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Internet of Things (IoT): Present State and Future Prospects

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SUMMARY The recent development of communication devices and wireless network technologies continues to advance the new era of the Internet and telecommunications. The various "things", which include not only communication devices but also every other physical object on the planet, are also going to be connected to the Internet, and controlled through wireless networks. This concept, which is referred to as the "Internet of Things (IoT)", has attracted much attention from many researchers in recent years. The concept of IoT can be associated with multiple research areas such as body area networks, Device-to-Device (D2D) communications networks, home area networks, Unmanned Aerial Vehicle (UAV) networks, satellite networks, and so forth. Also, there are various kinds of applications created by using IoT technologies. Thus, the concept of the IoT is expected to be integrated into our society and support our daily life in the near future. In this paper, we introduce different classifications of IoT with examples of utilizing IoT technologies. In addition, as an example of a practical system using IoT, a tsunami detection system (which is composed of a satellite, sensor terminals, and an active monitoring system for real-time simultaneous utilization of the devices) is introduced. Furthermore, the requirements of the next generation systems with the IoT are delineated in the paper.

key words: *Internet of Things (IoT), tsunami detection, Body Area Network (BAN), satellite, sensor*

1. Introduction

In recent years, the concept of the Internet of Things (IoT) is gaining momentum due to the development of the wireless networking technologies, such as Long Term Evolution Advanced (LTE-A), Wireless Fidelity (WiFi), Bluetooth, ZigBee, and so forth. Conventionally, these network technologies are utilized for establishing communication from the Person to Person (P2P) or the Person to Machine (P2M) perspectives. However, due to the diversification of the network equipment, Machine-to-Machine (M2M) communication is also utilized in numerous circumstances, such as inside homes, commercial buildings, schools, hospitals, and factories. The development of smaller and less expensive wireless devices enables not only smart-phones, tablets, and personal computers but also cars, home electrical appliances, and so forth, in order to connect them to the Internet. For example, electric lights, air conditioners, and water heaters can be connected to the network inside a building, and thus, they may be controlled for optimizing the environment inside the building with minimum power consumption. In addition, miniaturized network equipment allow communication with the so-called "nano" machines. The nano machines-based networks have attracted much attention, particularly the technologies for body area networks, which give rise to new applications in our daily life, e.g., health care systems utilizing the nano machines. On the other hand, the concept of IoT is also significant for large-scale information systems. For example, in freight transportation systems, each cargo in the system has an Integrated Circuit (IC) tag, which includes information such as address and sender information. In addition, the Global Positioning System (GPS) is used to confirm the current locations of the freights. By employing wireless networks, the information obtained from the IC tags and GPS are collected and utilized to efficiently control the transportation process. On the other hand, M2M communication technologies can be used for natural disaster detection purposes since the sensor devices equipped with wireless communication module can be deployed even in hazardous areas such as deep ocean, active volcanoes, and radioactive areas. Particularly since the East-Japan Catastrophic Disaster in March 2011, such large-scale data collection systems have been considered as a potential application of IoT systems. In this way, the concept of IoT can cover various scales and types of networks. But the main point regarding the IoT application in such scenarios is that numerous "things" are connected with one another, and controlled by the technologies of computing and networking. While connecting the "things" realizes to know the state of the "things", to control the "things" is the key issue to be considered in the future IoT research area. Thus, in this paper, we discuss the vision of IoT especially with respect to different types of networks, and represent some future perspectives of IoT.

The remainder of this paper is organized as follows. Existing works focusing on IoT systems are classified and introduced in Sect. 2. Section 3 introduces concept and experiment of a tsunami detection system and an active monitoring system for real-time simultaneous utilization as examples of practical IoT systems. In Sect. 4, the future perspective of IoT is discussed. Finally, concluding remarks are provided in Sect. 5.

