Technologies for Reducing Environmental Load of Next-generation Smart Cities

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Environmental problems are increasing at a fast pace: water and food shortages due to rapid population growth; climate change; the exhaustion of resources and energy sources; pollution of water, soil, and the atmosphere; and the decrease in biodiversity, to name a few. To provide solutions to these problems and achieve a sustainable, prosperous society, the potential of information and communications technology (ICT) must be leveraged both for the protection of the global environment and to secure economic growth—in other words, to attain "green" growth. Furthermore, more research and development is required not only on environment-related issues but also on social issues related to agriculture, energy, smart cities, transport, medicine, education, and other domains. Fujitsu is striving to expand the limits of social sustainability by pursuing a Human-Centric Intelligent Society while creating various innovations for society with new value through advantageous use of diverse types of information. From among research and development efforts designed to support innovations related to society and the environment, we will present in this paper an energy harvesting technology that supports machine-to-machine applications, environmental management technologies, and environmental measurement technologies, as technologies that reduce the environmental load of next-generation smart cities.

1. Introduction

World population broke through the 7-billion level in 2011 and is expected to increase to 9.2 billion by 2050. This dramatic growth is commonly called the "population explosion." This increase in the number of people inhabiting the planet is expected to magnify water and food shortages, and the trend toward highly populated urban centers is expected to greatly affect the living environment, such as degradation in living conditions and increases in traffic congestion. At the same time, environmental problems such as climate change, depletion of resources and energy, poor water and soil quality, atmospheric pollution, and loss of biodiversity are accelerating at a rapid pace. Faced with these problems, the earth is in a crisis situation.

These global problems must be solved, and a sustainable society must be achieved. Fujitsu envisions the creation of a Human-Centric Intelligent Society. It aims to use the power of information and communications technology (ICT) to expand the range of sustainability and to stimulate innovation in society by using diverse types of information to uncover new value.

From among the various research and development endeavors that Fujitsu is undertaking to support social and environmental innovation, this paper introduces important environmental-load reduction technologies for use in building next-generation smart cities.

2. Development of innovation-driving technologies

Fujitsu believes that a greater environmental-load-reduction effect can be achieved by creating solutions that combine past research and development achievements that have contributed to reducing the load on the environment. In the following, we give some examples of creating new value by integrating technologies that are needed for next-generation smart cities.

A smart city manages renewable forms of energy

and electrical energy for the power grid and reduces environmental load by optimizing the consumption of energy. Great importance is given to achieving environmental goals while simultaneously providing safety and security and a fulfilling way of life for the people who live in the city. That is, great importance is given to sustainability, which is an essential requirement for the society of the future. Fujitsu is engaged in research and development of technologies that can promote innovation across the environmental, social, and economic fields. This is explained below for four technology categories (**Figure 1**).

1) Energy harvesting technology for M2M data collection

A smart city must uncover optimal solutions by analyzing huge amounts of data. One way of collecting such data is to apply machine-to-machine (M2M) technology. For example, if smart meters were to be installed in every home as electric-power sensors, the technology used to support the collection of that data would be called M2M. A sensor, however, is typically a device that functions on electric power, which means that a power supply that can serve the number of sensors installed—even if a huge number—must be secured. One technology for solving this problem is "energy harvesting."

2) Environmental management technologies

These technologies encompass the management technologies that a smart city needs, including the management of electrical energy. They are based on the idea that urban assessment should recognize that the problems faced by an urban region with a high population density differ, for example, from those faced by a mountainous region with an abundance of nature and a lower population density and that it should derive solutions to problems unique to each type of region.[1)] Fujitsu is developing urban assessment technology that can highlight the unique values of a region and the problems that need to be solved there and that is based on a variety of assessment items arranged along three major axes representing social, economic, and environmental factors.

