Development of Ubiquitous Sensor Network

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The ubiquitous sensor network is drawing a lot of attention as a method for realizing a ubiquitous society. It collects environmental information to realize a variety of functions, through a countless number of compact wireless nodes that are located everywhere to form an ad hoc arrangement, which does not require a communication infrastructure. An example for its application under consideration is forecasting the outbreak of forest fires by monitoring the temperature of the hills and fields.

Incidentally, the use of sensor networks that collect information from established sensors for the purpose of control, such as systems that prevent mud slides through the monitoring of soil along the dangerous zones of rivers banks , are already in existence. These existing sensor networks were configured with a small number of sensor points, due to installation cost constraints, therefore, individual observational data was quite important. The ubiquitous sensor networks, on the other hand, are different in that they are capable of acquiring measurement information, which was previously unavailable. This is achieved by using miniaturized and wireless sensor nodes, to establish ad hoc networks that offer a higher degree of flexibility for settings and an increased number of sensor points. This has made it possible to create completely new functions that did not exist in the past. For example, it is now possible to estimate the amount of rainfall by taking instrumental measurements of the movement of windshield wipers on numerous vehicles. Another way to describe the ubiquitous network is as a mechanism with which a lot of information, not so important individually, is collected in large numbers to establish important information on a wider scope.

Expectations for the ZigBee[*1)], as a standard of the wireless communication method for ubiquitous sensor networks, are high. Oki Electric is developing wireless LSIs and feasibility testing platforms in concerted endeavors with ZigBee. Further, efforts are also being made in various elemental technology developments, with the aim to further conserve energy and make settings easier.

In this paper, a summary of ZigBee is provided, followed by descriptions of various elemental technologies, which leads finally to the introduction of a feasibility testing platform that is currently being developed, with main applied application examples.

What is ZigBee?

Sensors and control devices used for ubiquitous sensor networks are not required to have high-speed communication capabilities, but they are expected to have a limited amount of delay and a low energy consumption, due to their battery operations, at a low cost as its implementation will be widespread. ZigBee is a wireless communication standard created to satisfy such requirements. This standard is being formulated by the ZigBee Alliance[1)]. The ZigBee Alliance is an organization established as a committee, in which Oki Electric is currently involved.

(1) Protocol structure of ZigBee

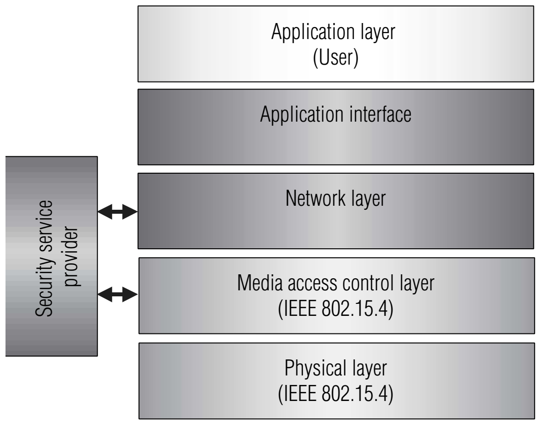

Fig. 1 Protocol structure of ZigBee

The protocol structure of ZigBee is shown in Figure 1. The physical layer and the media access control (MAC) layer adopt the IEEE 802.15.4[2)], while the network layer, the security service provider that realizes the security functions and the application interface are standardized by the ZigBee Alliance. Further, applications are prepared by individual users according to the ZigBee specifications.

(2) Summary of IEEE 802.15.4

The IEEE 802.15.4 was standardized by IEEE in May 2003 as a lower-rate version of the IEEE 802.15 series standard for wireless communications of the Wireless Personal Area Networks (WPAN). The cost and power consumption used by the physical layer and MAC layer are low, with the following features:

- It has a mechanism that prevents interference by other systems.
- The power consumption is inhibited through intermittent operations.
- Communications with a guaranteed bandwidth can be made available as an option.

