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A MODEM FUNCTION FOR DYNAMIC RESPONSE SCHEDULING OPTIMIZATION IN MOBILE EDGE COMPUTING ARCHITECTURE FOR IOT BASED DEVICES

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The Internet of things (IoT) describes devices with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.[1] The Internet of things encompasses electronics, communication, and computer science engineering. "Internet of things" has been considered a misnomer because devices do not need to be connected to the public internet; they only need to be connected to a network[6] and be individually addressable.[7]

The field has evolved due to the convergence of multiple technologies, including ubiquitous computing, commodity sensors, and increasingly powerful embedded systems, as well as machine learning.[9] Older fields of embedded systems, wireless sensor networks, control systems, automation (including home and building automation), independently and collectively enable the Internet of things.[10] In the consumer market, IoT technology is most synonymous with "smart home" products, including devices and appliances (lighting fixtures, thermostats, home security systems, cameras, and other home appliances) that support one or more common ecosystems and can be controlled via devices associated with that ecosystem, such as smartphones and smart speakers. IoT is also used in healthcare systems.[11]

There are a number of concerns about the risks in the growth of IoT technologies and products, especially in the areas of privacy and security, and consequently there have been industry and government moves to address these concerns, including the development of international and local standards, guidelines, and regulatory frameworks.[12] Because of their interconnected nature, IoT devices are vulnerable to security breaches and privacy concerns. At the same time, the way these devices communicate wirelessly creates regulatory ambiguities, complicating jurisdictional boundaries of the data transfer.[1]

1. ^ Jump up to:[a] [b] Gillis, Alexander (2021). "What is internet of things (IoT)?". IOT Agenda. Retrieved 17 August 2021.

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History

The main concept of a network of smart devices was discussed as early as 1982, with a modified Coca-Cola vending machine at Carnegie Mellon University becoming the first ARPANET-connected appliance,[4] able to report its inventory and whether newly loaded drinks were cold or not.[5] Mark Weiser's 1991 paper on ubiquitous computing, "The Computer of the 21st Century", as well as academic venues such as UbiComp and PerCom produced the contemporary vision of the IOT.[6][7] In 1994, Reza Raji described the concept in IEEE Spectrum as "[moving] small packets of data to a large set of nodes, so as to integrate and automate everything from home appliances to entire factories".[8] Between 1993 and 1997, several companies proposed solutions like Microsoft's at Work or Novell's NEST. The field gained momentum when Bill Joy envisioned device-to-device communication as a part of his "Six Webs" framework, presented at the World Economic Forum at Davos in 1999.[9]

The concept of the "Internet of things" and the term itself, first appeared in a speech by Peter T. Lewis, to the Congressional Black Caucus Foundation 15th Annual Legislative Weekend in Washington, D.C., published in September 1985.[2] According to Lewis, "The Internet of Things, or IoT, is the integration of people, processes and technology with connectable devices and sensors to enable remote monitoring, status, manipulation and evaluation of trends of such devices."[2]

The term "Internet of things" was coined independently by Kevin Ashton of Procter & Gamble, later of MIT's Auto-ID Center, in 1999,[2] though he prefers the phrase "Internet for things".[3] At that point, he viewed radio-frequency identification

(RFID) as essential to the Internet of things,[24] which would allow computers to manage all individual things.[5] The main theme of the Internet of things is to embed short-range mobile transceivers in various gadgets and daily necessities to enable new forms of communication between people and things, and between things themselves.[8]

In 2004 Cornelius "Pete" Peterson, CEO of NetSilicon, predicted that, "The next era of information technology will be dominated by [IoT] devices, and networked devices will ultimately gain in popularity and significance to the extent that they will far exceed the number of networked computers and workstations." Peterson believed that medical devices and industrial controls would become dominant applications of the technology.[9]

Defining the Internet of things as "simply the point in time when more 'things or objects' were connected to the Internet than people", Cisco Systems estimated that the IoT was "born" between 2008 and 2009, with the things/people ratio growing from 0.08 in 2003 to 1.84 in 2010.[3]

11.^ Hu, J.; Niu, H.; Carrasco, J.; Lennox, B.; Arvin, F., "Fault-tolerant cooperative navigation of networked UAV swarms for forest fire monitoring" Aerospace Science and Technology, 2022. doi:10.1016/j.ast.2022.107494.