2. Classifications and Examples of IoT Systems

As a result of rapid development in communication tech-

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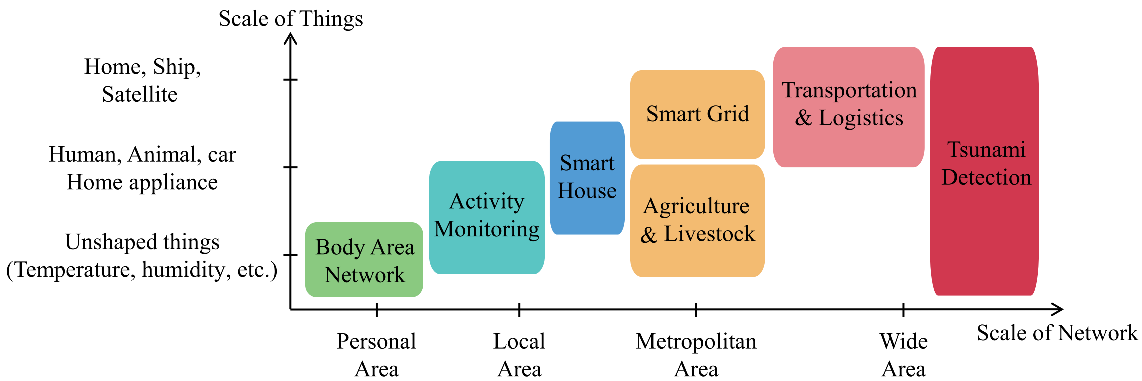

Fig. 1 Classifications and examples of IoT systems.

nologies, a huge variety of networking technologies with different scales are being utilized in our daily life. Due to the large diversity of networks being deployed, the concept of IoT can be broadly classified in terms of network scale as illustrated in Fig. 1. In this section, we aim to classify IoT systems and introduce examples of different IoT systems according to their respective scales of the network.

2.1 Internet of Nano Things

Firstly, we introduce the concept of the Internet of Nano Things (IoNT) as a type of IoT with small networks comprising extremely small devices in personal area. In the IoNT, by embedding nano-sensors to the various objects and devices that surround users, it becomes possible to add a new dimension to the IoT. Such miniature sensors, interconnected through nano-networks, could provide data from the things (i.e., devices) deployed in hard-to-access areas. The IoNT is expected to lead to the discovery of novel insights and applications in the IoT field.

The work conducted by Akyildiz *et al.* in [1] focuses on electromagnetic communication networks among nano-devices. Their considered network is composed of nano-machines, which include nano-nodes, nano-routers, nano-micro interface devices. These devices construct intra-body networks to provide health-care applications. Additionally, the work shows the model of interconnected office, where every single element normally found in an office are provided with a nano-transceiver. The nano-transceiver in each element allows it to be permanently connected to the Internet. Moreover, the work by Balasubramaniam *et al.* focuses on wireless body area networks constructed by nano devices [2]. The body area networks collect vital patient information and feed those information to service providers' computing systems. As a consequence, it achieves higher accuracy and efficiency in monitoring the health conditions of a large number of patients. Moreover, sensors embedded in the environment can passively assist daily life of the elderly and disabled people. With the development of small devices and their communications performance, such networks in tiny area are also expected to be required in the future.

From the afore-mentioned works, it is understood that IoT with nano-machines have attracted much attention as one of the new research areas. In addition, many research issues on the network are outlined in previously mentioned works. For instance, in the work of Balasubramaniam *et al.*, data collection challenges and middle-ware challenges are picked up. To efficiently collect a large amount of data that nano devices generate, their research attempted at solving the problems from the point of views of system architecture and routing technology. Due to the size of the devices in the network, there are some significant differences between macro and nano devices such as frequency range, energy consumption, and energy recharging method. Additionally, due to the limited memory storage and computational processing capability, it is almost impossible to utilize the knowledge pertaining to the topology of their considered communications environment. Thus, the traditional protocols and algorithms for macro networks cannot be applied to the nano networks.