*1) ZigBee is a trademark of the ZigBee Alliance.

Specifications of the physical layer, according to IEEE 802.15.4, is shown in Table 1. There are three types of frequency bands. The frequency band of 2.4GHz will be available for use in Japan.

Table 1 Specification of the physical layer in IEEE 802.15.4

Frequency band	2.4GHz	915MHz	868MHz
Number of channels	16	10	1
Modulation method	O-QPSK	BPSK	BPSK
Diffusion method	DSSS	DSSS	DSSS
Data rate	250kbit/s	40kbit/s	20kbit/s
Available regions	Worldwide	USA	Europe

The physical layer of the IEEE 802.15.4 has functional capabilities, such as the measuring of the reception power and notification for link quality, as well as Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA), which verifies the usage status of channels. It is capable of measuring the reception power of each channel during the building phase of the network, which makes it possible to seek out channels that give the least amount of power interference from other systems. Further, there is a mechanism available, which changes the communication channel when there is deterioration in the quality with the channel being used. In this manner, elaborate efforts are being undertaken to make it possible to conduct high-quality communications in an environment that is shared with other systems using the same frequency band, while avoiding as much interference as possible.

A beacon mode, in which intermittent operations and communication with a guaranteed bandwidth are performed and a non-beacon mode, in which direct and mutual communications are conducted between all nodes, are stipulated by the IEEE 802.15.4 for the MAC layer.

The beacon mode is used with Star-type networks that are configured with the network management node, referred to also as the “PAN coordinator”, at the core. The PAN coordinator sends off a beacon signal at fixed intervals, while other nodes synchronize with this beacon signal and perform communications during allotted periods. Since only the node that has been singularly assigned by the coordinator gains exclusive use of the channel, it becomes possible to conduct communications in which no collisions can occur. This mode, therefore, is used for communications requiring low delay levels.

The non-beacon mode, on the other hand, is a mode wherein the channel is accessed constantly with the CSMA-CA. When this mode is used in a mesh link, with which direct communications are conducted with peripheral nodes, each node can directly communicate with any other mode at any time, while each node can also be ready to receive data addressed to that node, at all times. This need for each node to constantly remain in a reception standby condition makes it impossible to conserve energy by conducting intermittent operations as in the case of the beacon mode.

It is possible to conserve the energy of the end devices with the implementation of the non-beacon mode in a Star-link situation by keeping the master unit in a constant reception standby condition, whereas the end devices are used intermittently in either a suspended condition or a standby condition. Requests to receive data this way are periodically sent to the master unit from the end devices, so that communications to the master unit from the end devices, which is the dominant flow pattern for data in the sensor networks, will be possible at all times using the CSMA-CA, even though transmission delays exist in communications originating from the master unit.

(3) Network layer of ZigBee

The ZigBee network is an established network in a cluster-tree structure, through a fusion of the topology of the Star-type network, assumed in IEEE 802.15.4 and the topology of the Mesh-type network. The ZigBee Alliance is currently formulating a routing algorithm for conducting multi-hop communications with this network, via other wireless nodes.

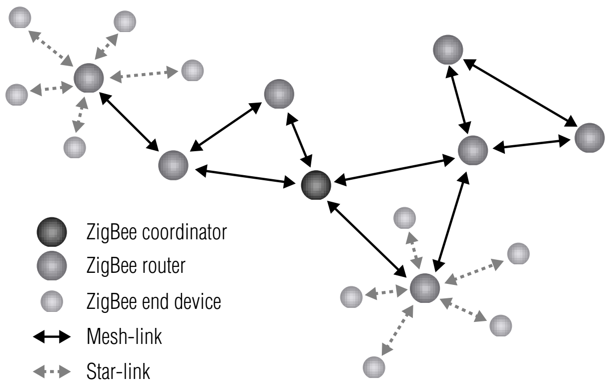

Fig. 2 Network model of ZigBee

A ZigBee network (Figure 2) consists of a ZigBee coordinator, ZigBee routers and ZigBee end devices. The coordinator and routers have PAN coordinator functions and form a Star-link (Cluster) configuration. Further, by simultaneously forming mesh-links between the coordinator and routers, it is possible to form a multi-hop network.

