smart cities and homes to offices, businesses, and even agriculture. Now, even simple items like lights, locks, and machines are part of this growing IoT world. This shift has changed how we manage both important and routine systems, making our lives safer, easier, and more efficient [2]. In 2024, there will be 5.35 billion internet users or 66.2 percent of the world's population. With 97 million new people using the internet for the first time in 2023, the number of internet users has increased by 1.8% in the last 12 months.[3]. In this paper, we will look closely at how IoT has evolved, identify key changes that have occurred, explore their impact on IoT's growth, and discuss what these changes might mean for the future of IoT.

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1. Introduction:

Today, the Internet of Things (IoT) plays a big role in our everyday lives, letting different devices talk to each other and share information on their own [4]. This shift has changed how we live, work, and connect with the world around us. Every day, we witness IoT devices chatting with one another, gathering useful data, and communicating without any help. More everyday items are now linked to the internet than ever before.[5]

Here, "things" refers to physical devices, forming a network of sensors and processors that help these devices exchange data. This setup makes it easy for devices to share information, creating a more connected and smarter world [6]. The goal of an IoT system is to make life better by helping us respond effectively to changes in our environment[7]. It provides tailored services that meet the specific needs of users[8]. IoT systems could change many areas of our lives, like healthcare, transportation, education, and entertainment.

An IoT device can be just about anything that has the tech needed to connect to the Internet, whether through wires or wirelessly. The users of these devices can be people, machines, or even a mix of both.[9]. This variety has led to IoT technology becoming common in many industries and areas.

Typically, IoT networks consist of lots of connected devices that work together through a management platform. This platform takes on several important jobs, like overseeing the devices, guarding against security

risks, analyzing data, processing, storing information, and coordinating how the devices respond to different situations.[10]

Devices in the IoT realm can either come with all their electronic parts from the start or have them added later on. For example, a pet with a GPS tracking tag or a human wearing an external or implanted biometric device is a case where smart features are added after the fact[11]. On the other hand, smart home heating systems and self-driving cars come ready with their smart capabilities right from the beginning.[12]

Every day, the IoT world is changing fast, with new gadgets, technologies, and uses popping up all the time. As this field grows, it's important to get a good grasp of the basic ideas, tools, and applications behind it. This understanding can help us make the most of IoT, leading to new solutions that can make a real difference in our lives.

IoT can change many different areas, like healthcare, transportation, energy, and manufacturing. For example, sensors connected to the IoT can keep track of patients' health from afar, allowing doctors to act quickly when needed. Likewise, smart traffic systems can help manage traffic better, easing jams and making the air we breathe cleaner.

Beyond industries, IoT is also making a mark on our everyday lives. Think about smart home gadgets that can take over tasks like adjusting lights, managing temperatures, and keeping an eye on security. Wearable tech, such as fitness trackers and smartwatches, helps us monitor our exercise, sleep, and other health-related information.

The Internet of Things (IoT) is opening doors to new ways for businesses to make money. For example, companies can create subscription services for devices that connect to the IoT, giving customers regular updates, maintenance, and help. These devices also collect tons of data, which can be looked at to understand how customers behave, what they like, and what they need.

On the flip side, the IoT brings some challenges too, like issues with security, privacy, and making different devices work together. As more IoT devices are used, the chances of cyber attacks and data theft grow. This makes it really important to set up strong security measures to keep both the devices and their data safe.

To wrap things up, the Internet of Things is changing quickly and could really alter many parts of our daily lives. As it keeps advancing, it's important to grasp how it works, the technology behind it, and what it can do. This study looked at how IoT has developed over the last few years, pointing out some major changes that have taken place. The results show just how much these changes are affecting the progress of IoT. Additionally, the study talks about what these changes might mean for IoT's future, sharing thoughts on its possible uses, advantages, and the challenges it faces. By looking at how IoT has evolved and its significant changes, this study gives a clearer picture of where IoT stands today and how it might influence different industries and our lives moving forward.