Additionally, from the viewpoint of using diverse types of energy, the effective use of thermal energy is an important element of environmental management. For example, data centers operated by ICT enterprises consolidate a large number of ICT devices that consume a considerable amount of electric power, and

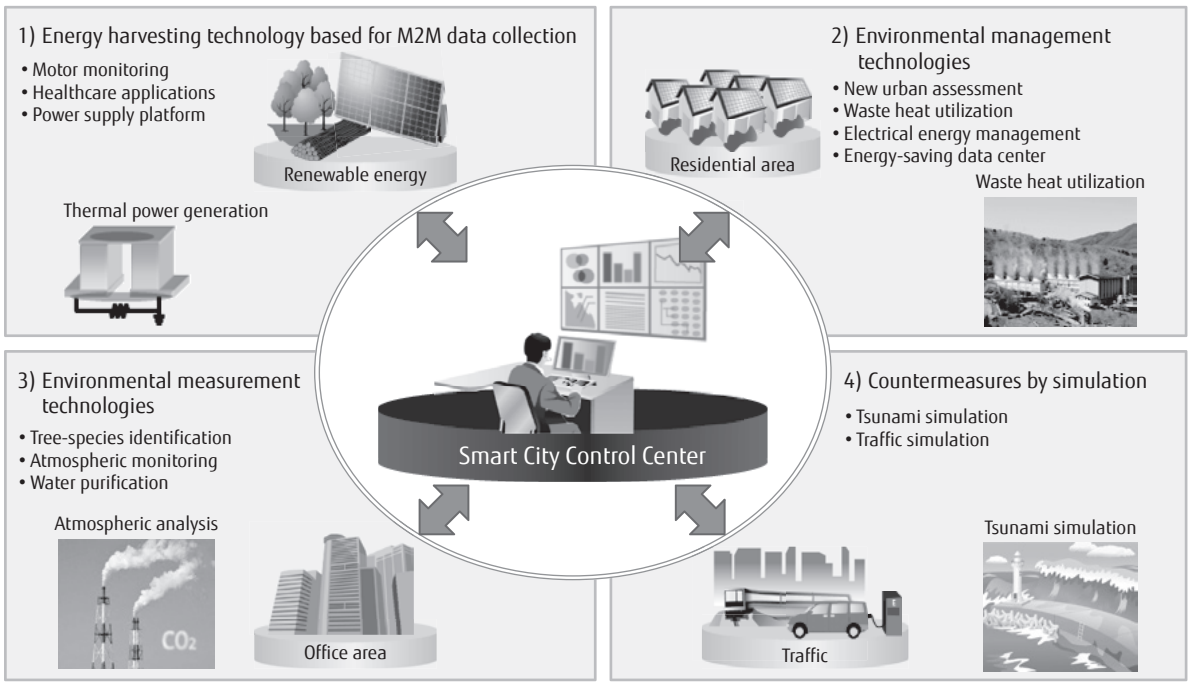

Figure 1
Technologies for next-generation smart cities.

this power is eventually discharged as thermal energy. When combined with electrical energy management technology, thermal energy management technology for making effective use of waste heat can optimize energy management in a smart city.

3) Environmental measurement technologies

Air and water—the source of life—are key elements when focusing on the environment that surrounds us all. Furthermore, while the increase in carbon dioxide concentrations in the atmosphere is a major factor in global warming, forests serve to absorb carbon dioxide while also providing us with materials in the form of wood that we need for living. The appropriate management of forests is therefore essential to achieving a sustainable society. Fujitsu has developed a technology for identifying tree species using ICT and is using this technology to provide solutions that can contribute to good forest management. Air pollution by particulate matter ($PM_{2.5}$) has also become a problem of late, and the need for air pollution monitoring using sensing technologies is expected to grow. Meanwhile, the total amount of water on earth is about 1.4 billion km^3, but the amount of water in easily accessible rivers and lakes that can actually be used is only about 0.8% of this total. This means that water purification technology will be indispensable to making more effective use of water resources. Fujitsu is contributing to the advancement of water purification technologies through its development of a photocatalytic material called "titanium apatite."

4) Countermeasures by simulation

Although not covered in detail in this paper, there is growing awareness that using disaster-prevention simulations to minimize the effects of abnormal weather brought on by global warming and mobility-related simulations to reduce environmental load can help achieve a sustainable society.