The end devices, on the other hand, participate in the network communications by linking to the coordinator and routers through the Star-link connections. The end devices conduct multi-hop communications via connected routers, to communicate with other devices connected to the network.

Development of IEEE 802.15.4 compliant wireless LSI

By incorporating the analog radio circuit (RF), the physical layer and the MAC layer all in one chip, Oki Electric was able to develop the world's very first wireless LSI (ML7065)[3] that is completely compliant with IEEE 802.15.4. Products of other manufacturers incorporate only the RF and physical layer into a single chip, while the MAC layer needs to be executed with software on a CPU. Since complex MAC processes are performed internally by the wireless LSI with the product from Oki Electric, it is possible to package and control a ZigBee network with a host CPU at a lesser capacity, such as an 8-bit CPU (upper diagram of Figure 3). The features of the wireless LSI are as follows:

- The world's very first IEEE 802.15.4 compliant 2.4GHz RF, with the physical as well as MAC layer contained internally on a single chip LSI (package size: 7mm x 7mm).

- The connection with the host CPU is via a synchronous serial interface.
- The low power consumption makes it possible to run the device on dry cell batteries over a long period of time.

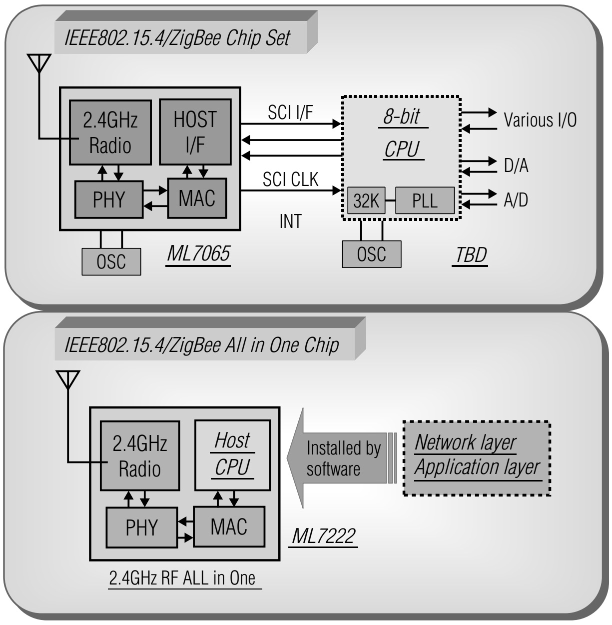

Fig. 3 The complete IEEE 802.15.4 compliant wireless LSI (above) and the ZigBee compliant one-chip wireless LSI (below).

- The 0.22μm low-leakage CMOS process

The wireless LSI was announced in May 2004, the shipment of samples began in September and mass production of the product is scheduled to start in December. This product is loaded with a CPU that contains the network layer and application layer all configured in a single chip, as shown in the lower diagram of Figure 3. It is planned for development and distribution in the future as a ZigBee compliant wireless LSI suitable for end devices with light processes.

Elemental technologies of ubiquitous sensor networks

Miniaturization and the conservation of power are major agendas for ubiquitous sensor networks, as they feature the installation of a countless number of wireless nodes at various locations. Further, in order to set wireless nodes freely, not only will it be necessary to acquire scalable technologies that adapt to the scale of the network, but other technologies, such as the zero-configuration technology, which make it possible to automatically set sensors, wireless communications and networks, will also become important, as well as technologies that make maintenance simpler.

The main technologies developed by the Corporate Research and Development Center of Oki Electric, in cooperation with universities and research organizations, are introduced here:

(1) Autonomous cluster building technology

With networks of a larger scale it is more efficient to conduct scalable management by dividing the network into clusters as shown in Figure 2, rather than establishing a mesh-type configuration of all the nodes. In such instances, the key issue will be how these clusters are formed.