Applications The extensive set of applications for IoT devices is often divided into consumer, commercial, industrial, and infrastructure spaces.

Consumers

A growing portion of IoT devices is created for consumer use, including connected vehicles, home automation, wearable technology, connected health, and appliances with remote monitoring capabilities.[4]

Home automation

IoT devices are a part of the larger concept of home automation, which can include lighting, heating and air conditioning, media and security systems and camera systems. Long-term benefits could include energy savings by automatically ensuring lights and electronics are turned off or by making the residents in the home aware of usage.[7]

A smart home or automated home could be based on a platform or hubs that control smart devices and appliances. For instance, using Apple's HomeKit, manufacturers can have their home products and accessories controlled by an application in iOS

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devices such as the iPhone and the Apple Watch. This could be a dedicated app or iOS native applications such as Siri. This can be demonstrated in the case of Lenovo's Smart Home Essentials, which is a line of smart home devices that are controlled through Apple's Home app or Siri without the need for a Wi-Fi bridge. There are also dedicated smart home hubs that are offered as standalone platforms to connect different smart home products. These include the Amazon Echo, Google Home, Apple's HomePod, and Samsung's SmartThings Hub. In addition to the commercial systems, there are many non-proprietary, open source ecosystems, including Home Assistant, OpenHAB and Domoticz.

Elder care

One key application of a smart home is to assist the elderly and disabled. These home systems use assistive technology to accommodate an owner's specific disabilities.[4] Voice control can assist users with sight and mobility limitations while alert systems can be connected directly to cochlear implants worn by hearing-impaired users. They can also be equipped with additional safety features, including sensors that monitor for medical emergencies such as falls or seizures.[6] Smart home technology applied in this way can provide users with more freedom and a higher quality of life.[44]

Organizations

The term "Enterprise IoT" refers to devices used in business and corporate settings. By 2019, it is estimated that the EIoT will account for 9.1 billion devices.[32]

Medical and healthcare

The **Internet of Medical Things** (**IoMT**) is an application of the IoT for medical and health-related purposes, data collection and analysis for research, and monitoring. The IoMT has been referenced as "Smart Healthcare",[5] as the technology for creating a digitized healthcare system, connecting available medical resources and healthcare services.

IoT devices can be used to enable remote health monitoring and emergency notification systems. These health monitoring devices can range from blood pressure and heart rate monitors to advanced devices capable of monitoring specialized implants, such as pacemakers, Fitbit electronic wristbands, or advanced hearing aids.[5] Some hospitals have begun implementing "smart beds" that can detect when they are occupied and when a patient is attempting to get up. It can also adjust itself to ensure appropriate pressure and support are applied to the patient without the

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manual interaction of nurses.[7] A 2015 Goldman Sachs report indicated that healthcare IoT devices "can save the United States more than $300 billion in annual healthcare expenditures by increasing revenue and decreasing cost."[6] Moreover, the use of mobile devices to support medical follow-up led to the creation of 'm-health', used analyzed health statistics."[7]

Specialized sensors can also be equipped within living spaces to monitor the health and general well-being of senior citizens, while also ensuring that proper treatment is being administered and assisting people to regain lost mobility via therapy as well.[8] These sensors create a network of intelligent sensors that are able to collect, process, transfer, and analyze valuable information in different environments, such as connecting in-home monitoring devices to hospital-based systems.[5] Other consumer devices to encourage healthy living, such as connected scales or wearable heart monitors, are also a possibility with the IoT.[9] End-to-end health monitoring IoT platforms are also available for antenatal and chronic patients, helping one manage health vitals and recurring medication requirements.[6]