2. Literature review:

1.Predictive Analytics in Maintaining and Ensuring the Reliability of Satellite Telecommunications Infrastructure: A Review of Strategies and Technological Advances by Nneka Adaobi Ochuba, Favor Oluwadamilare Usman, Enyinaya Stefano Okafor, Olatunji Akinrinola, and Olukunle Oladipupo Amoo. The use of IoT devices and sensors allows for real-time monitoring, providing valuable insights into environmental conditions and how equipment is functioning. This information is processed through advanced algorithms, such as AI and ML, to predict when equipment might fail and to refine maintenance strategies. With these technologies improving the accuracy of forecasts, companies can cut down on downtime and boost the reliability of their systems. In short, predictive analytics is a game changer for maintaining and ensuring the reliability of satellite communications. By adopting these methods, businesses can enhance the reliability of their infrastructure, reduce downtime, and streamline their maintenance efforts.[13]

2.In 2024, Thara Seesaard, Kamorrat Kamjornkittikoon, and Chachawal Wongchoosuk provided A comprehensive review of advancements in sensors for air pollution applications. Their review highlights the latest innovations in air quality sensors, focusing on how they can help monitor different sources of pollution such as industrial outputs, vehicle emissions, farming activities, indoor environments, and even natural events like volcanic eruptions and wildfires. Besides identifying these sources, they explored the effectiveness,

design, and functioning of various air quality monitoring devices. This includes affordable sensors, gas analyzers, weather stations, passive sampling methods, and remote sensing technologies like satellites and LiDAR. A key takeaway is that sensor technology is rapidly advancing to meet the growing need for accurate, cost-effective, and accessible real-time monitoring solutions.[14]

3.The paper "Internet of Things (IoT) review of review: Bibliometric overview since its foundation" was written by Abolghasem Sadeghi Niaraki in June 2023.The primary goal of this survey is to provide the scientific community with an overview, analysis, and list of the difficulties that still need to be solved in the field of IoT review studies that have been published thus far. This work additionally aims to highlight the risk factors and weaknesses found in the currently available survey papers, together with the enabling elements that were identified.[15]

4.The study "An Evaluative Study on IoT Ecosystem for Smart Predictive Maintenance (IoT-SPM) in Manufacturing: Multiview Requirements and Data Quality" was published in July 2023 by Yuehua Liu, Wenjin Yu, Wenny Rahayu, and Tharam Dillon.In addition, this essay addresses the challenges associated with IoT data when using analytical models on an actual industrial IoT system. Next, the state of IoT and IoT-SPM research is illustrated, and a research need regarding IoT data quality is noted. This paper examines the current solutions and provides a qualitative assessment with specific reference to the challenges with IoT data quality that have been found. Future directions and a number of open research questions are raised by these debates.[16]

5.The paper "Wireless Networks and IoT Applications" was written in 2023 by Sérgio F. Lopes, António D. Costa, and Henrique M. Dinis Santos. In this paper, they use a simulator known as NCS-EC (Network Coding Simulator with Error Correction), and the concept is examined in depth. An important performance gain over network error correction (NEC) without error detection was obtained when NEC-CRC was tested for transmission over coded networks, where each connection was represented as a CBS or GE channel.[17]

6.The article "IoT-Based E-Parking System for Multiplexes and Shopping Malls" was published in March 2023 by M. Nikhar and Surekha Kamath.The primary goals of this work, which were to provide a scalable, safe, and reasonably priced parking system for usage in multiplexes and shopping centres, have been met. With the use of improved sensors and computational power, it can be expanded to huge, functional parking systems. It can give young people in the city a way to make a living by creating and marketing smart car parking systems, which can then be sold at reasonable prices and installed in several malls and multiplexes with staff assistance. Additionally, it can assist in creating more modular and adjustable smart parking systems that can be used in any type of building.[18]

3. Transformative Changes in IOT:

In recent years, the Internet of Things (IoT) has changed a lot. This progress comes from better technology, a rise in smart device use, and more worries about security and privacy. One big change is moving from basic machine-to-machine (M2M) communication to smarter systems that can analyze information, make choices, and act on their own [43]. This shift has led to exciting new IoT applications and services, like smart homes, autonomous vehicles, and predictive maintenance.

The rise of IoT has also been fueled by the growing use of artificial intelligence (AI), machine learning (ML), and data analytics. These tools help IoT devices think for themselves and have created new possibilities for applications and services in this field.[41].For instance, AI-enabled IoT systems can look at data from various sensors, spot patterns and unusual occurrences, and suggest actions or predictions. This development has further paved the way for new solutions like smart cities, industrial automation, and healthcare monitoring.