The consumption of power is higher at the cluster head (CH: The ZigBee coordinator or ZigBee routers, as shown in Figure 2) in comparison with other nodes, since it not only performs data transfers within clusters and manages the network but also conducts inter-cluster communications with neighboring CHs. For this reason, a method is currently under investigation whereby the CHs are selected dynamically according to the remaining battery power at each node and power supply status. A mechanism with which an autonomous selection of the CH is made, is essential, as performing the centralized management of the CH selection here would make it incapable of supporting large-scale networks.

Further, because the data tends to flow in a single direction in ubiquitous sensor networks, almost entirely from sensors to server, multi-hop communications result in a large transmission load at the lower nodes (nodes closer to the server) of data transmissions. It is possible to improve the energy conservation effect, by taking such a phenomena into consideration when selecting the CH and cluster sizes.

(2) Autonomous control technology for communication timing

Time Division Multiple Access (TDMA) and CSMA-CA are the representative technologies for communication timing. The TDMA makes static assignments of communication slots and thus offers more efficient communications. It is also possible to use a sleep function with slots assigned to other nodes, to conserve more power. The TDMA requires centralized management however, making advance settings a complex task for large-scale networks. The CSMA-CA, on the other hand, acquires communication slots in an autonomous yet dynamic manner, while preventing collisions. Although this makes it possible to support networks with variable data quantities and topologies, optimized allocation is difficult due to the overhead collision avoidance process.

For this reason, we are considering an autonomous communication slot allocation method[4)5)] that is also adaptable for large-scale networks by applying the nonlinear oscillator theory. A topological relationship is formed through the interacting signals between the nodes in the vicinity, as shown in Figure 4. Each node acquires a communication slot, based on this topological relationship. Efficient communication is possible even in situations when the amount of traffic is high, making it a candidate for application in a variety of areas, other than sensor networks.

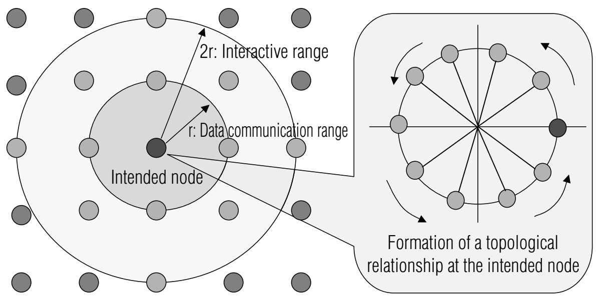

Fig. 4 Network model of ZigBee

(3) Positional detection technology

The positional detection technology can be used to identify a location in which detected data originates or to trace moving objects, making it a highly desirable technology for applications. Further, it is a very important technology for the network layer, since it can be used to control the transmission power by reducing the radio interference based on the position of wireless nodes. It can also assign addresses that are efficient and that correspond to the allocation topology, as well as apply routing controls.

Although some technologies, such as GPS systems or those employing other means, such as ultrasound or infrared radiation, which are also available as positional detection technologies, we are engaged solely in the development of a method that uses only radio waves, in order to lower costs, miniaturize and conserve the energy of wireless nodes. For methods that use radio waves, one exists that calculates the distance by measuring the propagation time of the radio wave, and another that estimates the distance based on the field intensity of the received signals. The problem with the former method is the time synchronization accuracy at each wireless node, while the problem with the latter method is its variation in the field intensity of the received signals.

We are proceeding with a study on the issue of the latter method, aiming to limit the positional estimate margin of error to within 1m by conducting modeling with consideration for the variation of field intensity of the received signals.

(4) Software updating technology

It is necessary to rewrite software for each node, in order to correct problems with the numerous wireless nodes that have been established, or to add on functions. However, this could become an enormous task for large-scale networks, if the software needs to be rewritten for each node.