2.2 Internet of WiFi-Enabled Things

Secondly, we show the concept of IoT consisting of WiFi-enabled devices in middle size of networks. WiFi has nowadays become a popular means of wirelessly connecting various electronic devices to the Internet. Recently, not only mobile devices such as smartphones and laptops but also home appliances and various kinds of sensors in local area are connected to the Internet by employing WiFi. Using the WiFi technologies, along with the concept of D2D, is considered to provide more flexible IoT systems.

In the work [3], Tozlu *et al.* focus on IoT constructed by WiFi equipped sensors and actuators. Especially, they focus on energy consumption of devices in the network. Since various types of devices are connected to the same network in this considered IoT, the difference in energy utilization becomes a significant problem to guarantee network connectivity. In their work, the devices having WiFi functionality are categorized into three types: AC-powered devices (home appliances, PCs), rechargeable devices (laptops, smart-phones), and battery-powered devices (sensors like smoke detectors, motion detectors, and so forth). In addition, the impact of interference and communication range are considered as the main problem.

On the other hand, the networks using D2D communication are also considered as a category of IoT. In the work [4], multi-hop D2D communication is focused. Generally, D2D communication is carried out by using WiFi technology. Additionally, smartphones can communicate with one another using their WiFi functionality. Nishiyama *et al.* developed a new type of multi-hop D2D communication system, namely "Relay-by-Smartphone" which enables message delivery by using only mobile devices. Additionally, in the developed system, the routing methods of Mobile Ad Hoc Network (MANET) and Delay/Disruption-Tolerant Network (DTN) are combined to achieve effective message delivery. The appropriate routing scheme of devices is chosen dynamically based on the devices' surrounding environment. Moreover, the results of real field experiments conducted by using device prototype are presented. By using this technology, a new type of network can be constructed and can be considered as one of the IoT systems.

2.3 Internet of Things for Smart Society

The concept of IoT has also drawn a great deal of research attention for realizing an intelligent society. Unlike the above mentioned examples, it focus on the concept of IoT from a larger scale. To see the IoT from the large area like a city or a metropolitan area can make a novel perspective for utilizing the network technologies.

Li *et al.* introduced an IoT application, namely the smart society, in their work in [5]. The smart society is a virtual environment consisting of networked smart homes located in a local geographic region. It can improve community safety, home security, health-care quality, and emergency response by continuously monitoring the community environment from various aspects. In their work, the authentication problem and unreliable nodes detection are denoted as networking challenges in the smart community. It is necessary to improve the security and reliability to make the smart society possible in the near future.

Vlacheas *et al.* [6] focus on the development of the future smart cities from the perspective of cognitive management framework of IoT. The main focuses of the proposal are summarized as follows.

- How to make the heterogeneity of connected objects in the networks transparent.
- How to ensure the resilience of dynamic service provisioning.
- How to instruct the systems to assess proximity between IoT applications and "things".
- How to use cognitive technologies to offer intelligence while minimizing users' intervention.

To develop a smart society with the help of IoT, such cognitive management framework is necessary.

Kortuem *et al.* discussed smart objects for industrial workplaces. In their work in [7], they classify the smart objects into three types, which are "activity-aware object", "policy-aware object", and "process-aware object". As an application of smart objects, they assign "pay-per-use", "health and safety", and "active work guidance", respectively. The authors mentioned that it is important to expand smart object design beyond hardware and software by including interaction design as well as social aspects. Additionally, the goal is to support people who perform complex physical tasks by using smart objects effectively.

From these works for IoT with smart things, it seems that the concept of IoT leads to a more convenient society. These challenges from multiple aspects are expected to make smart society possible in the future.

2.4 Global-Scaled Internet of Things

At last, we show some example of the IoT systems which are utilized in global-scaled area. Here, we introduce the concept of global-scaled IoT with some existing works on Unmanned Aerial Vehicle (UAV) and satellite networks. Both UAVs and satellites have large coverage and can connect to various devices on the ground such as sensors.