Advances in plastic and fabric electronics fabrication methods have enabled ultra-low cost, use-and-throw IoMT sensors. These sensors, along with the required RFID electronics, can be fabricated on paper or e-textiles for wireless powered disposable sensing devices.[6] Applications have been established for point-of-care medical diagnostics, where portability and low system-complexity is essential.[6]

As of 2018 IoMT was not only being applied in the clinical laboratory industry,[9] but also in the healthcare and health insurance industries. IoMT in the healthcare industry is now permitting doctors, patients, and others, such as guardians of patients, nurses, families, and similar, to be part of a system, where patient records are saved in a database, allowing doctors and the rest of the medical staff to have access to patient information.[6] IoMT in the insurance industry provides access to better and new types of dynamic information. This includes sensor-based solutions such as biosensors, wearables, connected health devices, and mobile apps to track customer behavior. This can lead to more accurate underwriting and new pricing models.[6]

The application of the IoT in healthcare plays a fundamental role in managing chronic diseases and in disease prevention and control. Remote monitoring is made possible through the connection of powerful wireless solutions. The connectivity enables health practitioners to capture patient's data and apply complex algorithms in health data analysis.[5]

Transportation

Digital variable speed-limit sign

The IoT can assist in the integration of communications, control, and information processing across various transportation systems. Application of the IoT extends to all aspects of transportation systems (i.e., the vehicle,[6] the infrastructure, and the driver or user). Dynamic interaction between these components of a transport system enables inter- and intra-vehicular communication,[7] smart traffic control, smart parking, electronic toll collection systems, logistics and fleet management, vehicle control, safety, and road assistance.

V2X communications

Main article: V2X

In vehicular communication systems, vehicle-to-everything communication (V2X), consists of three main components: vehicle-to-vehicle communication (V2V), vehicle-to-infrastructure communication (V2I) and vehicle to pedestrian communications (V2P). V2X is the first step to autonomous driving and connected road infrastructure.[9]

Home automation

IoT devices can be used to monitor and control the mechanical, electrical and electronic systems used in various types of buildings (e.g., public and private, industrial, institutions, or residential)[5] in home automation and building automation systems. In this context, three main areas are being covered in literature:[7]

- The integration of the Internet with building energy management systems to create energy-efficient and IOT-driven "smart buildings".[7]
- The possible means of real-time monitoring for reducing energy consumption[7] and monitoring occupant behaviors.[7]
- The integration of smart devices in the built environment and how they might be used in future applications.[7]

Industrial

Main article: Industrial internet of things

Also known as IIoT, industrial IoT devices acquire and analyze data from connected equipment, operational technology (OT), locations, and people. Combined with operational technology (OT) monitoring devices, IIoT helps regulate and monitor industrial systems.[7] Also, the same implementation can be carried out for automated

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record updates of asset placement in industrial storage units as the size of the assets can vary from a small screw to the whole motor spare part, and misplacement of such assets can cause a loss of manpower time and money.

Manufacturing

The IoT can connect various manufacturing devices equipped with sensing, identification, processing, communication, actuation, and networking capabilities. Network control and management of manufacturing equipment, asset and situation management, or manufacturing process control allow IoT to be used for industrial applications and smart manufacturing.[3] IoT intelligent systems enable rapid manufacturing and optimization of new products and rapid response to product demands.[55]

Digital control systems to automate process controls, operator tools and service information systems to optimize plant safety and security are within the purview of the IIoT.[4] IoT can also be applied to asset management via predictive maintenance, statistical evaluation, and measurements to maximize reliability.[5] Industrial management systems can be integrated with smart grids, enabling energy optimization. Measurements, automated controls, plant optimization, health and safety management, and other functions are provided by networked sensors.[5]

In addition to general manufacturing, IoT is also used for processes in the industrialization of construction.[6]

Agriculture

There are numerous IoT applications in farming[7] such as collecting data on temperature, rainfall, humidity, wind speed, pest infestation, and soil content. This data can be used to automate farming techniques, take informed decisions to improve quality and quantity, minimize risk and waste, and reduce the effort required to manage crops. For example, farmers can now monitor soil temperature and moisture from afar and even apply IoT-acquired data to precision fertilization programs.[8] The overall goal is that data from sensors, coupled with the farmer's knowledge and intuition about his or her farm, can help increase farm productivity, and also help reduce costs.