The remaining sections of this paper describe technologies 1) to 3) above in more detail.

3. Energy harvesting technology for M2M applications

A major issue in achieving an M2M wireless sensor network is the provision of an adequate power supply. The replacement of primary batteries installed in a large number of sensor modules is time consuming and costly. Also, battery replacement is usually very difficult in the case of marine and underground sensing separated from the power grid. Energy harvesting is a technology that can solve these problems. The application of this technology to an M2M sensor network enables a maintenance-free wireless sensor network using various types of sensors to be realized.

Energy harvesting technology captures ("harvests") energy that, while being all around us, has not been greatly used up to now and converts that energy into usable electric power. It is also called "environmental power-generation technology." For example, energy harvesting technology can be used to convert energy such as heat (temperature difference), vibration, and light existing in all sorts of places in the environment into electric power. The electric power obtained from such a conversion of energy is very weak (of the order of μW to mW), but using it in just the right way in just the right places can provide new value to M2M networks by supplying power to locations outside the power grid and providing maintenance-free, battery-free, and cable-free operation. Of course, a storage device is essential to making effective and efficient use of the weak electric power generated by an energy harvesting device. And such a storage device should be integrated with the energy harvesting device when developing an M2M wireless sensor module. This is because a series of operations including sensing and radio transmission must continue to be performed even if the energy harvesting device stops generating power due to environmental factors. Combining the energy harvesting device and storage device in this way makes it possible to control generated power and provide the module with a stable supply of power regardless of the type of sensor (**Figure 2**).

Fujitsu is researching and developing an all-solid-state secondary battery as a power supply device for M2M wireless sensor modules. While Li-ion secondary batteries, like those used in notebook computers and smartphones, contain an organic electrolyte solution or a polymer electrolyte, which may be a source of battery ignition at elevated temperatures, an all-solid-state secondary battery contains a solid electrolyte, which is both non-combustible and robust to deterioration from repeated use. Since Li ions within the solid electrolyte must be able to move back and forth with ease at high speed, ion conductivity, which is the index of Li-ion mobility within an electrolyte, must be improved in

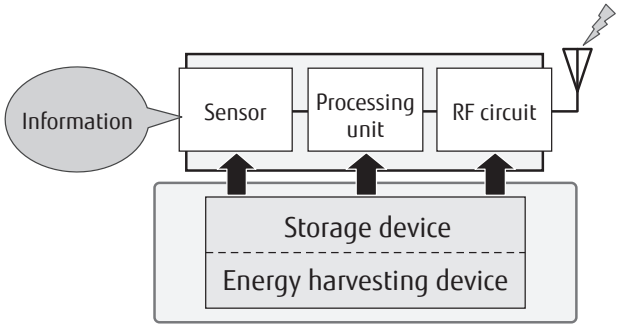

Figure 2
Self-powering wireless sensor module for M2M applications.

all-solid-state secondary batteries. In response to this problem, Fujitsu has developed a sulfide-based solid electrolyte for all-solid-state Li secondary batteries. It has an ion conductivity of 2.2×10^{-4} S·cm^{-1}, which surpasses that of conventional nitride-based solid electrolytes (1.0×10^{-6} S·cm^{-1}) and exceeds our target value (1.0×10^{-4} S·cm^{-1}).[2] Fujitsu continues to research and develop new batteries toward their practical application to M2M wireless sensor modules.

With the aim of implementing practical M2M wireless sensor modules using energy harvesting technology, Fujitsu has designed and fabricated prototype general-purpose circuits for energy harvesting that can use a storage device (such as an all-solid-state secondary battery) and various types of harvesters (thermoelectric, solar power, etc.) as a power supply and that enable various types of sensors to be selected and connected as the input device. The wireless module used can incorporate a radio device conforming to any of various telecommunication standards and the M2M wireless sensor module used has a circuit for energy harvesting to monitor the amount of power generated by the temperature difference between the elevated temperature at the surface of the motor (approximately 50°C) and ambient air (approximately 20°C). That difference was successfully transmitted and received elsewhere at 10 s intervals, thereby demonstrating that energy harvesting technology could indeed be applied to M2M wireless sensor modules.