Giorgetti *et al.* focus on data retrieval from a sensor field by using a UAV [8]. By using a UAV to collect data form sensors, a large area can be covered and the data collection can be more flexible due to the mobility of UAV. On the other hand, sensors on the ground can collect various kinds of environmental information such as temperature, pressure, humidity, and so forth. Additionally, wireless sensor networks are expected to play a major role in disaster detection [9], [10]. Especially after East-Japan Catastrophic Disaster in March 2011, early and accurate disaster detection system is required. Thus, the integration of UAV and wireless sensor networks is one of the possible solutions for environmental observation and disaster detection systems. Moreover, the UAV can contribute to enabling communication in disaster area. In the disaster area where ground-based stations used by existing communication methods were destroyed, alternate communication methods can be provided by relaying the data from users on the ground to surviving ground-based station via the UAV. Furthermore, Luke *et al.* considered to construct a network consisting of multiple UAVs for gathering information on the ground [11].

On the other hand, the global-scaled IoT utilizing the satellites network is focused in the work in [12]. The work envisioned a novel data collection method in Satellite-Routed Sensor System (SRSS) to accomplish a global-scaled IoT. In that system, the satellite communicates with smart things equipped with sensors located on the ground directly to collect various kinds of information. Another application of global-scaled IoT is to prevent traffic jams by using data collected from cars in a large area, where the data collection can be carried out by using satellites. Additionally, satellites enable data collection from isolated areas where ground communications infrastructure has not been provided, such as sea or mountain areas and developing countries. Similarly, Bisio *et al.* consider an environmental monitoring system over a wide area by using satellite networks [13]. In their work, the satellite collects data form sensor nodes deployed in wide area via sink nodes. They consider how to select an appropriate sink node to forward data to the satellite to improve reliability and reactivity, and reduce energy consumption. From these works, it is shown that not only devices on the surface but also satellites can play a major role to construct an IoT.

3. A Practical System in Collaboration with IoT

In this section, we introduce two successive practical systems as examples of pragmatic IoT systems, one is global scale and another is local area. As examples, we illustrate the tsunami detection system and activity monitoring system for real-time simultaneous utilization. In this introduction, the concept of these systems and some experiments which are conducted with these systems are described in the following.

3.1 Tsunami Detection System

Here, we introduce the tsunami detection system as an example of pragmatic global-scaled IoT systems. This system is developed as a joint project of Kochi National College of Technology (KNCT), Earthquake Research Institute, University of Tokyo, Hitachi Zosen Corporation, Japan Aerospace eXploration Agency (JAXA), and National Institute of Information and Communications Technology (NICT). This project aims to facilitate early detection of the tsunami by using real-time observation of the sea level. In this system, a large number of buoys equipped with sensors and small earth stations are planned to be deployed around Japan. The sensors can measure the fluctuation of the wave height while the small earth stations can send the data gathered from the sensors to the satellite. In the remainder of the paper, we refer to a buoy equipped with a sensor and a small earth station as a sensor terminal. In order to cover the entire Japan and detect a tsunami as early as possible, it is necessary to deploy numerous sensor terminals. In the case where the sensor terminals are deployed in a large scale, it is difficult to send the data gathered from the sensors directly to the base station on the ground by ground-based wireless networks due to the remotely located base station. Therefore, in this system, the data is sent from the sensor terminals to the base station via a satellite. Since the satellite has a large coverage, it is possible to collect data from sensor terminals deployed throughout Japan.