A. Advancements in IoT Devices and Sensors:

As we look forward to the future of IoT technologies, let's explore big data, its benefits, the five Vs, and how it's been growing lately. IoT devices send a tremendous amount of data to the network. To gather, analyze, and manage this vast information, strong programming skills and statistical knowledge are needed. This data comes from all sorts of IoT sources. The next steps are to analyze the data we collect and then manage it effectively.Over time, as we gather more and more redundant and noisy data, the performance of IoT devices can suffer. One significant advantage of big data is its ability to reduce errors, ensuring we have accurate information.[19]

A recent survey highlights the trends in data growth and future predictions, shown in Figure 1. This figure illustrates a dramatic increase in data size over the last 16 years, with projections suggesting it could hit an incredible 175 zettabytes by 2024-2025.[20]

The cloud is essential for connecting various IoT devices, such as smart home devices, CCTV cameras, and traffic light sensors.[21] These gadgets produce an enormous amount of data, often referred to as big data. This data comes in different forms and is typically stored using budget-friendly cloud storage solutions.[22] To manage all this information, big data analytics techniques are applied, guided by the five Vs.

Large storage systems, especially cloud services, keep this data secure. The final part of the process involves using tools like Spark [23], Mapreduce,[24] and Skytree to analyze the data. These tools help us understand the information better. One challenge that came up during this process was the integration of IoT technology with smart software [19]. Data science mostly relies on information collected from IoT systems and other technologies.

Through analysis and visualization, this data can be transformed into useful systems that aid decision-making.[21] This approach allows companies and organizations to meet standards and remain competitive. For example, advances in nanotechnology have led to the creation of sensors that can identify biomarkers for diseases like cancer, as well as those that can monitor environmental factors and detect pathogens.[25]
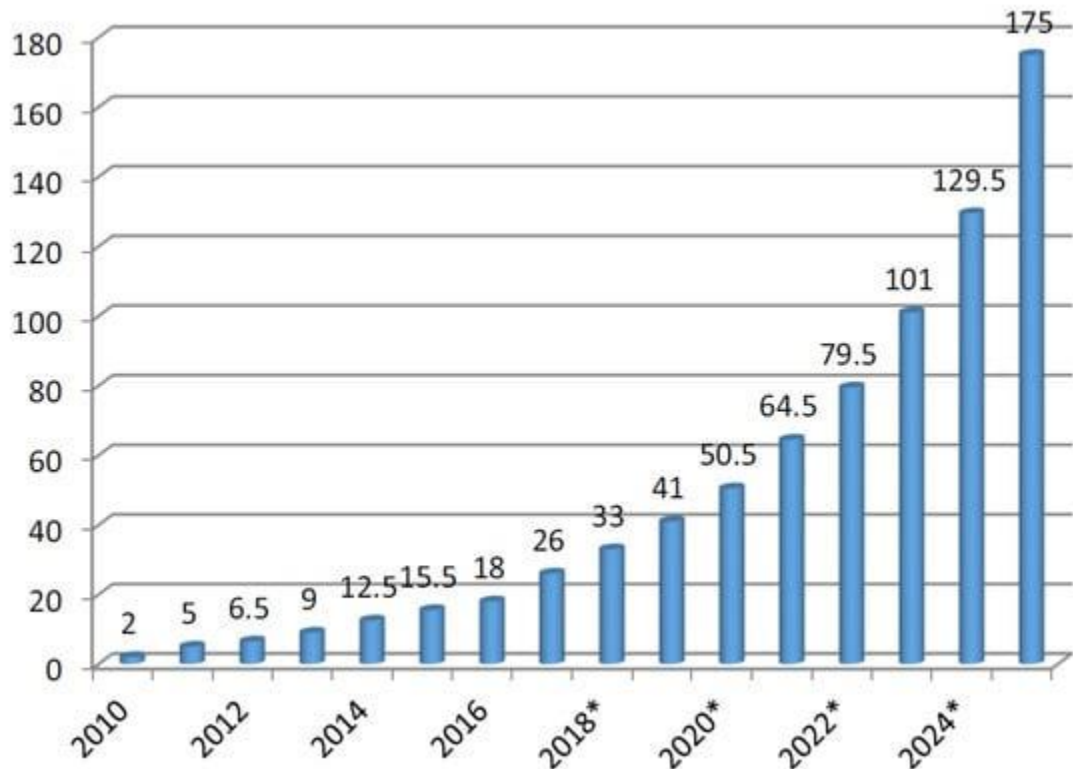

Figure (1): Data growth prediction dynamics worldwide.

The chart illustrates a notable rise over the last ten years, showing the value climbing from 2 in 2010 to 175 by 2024. That's an impressive increase of 87.5 times, and the pace has picked up lately. Every two years, the chart reflects steady and significant gains, with the most considerable leaps happening between 2018 and 2020, as well as from 2020 to 2022. This swift growth hints at a major change in the industry or metric, carrying important effects for what lies ahead.