In August 2018, Toyota Tsusho began a partnership with Microsoft to create fish farming tools using the Microsoft Azure application suite for IoT technologies related to water management. Developed in part by researchers from Kindai University, the water pump mechanisms use artificial intelligence to count the

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number of fish on a conveyor belt, analyze the number of fish, and deduce the effectiveness of water flow from the data the fish provide.[9] The FarmBeats project from Microsoft Research that uses TV white space to connect farms is also a part of the Azure Marketplace now.[8]

Maritime

IoT devices are in use to monitor the environments and systems of boats and yachts.[8] Many pleasure boats are left unattended for days in summer, and months in winter so such devices provide valuable early alerts of boat flooding, fire, and deep discharge of batteries. The use of global internet data networks such as Sigfox, combined with long-life batteries, and microelectronics allows the engine rooms, bilge, and batteries to be constantly monitored and reported to connected Android & Apple applications for example.

Infrastructure

Monitoring and controlling operations of sustainable urban and rural infrastructures like bridges, railway tracks and on- and offshore wind farms is a key application of the IoT.[7] The IoT infrastructure can be used for monitoring any events or changes in structural conditions that can compromise safety and increase risk. The IoT can benefit the construction industry by cost-saving, time reduction, better quality workday, paperless workflow and increase in productivity. It can help in taking faster decisions and saving money in Real-Time Data Analytics. It can also be used for scheduling repair and maintenance activities efficiently, by coordinating tasks between different service providers and users of these facilities.[5] IoT devices can also be used to control critical infrastructure like bridges to provide access to ships. The usage of IoT devices for monitoring and operating infrastructure is likely to improve incident management and emergency response coordination, and quality of service, up-times and reduce costs of operation in all infrastructure-related areas.[8] Even areas such as waste management can benefit[8] from automation and optimization that could be brought in by the IoT.

Metropolitan scale deployments

There are several planned or ongoing large-scale deployments of the IoT, to enable better management of cities and systems. For example, Songdo, South Korea, the first of its kind fully equipped and wired smart city, is gradually being built[when?], with approximately 70 percent of the business district completed as of June 2018.

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Much of the city is planned to be wired and automated, with little or no human intervention.[8]

Another application is currently undergoing a project in Santander, Spain. For this deployment, two approaches have been adopted. This city of 180,000 inhabitants has already seen 18,000 downloads of its city smartphone app. The app is connected to 10,000 sensors that enable services like parking search, and environmental monitoring. City context information is used in this deployment so as to benefit merchants through a spark deals mechanism based on city behavior that aims at maximizing the impact of each notification.[8]

Other examples of large-scale deployments underway include the Sino-Singapore Guangzhou Knowledge City;[7] work on improving air and water quality, reducing noise pollution, and increasing transportation efficiency in San Jose, California;[8] and smart traffic management in western Singapore.[8] Using its RPMA (Random Phase Multiple Access) technology, San Diego-based Ingenu has built a nationwide public network for low-bandwidth data transmissions using the same unlicensed 2.4 gigahertz spectrum as Wi-Fi. Ingenu's "Machine Network" covers more than a third of the US population across 35 major cities including San Diego and Dallas.[9] French company, Sigfox, commenced building an Ultra Narrowband wireless data network in the San Francisco Bay Area in 2014, the first business to achieve such a deployment in the U.S.[9] It subsequently announced it would set up a total of 4000 base stations to cover a total of 30 cities in the U.S. by the end of 2016, making it the largest IoT network coverage provider in the country thus far.[94][95] Cisco also participates in smart cities projects. Cisco has deployed technologies for Smart Wi-Fi, Smart Safety & Security, Smart Lighting, Smart Parking, Smart Transports, Smart Bus Stops, Smart Kiosks, Remote Expert for Government Services (REGS) and Smart Education in the five km area in the city of Vijaywada, India.