In order to construct the tsunami detection system, a lot of components are developed such as sensors, small earth stations, base stations, and satellites. Figure 2 illustrates the components of our considered tsunami detection system that have been currently developed as prototypes in the project. The sensors measure the change of the Z-axis position by using the GPS. The change of the Z-axis position implies the change of the sea level. The collected data is sent to the base station via a satellite and then the data are analyzed to distinguish the tsunami from normal waves. Thus, the occurrence of a tsunami can be detected at the base station. To transmit the data gathered from the sensors to the satellite, non-directional helical antenna is employed. It is because the direction towards the satellite is always shifting due to the movement of the buoys. The size of the antennas are relatively small at approximately 500 millimeters. This is possible because the satellite has a large antenna to communicate with the ground stations. In this project, the Engineering Test Satellite VIII (ETS-VIII), which was launched by JAXA in December, 2006, was utilized for various experiments including the communication with the sensors. The large deployable antenna of ETS-VIII allows the ground stations to be smaller. Additionally, it decreases the energy consumption of the ground stations. Moreover, since ETS-VIII employs the S-band frequency, it can avoid rain attenuation in the satellite-sensor and satellite-ground station links. Furthermore, Time Division Multiple Access (TDMA) is adopted as the channel access method to treat multiple sensor terminals by using the same channel. By using these components, the sea level fluctuation data are collected and analyzed at the base station.

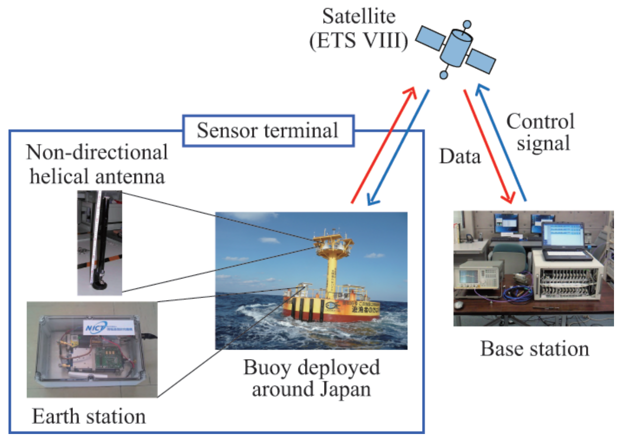

Fig. 2 Components of our considered tsunami detection system.

The data transmission experiment which was conducted with the prototype equipment is performed. In this experiment, a buoy equipped with a sensor and a earth station is deployed at approximately 35 kilometers from Muroto-misaki Cape in Kochi Prefecture, Japan. The data gathered from the sensor are transmitted to the base station at Kashima Space Technology Center of NICT via ETS-VIII. Additionally, the data are transmitted from the base station in real time to KNCT, which analyzes the data. Figure 3 demonstrates the result of the conducted experiment. The graph represents the change of Frame Error Rate (FER) of hourly measurement. The measurements were carried out over five days. In the conducted experiment, the data generated at the sensor termianl is observed at the base station. From the result, it is also understood that the FER is different from time to time, and also from day to day. This happens because the communication environment between the sensor terminal and the satellite is significantly influenced by

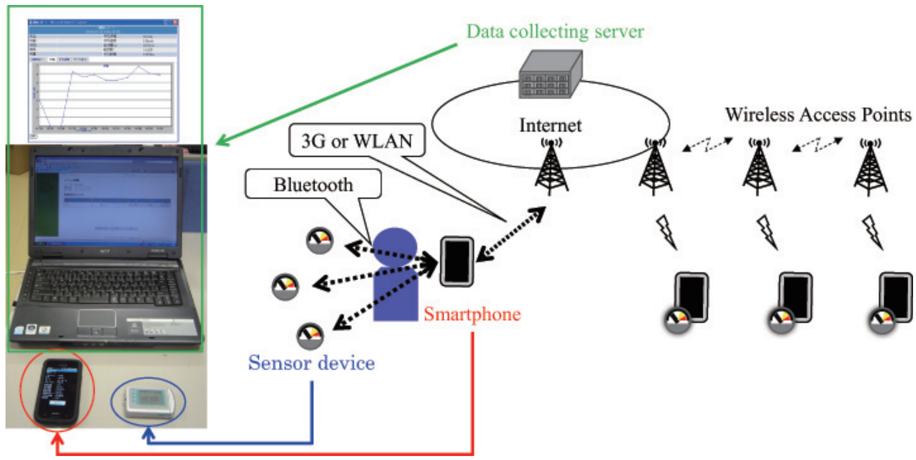

Fig. 4 The system constitution of the activity monitoring system for real-time simultaneous utilization.