In the Human-Centric Intelligent Society envisioned by Fujitsu, the huge amount of data output by wireless sensors will have to be efficiently collected. Fujitsu believes that energy harvesting technology can achieve a maintenance-free wireless sensor network and make a major contribution to the collection of big data.

4. Environmental management technologies

Urban assessment for uncovering the values of a city and electrical energy management for making efficient use of energy are considered to be important technologies for building a smart city. The following describes the circumstances leading to the development of each of these technologies.

1) Urban assessment technology[3]

Ideally, a sustainable society is moving forward and progressing while striking a balance among its environmental, social, and economic aspects. A promising approach to achieving such a society is to visualize a region's resources and unique problems, provide appropriate countermeasures and ICT solutions, and stimulate the region's economy. Since the problems enveloping a region are diverse in nature, it is important that the region-unique problems be clearly identified and that appropriate measures toward solving those problems be proposed. However, understanding the characteristics of a region is difficult because the problems enveloping it cannot be clarified by simple comparison with a nationally uniform standard. For example, if an urban region and a mountainous region are compared using the same standard, the degree of economic activity would tend to be higher for the urban region while the degree of environmental impact would tend to be lower for the mountainous region, much of which consists of forests and fields.

The technology that Fujitsu has developed enables the characteristics and problems of a certain region to be extracted by comparison with the national average of regions of the same type or by performance of a comparative assessment against similar local governments. Specifically, after subdividing the axes of environment, society, and economy into various factors and performing an assessment against more than 40 of those factors, this technology enables regions to be classified in accordance with population, industrial characteristics, etc. and for cluster analysis to be performed. As an example of applying this technology, the results of assessing an urban region (City A) and mountainous region (Town B) are shown in **Figure 3**. City A is better than the national standard in terms of

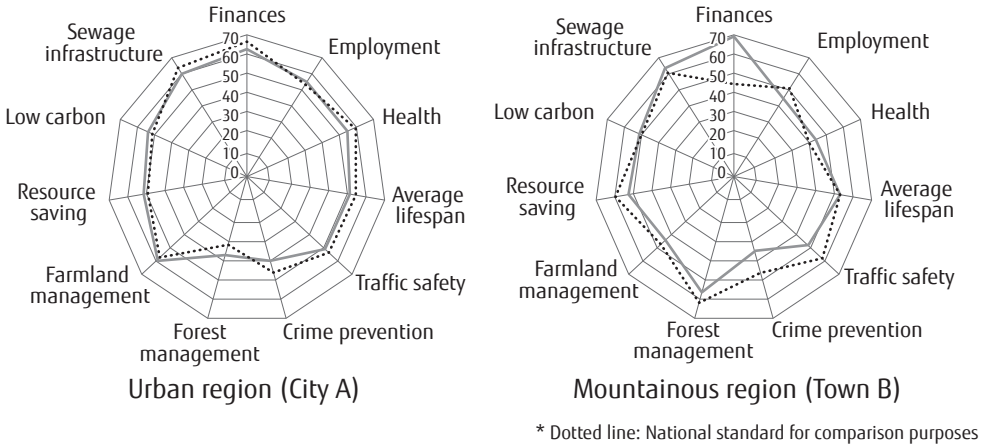

Figure 3
Assessment results for urban and mountainous regions.

finances and employment but is below the standard in terms of crime prevention. Town B is also above the standard in terms of finances and below the standard in terms of crime prevention. Investing in crime prevention can therefore be proposed in both cases due to the strong financial situation. Surprisingly, farmland management in Town B is below the standard while that in City A is above the standard despite the fact that the former is situated in a mountainous region. This is attributed to an aging population and a decrease in individuals engaged in agricultural activities.