Therefore, we are currently developing a technology that will rewrite software using wireless communications. In particular, we are also conducting a study on the updating of programs for nodes that are equipped with only the minimal amount of necessary memory for storing programs in order to maintain the low cost of wireless nodes. With this technology it will become possible to download various programs, according to a particular location or situation, to realize wireless nodes with various required functions.

(5) Security technology

Since the computing capabilities and communication rates of wireless nodes are low, it is necessary to preserve an overall high level of security with a limited amount of processing. For example, although the value of each individual piece of data transmitted over a ubiquitous sensor network may be low, the value of the information resulting from the aggregate of such data may be high. We are, therefore, conducting a study on a mechanism to protect the data that has been gathered on the server in a global manner, rather than concentrating on protecting local communications between individual nodes.

Further, since data communications are conducted via neighboring nodes when multi-hop communications are performed, it is relatively easy for a malicious node to participate in the data transfer as one of the relaying nodes and tamper with the data. The mechanism for authenticating nodes is important for this reason. With the method that involves the use of a server to perform authentication, however, peripheral nodes cannot be trusted during the authenticating process. It will be necessary, therefore, to perform one-hop communications with the server as well, which will result in an inappropriate method of authentication for the environment, wherein multi-hop communications are conducted. Consequently, we are conducting a study on a method of local authentication[6] without the use of a server.

Further, in order to ensure the delivery of critical information sent from the server to the nodes, we are also looking into a study on a mechanism for verifying that the node has definitively received the correct information[7], by using the data transfer routing information. Through the use of this mechanism, it is possible to realize software updates described above in a secure manner.

Development of platform for feasibility tests

Oki Electric is promoting a feasibility test through the joint development of a feasibility platform with Oki Techno Creation Co., Ltd.

Since elemental technologies, such as those described in the previous section, consist of an association of multiple nodes using radio waves, there are a variety of elements that cannot be considered merely through theoretical investigation or simulation. For this reason, a feasibility evaluation using actual devices is essential. Further, since technical issues are not limited to the network area but a variety of disciplines, it is not possible for Oki Electric to pursue development alone. Consequently, it is expected that the practical implementation of technologies and undertakings relating to a variety of technical issues, will be accelerated with the provision of a platform for a feasibility test to a broad range of our technical development partners, such as universities and research organizations.

Further, since there are diverse areas for the application of the ubiquitous sensor network, many potential individual issues will emerge with its practical use. It is necessary for businesses to be actual participants in such diverse areas, in order to address these issues in the early stages. We hope to accelerate the process of resolving related issues, by utilizing a platform for the feasibility test and through cooperation with many application businesses.

The platform for the feasibility test consists of a wireless node, capable of performing multi-hop communications with the ZigBee specification, a synch node that collects data from respective wireless nodes and a gateway (GW), which makes it easier for the respective applications to control the sensor network, as shown in Figure 5. We began to provide this platform to our development partners in August 2004.