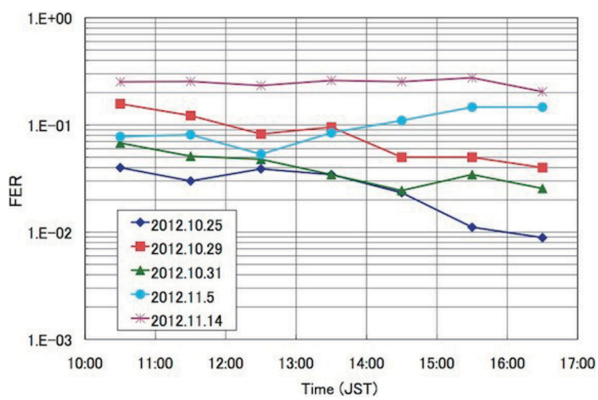

Fig. 3 The change of FER of hourly measurement.

the size of the wave and its cycle at the measurement time. Since the sensor terminal is deployed on the sea, its position drastically changes over time, which causes communication link to the satellite to become unstable. However, the experimental results demonstrate that the data from the sensor terminals are successfully transmitted to the base station on the ground via satellites even though the communication environment is not stable. For interested readers for further reading, an effective way to collect data from numerous sensors can be found in the research conducted in [12], [14].

3.2 Activity Monitoring System for Real-Time Simultaneous Utilization

Next, we introduce the activity monitoring system and the experiment that we conducted with a prototype of this system. This system can be considered as an example of integrated IoT system, which consists of local area networks and personal area networks. The significance of the integrated IoT system will be further explained in the next section. This particular system has been developed via industry-university cooperation which is supported by the Greater Sendai Area Knowledge Cluster Initiative (GSAKCI) of the knowledge cluster initiative (2nd stage) in Japan. As the member of this project, our team from Tohoku University joined with Tohoku Institute of Technology, Cyber Solutions Inc., and I. T. Research Co. LTD to develop the system. This system aims to measure the stabilizing exercise habits of individual users and visualize the benefit of exercise. Especially, in this system, the measuring of the users' outdoor exercise, measuring multiple users' conditions simultaneously, and summarizing the measurement data and generating a report immediately after the exercise are listed as the requirements of the system.

To realize the requirements, we developed the system as demonstrated in Fig. 4. In this system, each user moves with an activity monitoring device, namely "I-moni", and a smartphone. I-moni is a sensor to measure the activity of the user such as the length of stride, speed, expenditure of calories, number of steps, and walking distance. These activity is presumed from the data measured by I-moni equipped with a triaxial acceleration sensor. These data are sent to the smartphone by using Bluetooth. The smartphone which received the data from I-moni sends it to the servers to monitor the information via Wireless Local Area Network (WLAN). The Access Points (APs) in the WLAN are also connected by wireless with one another to relay the data to the servers. At the server, the data are statistically analyzed and indicated to the monitor in real time. Additionally, the information are provided as a report to the users immediately after the exercise.

An experiment to test the system was conducted in the project as a part of a Nordic walking event [15]. In the experiment, about 20 users measured their activities for 10 to 15 minutes. The users moved around the area where the APs were deployed and the data were successfully collected by the servers and monitors. Additionally, the statistically analyzed data were provided to the users immediately after the exercise. From the experiment, it can be understood that many "things" such as sensors, smartphones, APs, and servers can be connected to each other by using wireless communication technologies, and this makes it possible to provide a new service. Although this is just one of the ex-