B. Evolution of IOT Communication protocols:

Recently, the Internet of Things (IoT) has changed a lot, mainly because of new communication technologies. A big change has been the arrival of 5G networks. These networks are much faster, have less delay, and can connect more devices than older ones. With 5G, IoT devices can communicate better, handle many connections at once, and transfer data quickly.[26]

Another important step in IoT communication is the introduction of the Wi-SUN standard. This wireless protocol is tailored for smart utility networks, making it easy for devices to talk to each other safely and reliably.[27] Wi-SUN is likely to boost how IoT devices work in areas like smart grids, allowing for real-time energy monitoring and management.

The growth of IoT protocols has also paved the way for new technologies, such as NB-IoT and LoRaWAN. These technologies provide low-power and low-bandwidth options for connecting IoT devices, supporting a variety of uses from smart cities to factory automation.[28]. The influence of these protocols on IoT capabilities is significant, opening doors to new applications that we couldn't have imagined before.

C. Increased Focus on IOT security and Privacy:

The rise of IoT devices has made us think more about their security and privacy. As these devices spread, they also face more risks from cyber-attacks. A troubling new threat in this area is the emergence of IoT botnets. These are collections of hacked IoT devices that can be used to carry out big cyber-attacks [29]. For example, the Mirai botnet, which came to light in 2016, took control of over 600,000 IoT devices to execute a huge DDoS attack.[30]

People are working on new ways to keep devices safe in response to these security issues. One interesting approach is using blockchain technology for security. This tech offers a secure and decentralised method to manage IoT devices, helping to shield them from online threats.[31]. For instance, an IoT security system based on blockchain can use smart contracts to verify and allow access for IoT devices, making sure that only the right devices can connect to the network.[32].

D. Growing Importance of Artificial Intelligence (AI) and Machine Learning (ML) in IoT:

Artificial intelligence (AI) and machine learning (ML) are becoming more and more essential for the Internet of Things (IoT). These technologies help us make sense of the huge amounts of data that IoT devices create, allowing us to predict issues before they happen [33]. For example, AI-driven IoT systems can foresee when equipment might fail, which helps keep things running smoothly and boosts overall productivity.[34]

Moreover, AI and ML play a big role in making IoT devices safer. Take, for instance, AI-based security systems that can spot unusual activity in network traffic, helping to pinpoint security risks.[35] Furthermore, ML can assist in categorizing IoT devices, helping us find those that might be at risk of cyber-attacks[36].

4. Case studies:

The Internet of Things (IoT) is changing many industries and our everyday lives in exciting ways. Take the smart city initiative in Barcelona, The City Council's International Economic Promotion team recently hosted 58 international delegations eager to discover more about the economic policies and services offered by Barcelona Activa and the 22@ innovation district. This year, the largest groups represented Asia, particularly South Korea, alongside many European delegates.

The Council also opened its doors to visitors curious about specific initiatives, such as the urban innovation challenges led by BIT Habitat. These gatherings showcased the various ways Barcelona is aiming to lead in digital transformation. For example, there are digital replicas of the city, known as Digital Twins, which assist in future planning and development. Another interesting project is Lordimas, a free online tool designed to help cities navigate digital transformation and compare their progress with others.

Lastly, the EDIC (European Digital Infrastructure Consortium) is a project from the European Commission that aims to create useful resources for cities and member states involved with Digital Twins.

for example. The city has created an IoT system to handle public services like waste collection, parking management, and street lighting.[37] By using sensors and analyzing data, this system helps make these services more efficient, cut down on waste and energy use, and enhance the quality of life for the people living there.

A great example of how IoT is being used can be seen with GE Appliances and their predictive maintenance system. They have set up sensors that work with machine learning to figure out when equipment might break down. This method helps keep things running smoothly and saves time. [38] Installed in different manufacturing locations, this system has not only cut costs but has also improved the quality of their products.

Thanks to its smart data analysis, GE Appliances can spot problems before they happen, which helps avoid unexpected outages and the losses that come with them. Moreover, this data-driven approach allows them to plan maintenance more effectively and reduce waste. Because of this, they have managed to lower maintenance expenses and enhance the performance of their equipment. The success of this system has encouraged the company to implement it in other departments, like supply chain management and quality control.