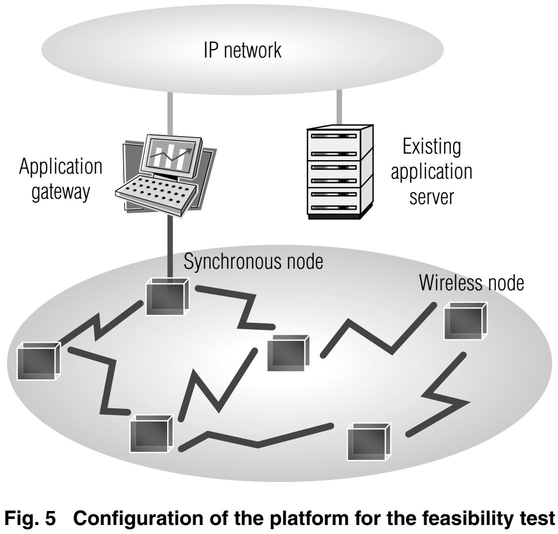

Fig. 5 Configuration of the platform for the feasibility test

(1) Wireless node for the feasibility test

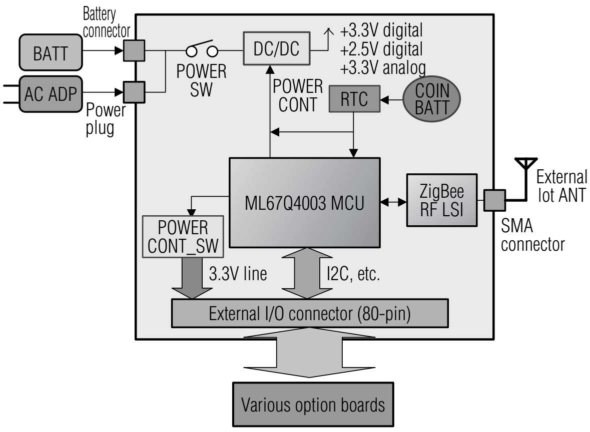

Fig. 6 External view (upper) and configuration diagram (lower) of the wireless node for feasibility experiments

The wireless node is equipped with a 2.4GHz IEEE 802.15.4 compliant wireless LSI and a network layer, which is based on the ZigBee specification. This platform received engineering conformity certification for the radio wave by the Telecom Engineering Center (TELEC), which makes it possible to use this platform anywhere for tests using radio waves (Figure 6).

A unique architecture, which makes it possible to change the hardware in a flexible manner, according to the purpose of the tests, has been adopted. Optional boards that are mounted with sensors, actuators or display devices can easily be added on. It is also possible to add on other wireless components for minute radio waves or special low-power radio waves.

Further, since an API that is similar to POSIX is made available, which is the minimum specification set for UNIX, development can be performed in C language, making it possible for anyone to easily develop network protocols and applications.

Other than the above, the platform also incorporates functions, such as transmission output control, reception sensitivity notification and remaining battery power detection, which makes it possible to easily set the sleep control as well. An external AC power source can also be used besides the battery mounted inside the housing. Further, it can be connected to a personal computer via an RS232C connection.

Since the main focus of this wireless node was an ease for verifying a wide range of functions, a 32-bit CPU has been adopted to give an ample processing capability and memory capacity. For commercial systems, the functions that have been verified in feasibility experiments, which will be necessary for each application, are planned to be extracted and mounted in an 8-bit CPU to provide wireless nodes that are compact, low cost and low power consuming.

(2) Application gateway

The numerous wireless nodes that constitute the ubiquitous sensor network are considered to be a single group of nodes. In order to configure a group of these wireless nodes to make it appear as a single appliance to the applications, an application gateway is provided. The existing application server does not deal with individual wireless nodes as separate entities, but rather, information from each individual sensor is available to the applications simply by accessing the application gateway.

The application gateway incorporates functions, such as a function that manages the IDs of individual wireless nodes and security, as well as a function that translates the protocols of existing applications and the group of wireless nodes.

Further, the AP@PLAT, the concept for fusing information and communication together, is expected to be supported, which will make it easier to develop applications that combine HTTP and SIP service.

Examples of applied applications

Although the applied disciplines of the ubiquitous sensor networks are diverse, an example of its use with a building (Figure 7) is introduced here as one of the main applications.

Control of air conditioning systems in offices is already interlocked with temperature sensors. A reduction in the control units is possible by implementing a ubiquitous network. Numerous sensors and actuators can be installed with a ubiquitous network, making it possible to control the air conditioning for individual booths. Further, temperature sensors that were previously installed on ceilings can now be installed at a height that is equivalent to the height of a seat, making it possible to further reduce the gap between the sensory temperature and the set temperature. Furthermore, if the occupants of these areas wear wireless nodes, not only will the energy conservation efficiency improve, due to a reduction in the use of the air conditioning in areas where there are no occupants, but it will also be possible to offer better control of the air conditioning that is more considerate to the occupants, such as setting the temperature to a slightly higher level for an area occupied by a person who is sensitive to the cold. In the future, it is potentially possible to implement controls to maintain areas occupied by people who have caught a cold, or to divert the flow of air away from such areas by operating air conditioning systems interlocked with health management systems.