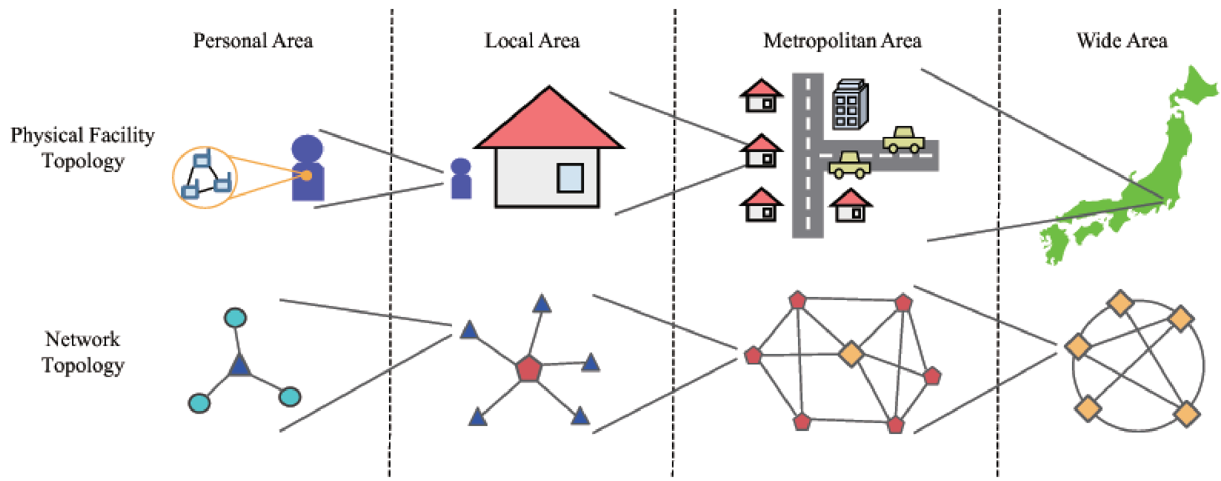

Fig. 5 An example of the situation where the different sizes of existing IoT systems coexist.

amples to utilize the IoT technologies, it indicates the possibility for futuristic smart society that are expected to seamlessly utilize IoT technologies.

4. Future Perspective of IoT

In this section, we consider the integrated IoT system, which shows that the different sizes of existing IoT systems can cooperate, as depicted in Fig. 5. In the future, things may be controlled not only inside the network that they are the parts of but also with the condition of other network scales. In such situations, it is necessary to consider the way to efficiently utilize the new type of IoT systems. In this section, we discuss the future perspective of IoT with several challenging issues.

4.1 Integrated Future IoT Systems

From the investigation of the existing researches on IoT, it is understood that almost all existing research works consider the IoT system in a limited size of area or using a limited communication method. In the earlier section, we classified these researches into four groups, including the "Internet of nano things", "Internet of WiFi-enabled Devices", "Internet of Things for Smart Society", and "Global-scaled Internet of things". As seen in these works in each group, they attempted to solve the problem which occurs inside the network that they are focusing on. Additionally, they do not employ a wide variety of communication methods. Moreover, from a different point of view, many of the earlier research works aimed to extend the existing researches on Wireless Sensor Networks (WSNs) to construct IoT-based networks. Therefore, it is imperative that researchers take upon a more direct approach to IoT by envisioning more specialized themes in this area. Thus, we focus on integrated future IoT systems as one of the future topics.

In the integrated future IoT system, many "things" which have different types of communication methods and belong to different kinds of networks are connected, and by this way, they can share the required information. In the existing works like WSNs, the connected and controlled objects usually have the same purpose. Thus, the requirements for the system such as protocol, security, and management schemes are considered in the limited area or for a limited communication methodology. However, in the future IoT systems, different systems having different objectives and purposes coexist in the same network. Additionally, it might be that an object is observed and controlled by different systems with different purposes. Therefore, it is needed to consider how to integrate the coexisting systems and construct new IoT systems. So in the following, the requirements of the future IoT system is discussed from the point of view of the integrated IoT systems.