2) Electrical energy management technology

The expansion of cloud services provided over the Internet is expected to dramatically increase the amount of electrical power consumed by data centers, which are the critical infrastructure for providing those services.[4] Furthermore, the trend toward consolidating more ICT devices in data centers will not only increase the power consumed by ICT devices but also increase the power consumed by air conditioning and other data center facilities. In fact, facility power consumption occupies about 40% of the total, so it is imperative that any initiatives to save power in a data center include facilities in addition to the ICT devices themselves. To this end, Fujitsu Laboratories has been conducting comprehensive and integrated research and development on a global scale across many fields, from energy-saving chips and system boards to server-system/network construction, power supplies, cooling systems, and software. It has been pursuing energy efficiency through bottom-up technology development while also constructing a value chain of energy-saving technologies.

Using free cooling (i.e., cooling using outside air) can greatly reduce the power needed to cool a data center. Fujitsu Laboratories has installed a container data center using free cooling on the premises of a Fujitsu plant and is evaluating its energy-saving performance as a method using no traditional cooling equipment such as air conditioners or chillers. Although free cooling is often adopted by data centers situated in cold regions, it was found from a one-year operational test that such a system could operate at a power usage effectiveness of 1.05 even in the Tokyo suburbs.[5]

The heat generated by ICT devices within a data center is discharged as warm air at below 100°C, which is difficult to reuse. Fujitsu Laboratories is developing a system for putting the waste heat from ICT devices to use. This system is based on an adsorption heat pump that makes use of the temperature difference between water heated by that waste heat and water at room temperature to produce cooling water under 20°C. This is a non-fluorocarbon, environmentally friendly cooling system using only an adsorption reaction. It requires no electric power other than that needed for driving a circulating pump and can operate on waste heat only. Fujitsu plans to combine this adsorption heat pump with a function that recirculates some of the exhaust from a server group back into the intake side as warm air to prevent condensation in winter. The goal is to

develop an advanced data center that uses waste heat to optimal effect.

It is important that the temperature distribution within a data center be understood in order to determine the state of heat generation from rack to rack and to operate the cooling system under optimal conditions. Known methods for obtaining this distribution include the installation of temperature sensors and the use of infrared cameras to the rate of infrared emission on the surface of racks. With these methods, however, the spatial resolution of the temperature distribution is low, and obtaining accurate measurements of the temperature distribution in real time is difficult. Fujitsu Laboratories has developed an optical-fiber temperature measurement system as a technology that can accurately determine the temperature distribution within a data center machine or server room in real time. This system has been offered by Fujitsu Network Solutions since April 2012 as a solution for visualizing the temperature distribution within a data center. It enables local hot spots within a machine or server room to be detected and high-reliability improvements to be implemented on the basis of actually observed temperatures instead of using predicted values from thermal flow simulations.[6)]

5. Environmental measurement technologies

To maintain and manage the environment well, first, the state of the environment must be understood. Next, measures for making improvements must be drafted and implemented, and finally, the effects of those measures must be evaluated. This section first introduces technologies for measuring environmental conditions, namely, a technology for measuring atmospheric corrosion, which can lead to corrosion failure in electrical and electronic devices, and a technology for identifying the species of trees in forests, which play an important role as a carbon dioxide sink. Next, as an example of an environmental countermeasure, it introduces purification technologies for air and water, the source of life on earth.

1) Atmospheric-corrosion measurement technology using QCM sensor

A quartz crystal microbalance (QCM) utilizes a phenomenon in quartz crystal oscillators: a substance that attaches to the surface of a quartz crystal oscillator acts as an oscillation load, causing the characteristic resonant frequency of the oscillator to drop. This means that forming a thin film of a target metal on an electrode quartz crystal oscillator and measuring the change in frequency to calculate the weight of the resulting corrosion product enables atmospheric corrosion for that metal to be evaluated. This technology has been used to develop environmental monitoring equipment having a compact sensor unit capable of battery-driven operation, wireless control, and data transmission and has been applied to a corrosion-countermeasure service provided by Fujitsu Quality Laboratory Ltd.[7)] It enables the source of a corrosive substance to be investigated and the effects of any countermeasures to be quickly and efficiently assessed. Through this technology, Fujitsu aims to achieve a safe and secure society by contributing to the prevention of corrosion-related failure in electrical and electronic devices and information equipment supporting the ICT society at production-control sites and data centers, in social infrastructures, etc.