In the past, lighting equipment inside offices needed to have control lines rewired every time a change was implemented to the office layout, in order to maintain the collation between the lighting equipment and the switches with the control lines. Once a ubiquitous sensor network is implemented, however, it becomes possible to make a wireless collation between the lighting equipment and switches, thus the layout changes can be accommodated simply by modifying the logic in the control system. Further, in the past several lights were controlled by the same set of switches in order to reduce wiring costs. It will be possible to eliminate such concerns and control individual lights in the future. Further, it will also be possible to increase the level of power conservation through the control of lighting that is interlocked with the movements of people or the occupancy status of seats. It will also be possible to control lighting to accommodate the work being performed, such as reducing the reflection on a monitor screen when a personal computer is in use.

Furthermore, it will be possible to quite easily interlock several pieces of equipment. For example, when it is light outside, the blinds on the windows can be raised and the lighting may be dimmed to conserve energy. When the sunlight coming in through the window becomes strong, the blinds can be closed to prevent a deterioration in the effect of the air conditioning and the lighting turned up. In this way, it is possible to interlock multiple systems, with the aim to conserve the overall energy.

If disaster occurs in a building, due to fire or earthquake, the system can be used to maintain communications between survivors still trapped in the building and the rescue workers. Further, depending on the status of the fire and smoke, it may also be possible to guide these survivors to appropriate emergency exits. Furthermore, by taking measurements of the distortion of a building, due to an earthquake or strong winds, it will also be possible to maintain the monitoring of a building's condition as well.

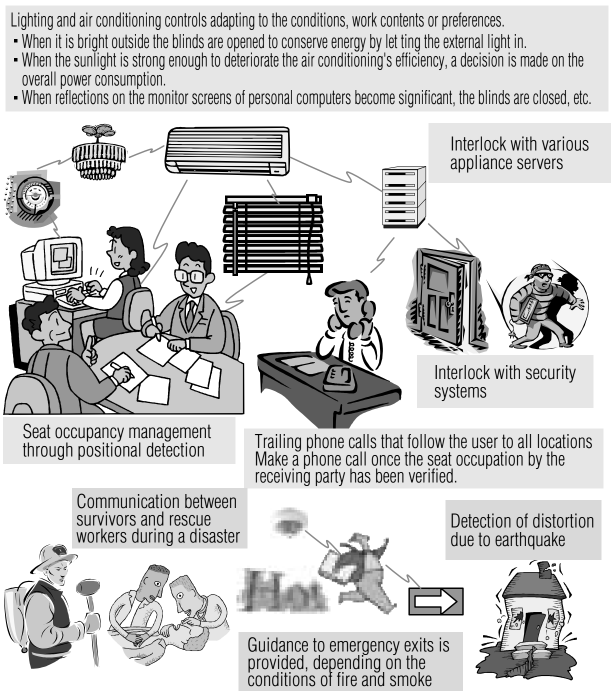

Fig. 7 Application for use in buildings

Summary

Summaries of the ubiquitous sensor network, which is expected to become one of the means to realize the ubiquitous society and its wireless standard, ZigBee were provided. Introductions to the elemental technologies currently being developed at Oki Electric, as well as the platform for feasibility experiments were also provided. In the future, evaluations for practical implementation will be carried forward with application business partners, aiming for the commercialization of the technologies, while joint developments of the methods with technology development partners will be accelerated. Further, the formulation of a standardized UWB, which is considered to be a wireless method with a high degree of accuracy for positional detection that is compliant with IEEE 802.15.4a[8], is already under way. We intend to continue with our technical developments, using these new wireless methods in our perspective, without being limited those of ZigBee.

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