Another example of a large deployment is the one completed by New York Waterways in New York City to connect all the city's vessels and be able to monitor them live 24/7. The network was designed and engineered by Fluidmesh Networks, a Chicago-based company developing wireless networks for critical applications. The NYWW network is currently providing coverage on the Hudson River, East River, and Upper New York Bay. With the wireless network in place, NY Waterway is able to take control of its fleet and passengers in a way that was not previously possible. New applications can include security, energy and fleet management, digital signage, public Wi-Fi, paperless ticketing and others.[8]

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Energy management

Significant numbers of energy-consuming devices (e.g. lamps, household appliances, motors, pumps, etc.) already integrate Internet connectivity, which can allow them to communicate with utilities not only to balance power generation but also helps optimize the energy consumption as a whole.[5] These devices allow for remote control by users, or central management via a cloud-based interface, and enable functions like scheduling (e.g., remotely powering on or off heating systems, controlling ovens, changing lighting conditions etc.).[5] The smart grid is a utility-side IoT application; systems gather and act on energy and power-related information to improve the efficiency of the production and distribution of electricity.[9] Using advanced metering infrastructure (AMI) Internet-connected devices, electric utilities not only collect data from end-users, but also manage distribution automation devices like transformers.[5]

Environmental monitoring

Environmental monitoring applications of the IoT typically use sensors to assist in environmental protection[10] by monitoring air or water quality,[1] atmospheric or soil conditions,[2] and can even include areas like monitoring the movements of wildlife and their habitats.[3] Development of resource-constrained devices connected to the Internet also means that other applications like earthquake or tsunami early-warning systems can also be used by emergency services to provide more effective aid. IoT devices in this application typically span a large geographic area and can also be mobile.[5] It has been argued that the standardization that IoT brings to wireless sensing will revolutionize this area.

Living Lab

Another example of integrating the IoT is Living Lab which integrates and combines research and innovation processes, establishing within a public-private-people-partnership. Between 2006 and January 2024, there were over 440 Living Labs (though not all are currently active) that use the IoT to collaborate and share knowledge between stakeholders to co-create innovative and technological products. For companies to implement and develop IoT services for smart cities, they need to have incentives. The governments play key roles in smart city projects as changes in policies will help cities to implement the IoT which provides effectiveness, efficiency, and accuracy of the resources that are being used. For instance, the government provides tax incentives and cheap rent, improves public transports, and offers an environment where start-up companies, creative industries, and multinationals may co-create, share a common infrastructure and labor markets, and take advantage of locally embedded technologies, production process, and transaction costs.

Military

Main article: Internet of Military Things

The Internet of Military Things (IoMT) is the application of IoT technologies in the military domain for the purposes of reconnaissance, surveillance, and other combat-related objectives. It is heavily influenced by the future prospects of warfare in an urban environment and involves the use of sensors, munitions, vehicles, robots, human-wearable biometrics, and other smart technology that is relevant on the battlefield.

One of the examples of IOT devices used in the military is Xaver 1000 system. The Xaver 1000 was developed by Israel's Camero Tech, which is the latest in the company's line of "through wall imaging systems". The Xaver line uses millimeter wave (MMW) radar, or radar in the range of 30-300 gigahertz. It is equipped with an AI-based life target tracking system as well as its own 3D 'sense-through-the-wall' technology.

Internet of Battlefield Things

The **Internet of Battlefield Things** (**IoBT**) is a project initiated and executed by the U.S. Army Research Laboratory (ARL) that focuses on the basic science related to the IoT that enhance the capabilities of Army soldiers. In 2017, ARL launched the Internet of Battlefield Things Collaborative Research Alliance (IoBT-CRA), establishing a working collaboration between industry, university, and Army researchers to advance the theoretical foundations of IoT technologies and their applications to Army operations.