4.2 Requirements of Next Generation IoT Systems

4.2.1 Large Address Space

First of all, the development of the communication technologies in each scale of the network is needed. Especially, in the personal area network, various types of communication ways such as P2P, P2M, M2M, D2D, and so forth, are utilized in the same system. Additionally, the number of "things" in the network is dramatically increased. Thus, appropriate protocols for the communication in the personal area is required. In these surroundings, the Internet Engineering Task Force (IETF) has developed a suite of protocols to support the IoT [16]. In particular, as introduced in the work of Sehgal *et al.*, the IPv6 protocol has attracted much attention in improving the IoT communications [17]. Due to the large address space available in IPv6 and a large number of existing protocols that are already functioning over the IP, IPv6 is expected to become a fundamental part of IoT. Moreover, the efficient usage of low power and low bandwidth still remains as one of the challenging issues. Thus, the IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) standard is expected to support the IoT communication. The 6LoWPAN is an adaptation layer enabling the exchange of IPv6 packets over IEEE 802.15.4 links, which is a radio technology standard for low-power and low-data-rate applications with a radio coverage of only a few meters. From these research works, it is understood that the concept of 6LoWPAN is, indeed, adequate for the IoT. Moreover, downsizing of the devices and energy minimization problem are also significant issues in the personal area networks [18]–[20].

4.2.2 Network Scale Based Security Frameworks

Secondly, the security issue is also focused as an important research topic in IoT [21]–[23]. Since many kinds of devices having various information are connected to the IoT network, security requirements are varied according to network conditions. Additionally, since the required information is different in each scale of the system, the required security framework is also different in each scale of the system. Thus, the existing framework of security is not sufficient to keep the IoT secured. For example, in the Smart Grid (SG) system [20], [24], the information from each smart house is collected by a management center and they are controlled by the center. At the same time, in each smart house, the energy consumption of each home electrical appliance is the required information and controlled object. But, such detailed information are not required for the management center. In this way, the required information is different in each system having different network scales. Thus, the security framework, which is needed for each network is also different. As introduced in [25], since many "things" are connected to the untrusted Internet, how to construct a safe and secure network is also important for the IoT systems.

4.2.3 Data Proccessing

Finally, we focus upon the technology for controlling big data as the requirements for the future IoT system. In the integrated IoT system, since various kinds of data are collected from many systems, huge quantities of data are needed to be controlled. In existing works on big data, there have been already some solutions to control such a massive amount of data. However, in the future integrated IoT system, not only the amount but also the number of varieties of data is also quite large, which causes the difficulty of the data management in the existing system. Thus, to realize the effective big data management in the integrated IoT system, management schemes for big data in each scale of network and a novel framework to control the summarized data in each network is essential.

As just described, it is shown that there are many remaining issues to realize the future IoT system. Since various kinds of objectives are observed and controlled in the future system, integrating various systems is required to control these systems efficiently. Thus, to realize the future integrated IoT systems, it is significant to consider an efficient way to integrate various kinds of systems from the point of view of multiple scales of the network systems.

5. Conclusion

This paper described the present state and future prospects of IoT. As introduced in this paper, various kinds of network systems have been created in the recent years. Since the concept of IoT is associated with different types of networks, which can be constructed by many "things" such as nano machines, smartphones, home appliances, sensors, actuators, UAVs, satellites, and so forth, there are many research directions on IoT. The differences of devices, communication methods, ranges, surrounding environment, applications, and so forth, cause the different requirements of the IoT technologies. Thus, in this paper, we introduced some existing works on IoT from the point of view of different networks and summarized the requirements to make next generation IoT systems possible. In addition, we introduced a tsunami detection system, which is constructed by a satellite and sensor terminals, and an active monitoring system for real-time simultaneous utilization as examples of practical IoT systems. From the results of the conducted experiments, these systems have potential to improve our daily lives and are expected to be practically used in the near future. Moreover, we discussed the future perspective of IoT systems. From the discussion, as the future aspect of the IoT system, an integrated future IoT system was introduced. To realize the next generation IoT system, we should address some research issues by utilizing exiting researches as the initial IoT framework. Furthermore, it was shown, in the paper, that various kinds of the future system with IoT have gradually begun to emerge. Indeed, the concept of the IoT is not only for a limited research area but also fits, interestingly, into multiple topics of networking areas that need to be pursued in future.

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