2) Tree-species identification technology using hyperspectral imaging analysis

The recent phenomenon of climate change is considered to be caused by an increasing carbon dioxide level and to be the reason behind the frequent occurrence of abnormal weather throughout the world. There are fears that the impact of climate change will become even greater in the years to come. Forests are not only a source of carbon dioxide absorption but also a source of biodiversity preservation—they are a treasure trove of rich resources. To preserve our forests and make effective use of them, it is essential that the species of trees making up these forests be accurately identified. To meet this need, Fujitsu developed a technology that can distinguish between cedar and cypress trees with greater than 90% accuracy through the analysis of hyperspectral data. Compared with tree-species identification accomplished by conventional methods such as on-the-ground surveys and aerial photographs, this new technology can identify a wide range of tree species at low cost with high accuracy. Fujitsu is contemplating a "forest resource measurement service" using this technology with the aim of contributing to the sustainable use of forest resources in conjunction with advanced forest-management techniques and appropriate forest-preservation measures.

3) Water purification technology using titanium apatite

Fujitsu is expanding the product application of photocatalytic titanium apatite,[8] a purification material that was developed by Toshiya Watanabe, a professor at the University of Tokyo, and Fujitsu Laboratories. Titanium apatite decomposes organic matter adsorbed on the surface of material into water and carbon dioxide through a photocatalytic reaction caused by the irradiation of ultraviolet light. The adsorption ability of two types of photocatalytic material is shown in **Figure 4**. Compared with conventionally used titanium oxide, titanium apatite has higher substance adsorption ability. It can efficiently decompose toxic endocrine disrupters such as ethinyl estradiol as well as viruses and bacteria. Up to now, titanium apatite has been mostly used for air-related applications such as masks and filters for air purification systems, but its use in water-related applications is expanding. Fujitsu has begun the development of a high-performance water purification filter and is forming tie-ups with makers of water-processing equipment, Kawasaki City, and other parties. It has also begun an initiative to solve the problem of polluted drinking water in parts of Africa using this technology. This water purification filter was exhibited at CEATEC JAPAN 2013 ("Cutting-Edge IT & Electronics Comprehensive Exhibition," Makuhari Messe, Japan, October 1–5, 2013). Going forward, Fujitsu will promote further product development of this technology by licensing it out and will strive to contribute to society though environmental purification technologies.

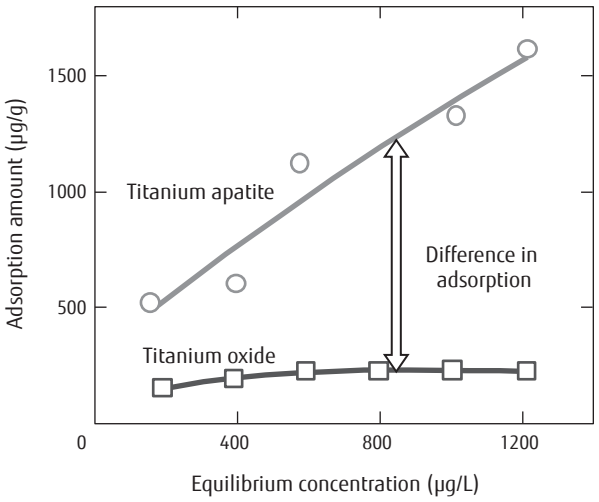

Figure 4
Adsorption ability of two photocatalytic materials.

6. Conclusion

This paper introduced three Fujitsu technologies, energy harvesting technology based on M2M data collection, environmental management technologies, and environmental measurement technologies, that address environmental issues that must be resolved to create a sustainable society. Fujitsu views these technologies as a major driver of innovation.

To create a sustainable, prosperous society, Fujitsu boldly takes up the challenge of building a Human-Centric Intelligent Society using the power of ICT and of achieving green growth that provides for both environmental protection and economic growth.

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