Philips Healthcare is changing the game in patient care with its new remote monitoring system. This innovative setup uses sensors and data analysis to keep an eye on patients' vital signs and health from a distance. Thanks to this system, doctors can check on their patients' health conditions, catch potential issues early, and step in quickly to help avoid hospital visits.[39]

The monitoring system gathers important health data like heart rate, blood pressure, and oxygen levels through the sensors. This information is sent to a central location where healthcare providers can view it live. By analyzing this data, they can spot trends and patterns that help them make better decisions regarding patient care.

The benefits of this system are impressive. It leads to better patient care, fewer hospital readmissions, and lower healthcare costs. By keeping track of patients remotely, healthcare providers can find complications early and act swiftly, which helps keep patients out of the hospital. This not only leads to better health outcomes but also saves money that would otherwise be spent on readmissions.

Moreover, this remote monitoring system allows healthcare providers to give more individualized and proactive care. With real-time data, they can adjust care plans to fit each patient's specific needs. This way of delivering care not only boosts patient satisfaction but also improves their health while cutting down on costs.

In summary, Philips Healthcare's remote patient monitoring system is a great example of how using technology can enhance patient care and health outcomes while lowering costs. By incorporating sensors, data analysis, and remote monitoring, healthcare providers can offer more tailored, forward-thinking, and effective support to their patients.

5. Future Directions along IOT:

In recent years, the Internet of Things (IoT) has changed a lot, shaped by new technologies, a rising interest in smart devices, and increasing worries about security and privacy. This chapter has highlighted the main points from IoT research and development, pointing out the big changes happening across different industries and in our daily lives.[40]

One major outcome of these changes is how IoT can make industries operate more efficiently and boost productivity, improve people's lives, and open up new ways for businesses to earn money. For instance, IoT can help streamline manufacturing, enhance healthcare results, and optimize transportation systems.

On the flip side, these advancements also bring up important issues around security, privacy, and protecting data. As IoT devices become more common and connected, they face greater risks from cyber threats and data leaks. This means it's crucial to create strong security measures and data protection laws to lessen these risks.

Additionally, the shift in IoT means there is a need for fresh business models and new ways to make money. With more connected devices, businesses can explore new revenue opportunities through data analysis, advertising, and other services.[41]

Looking forward, IoT research and development will likely center on several important areas. These include creating more sophisticated IoT devices, building stronger and safer IoT networks, and developing better ways to manage and analyze IoT data.[43][44]

There's also a growing demand for more studies on the social and economic effects of IoT, such as how it influences jobs, education, and healthcare [45]. This kind of research can help us understand the benefits and challenges of IoT and guide the creation of policies that encourage responsible use and growth of these technologies.[46]

In summary, the future of IoT is promising and filled with opportunities. As IoT continues to evolve and impact various industries and aspects of our lives, it's vital to keep research and development a priority, aiming for more advanced, secure, and efficient IoT systems, along with considering the social and economic effects of this technology.

6. Conclusion:

Since it first started, the Internet of Things (IoT) has changed a lot. What began as a simple set of connected devices has grown into a complex network of systems that can operate independently. This change has happened due to several important steps, like the development of Radio Frequency Identification (RFID), the growth of wireless sensor networks, and the rise of smart devices and IoT platforms.

Today, the IoT market is booming. There are billions of devices already connected, and many more are on the way. As IoT keeps changing industries and our everyday lives, we need to pay attention to the big differences it is creating and how they affect us.

One major advantage of IoT is how it can increase efficiency and productivity across different areas. For example, sensors and devices can help monitor and improve industrial processes, anticipate equipment failures, and make supply chains run smoother. In healthcare, IoT technology allows for remote monitoring of patients' vital signs, tracking of medical equipment, and better health outcomes.

Moreover, IoT also makes our daily lives better in many ways. Smart home devices can be controlled from afar, letting homeowners easily adjust lights, temperature, and security. Wearable technology can keep track of fitness and health data, giving people helpful information about their wellness. Additionally, IoT can make transportation systems more efficient, safe, and user-friendly.

However, as more devices join the IoT, there are serious worries about security, privacy, and how we protect our data. With this growth, the chances of cyber-attacks and data breaches become more pronounced. That's why it's important to create strong security practices and data protection laws to address these problems.

In summary, what happens next for IoT relies on how we tackle its challenges while making the most of its advantages. By building solid security and promoting responsible practices, we can make sure IoT continues to transform industries and enhance our everyday lives in a meaningful and sustainable way.[40][41]

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