Ocean of Things

The **Ocean of Things** project is a DARPA-led program designed to establish an Internet of things across large ocean areas for the purposes of collecting, monitoring, and analyzing environmental and vessel activity data. The project entails the deployment of about 50,000 floats that house a passive sensor suite that autonomously detect and track military and commercial vessels as part of a cloud-based network.

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Product digitalization

There are several applications of smart or active packaging in which a QR code or NFC tag is affixed on a product or its packaging. The tag itself is passive, however, it contains a unique identifier (typically a URL) which enables a user to access digital content about the product via a smartphone. Strictly speaking, such passive items are not part of the Internet of things, but they can be seen as enablers of digital interactions. The term "Internet of Packaging" has been coined to describe applications in which unique identifiers are used, to automate supply chains, and are scanned on large scale by consumers to access digital content. Authentication of the unique identifiers, and thereby of the product itself, is possible via a copy-sensitive digital watermark or copy detection pattern for scanning when scanning a QR code, while NFC tags can encrypt communication.

The IoT's major significant trend in recent years[when?] is the explosive growth of devices connected and controlled via the Internet. The wide range of applications for IoT technology mean that the specifics can be very different from one device to the next but there are basic characteristics shared by most.

The IoT creates opportunities for more direct integration of the physical world into computer-based systems, resulting in efficiency improvements, economic benefits, and reduced human exertions.

The number of IoT devices increased 31% year-over-year to 8.4 billion in the year 2017[3] and it is estimated that there will be 30 billion devices by 2020.[8]

Intelligence

Ambient intelligence and autonomous control are not part of the original concept of the Internet of things. Ambient intelligence and autonomous control do not necessarily require Internet structures, either. However, there is a shift in research (by companies such as Intel) to integrate the concepts of the IoT and autonomous control, with initial outcomes towards this direction considering objects as the driving force for autonomous IoT.[124] An approach in this context is deep reinforcement learning where most of IoT systems provide a dynamic and interactive environment.[125] Training an agent (i.e., IoT device) to behave smartly in such an environment cannot be addressed by conventional machine learning algorithms such as supervised learning. By reinforcement learning approach, a learning agent can sense the environment's state (e.g., sensing home temperature), perform actions (e.g., turn HVAC on or off) and learn through the maximizing accumulated rewards it receives in long term.

IoT intelligence can be offered at three levels: IoT devices, Edge/Fog nodes, and cloud computing. The need for intelligent control and decision at each level depends on the time sensitiveness of the IoT application. For example, an autonomous vehicle's camera needs to make real-time obstacle detection to avoid an accident. This fast decision making would not be possible through transferring data from the vehicle to cloud instances and return the predictions back to the vehicle. Instead, all the operation should be performed locally in the vehicle. Integrating advanced machine learning algorithms including deep learning into IoT devices is an active research area to make smart objects closer to reality. Moreover, it is possible to get the most value out of IoT deployments through analyzing IoT data, extracting hidden information, and predicting control decisions. A wide variety of machine learning techniques have been used in IoT domain ranging from traditional methods such as regression, support vector machine, and random forest to advanced ones such as convolutional neural networks, LSTM, and variational autoencoder.

In the future, the Internet of things may be a non-deterministic and open network in which auto-organized or intelligent entities (web services, SOA components) and virtual objects (avatars) will be interoperable and able to act independently (pursuing their own objectives or shared ones) depending on the context, circumstances or environments. Autonomous behavior through the collection and reasoning of context information as well as the object's ability to detect changes in the environment (faults affecting sensors) and introduce suitable mitigation measures constitutes a major research trend, clearly needed to provide credibility to the IoT technology. Modern IoT products and solutions in the marketplace use a variety of different technologies to support such context-aware automation, but more sophisticated forms of intelligence are requested to permit sensor units and intelligent cyber-physical systems to be deployed in real environments.

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