Electric Power Conservation Technology for Wireless Sensor Networks

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Wireless networks comprised of sensors with wireless communication functions are called wireless sensor networks. Diverse research and development is being carried out for these networks, with applications anticipated for environmental monitoring, automated metering, structure monitoring and home security. Wireless sensor networks add wireless communication functions to sensors, comprise wireless multi-hop networks to broaden the scope of observations and make the installation process of the sensors easier. The requirements for such wireless sensor networks include battery driven operations and sensing periods that last over a long term, often lasting several years. Currently available wireless sensor network technologies, however, are restricted by the fact that the relaying sensor nodes are unable to be operated in an energy saving mode, thus it is difficult to operate battery driven sensor nodes over many years. Such restrictions narrow down the scope of application for wireless sensor networks creating a need for the development of a technology that enables all sensor nodes in a network to perform in an energy saving mode.

People are becoming more and more aware of issues relating to the global environment and in such circumstances it is often said that it is important to understand the current status of the global environment. Wireless sensor networks have been considered for implementation as a means to understanding the current status. When environmental monitoring systems or energy conservation systems are being established using wireless sensor networks, the implementation of such systems may bring about an extremely high electric power conservation effect, but if electric power conservation of the system itself is not adequate or if wiring for the power source to the feed sensor nodes is necessary in order to install such electric power conservation systems, the value of such electric power conservation systems may be diminished. The electric power conserving technology for sensor nodes, developed through our research, converts nodes into electric power conserving types, conserving energy of the system itself and conserving electric power consumed by nodes, which made the wiring of the power supply to these nodes unnecessary, thereby improving the ease of installation. Therefore, this is expected to promote the popularization of systems for conserving energy using wireless sensor networks.

Electric power conservation of sensor nodes

The majority of electric power consumed at sensor nodes is used to drive wireless devices. Short range wireless devices with a small transmission output in particular, tend to consume more power for receiving than transmitting. The power for packet transmissions is consumed not only when receiving, but nearly the same amount of electric power is consumed in the standby mode. It is possible to limit the electric power consumption in the standby mode by putting the wireless device into the sleep mode during standby. When the electric current that actually flows through these sensor

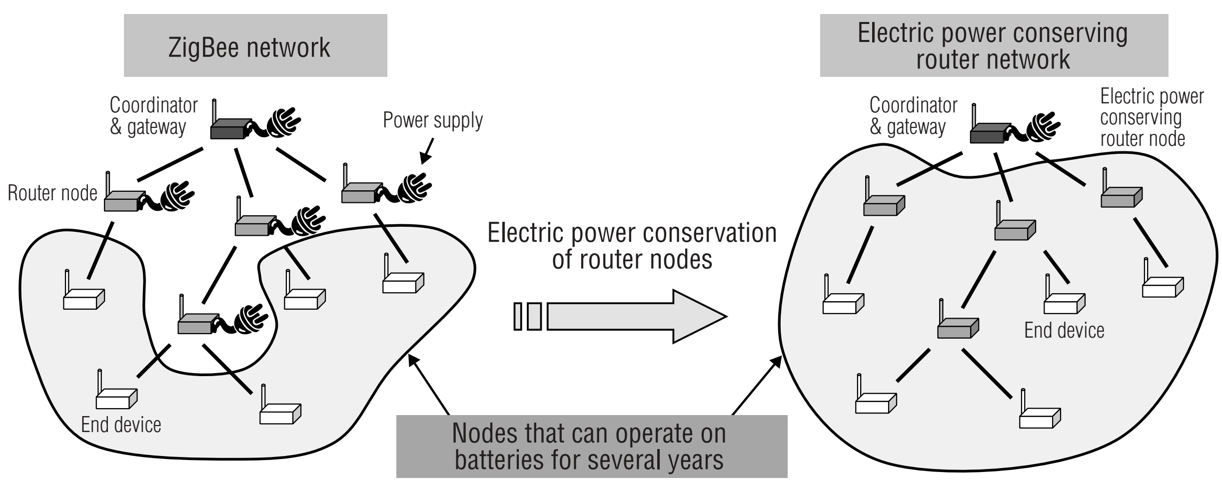

Fig. 1 Comparison of wireless sensor networks and scope of nodes that can operate on batteries over several years

nodes was measured, an electric current of about 26 mA was measured in the standby mode, whereas in the sleep mode this figure changed to about 23 μA. Consequently the electric power consumption could be reduced to less than one-one thousandth by changing from the standby mode to the sleep mode. Battery-driven sensor nodes can be employed for several years using ZigBee*1), known as a protocol for wireless sensor networks. This is due to a mechanism that involves the receiving and sending of signals while in the sleep mode, which was conceived for sensor nodes (end devices) that do not relay. Since router nodes conduct asynchronous communications with other router nodes and end devices, however, it is difficult to determine in advance when a packet is sent to any one of these router nodes. This is currently an issue, since mechanisms to conserve electric power through sleep mode control are not available. Hence a power source is required for router nodes in order for them to operate over a long period of time. When networks are established using ZigBee, sensor nodes that can operate over long period of time driven by batteries, as shown on the left of **Fig. 1**, will be limited to the end devices only. Therefore even though communication routes for router nodes can be converted into wireless routes, wiring for the electric power supply is still necessary. If electric power could be conserved at the router nodes, however, it would not be necessary for any wiring to supply electric power to all sensor nodes other than the gateway nodes (hereinafter referred to as "GW"), as shown on the right of **Fig. 1**, making it possible to convert all sensor nodes into wireless connections (**Fig. 1** depicts an example with the ZigBee coordinator and GW configuration at an identical node). Once the conversion to wireless connections has been completely attained, the ease of installing sensor nodes improves dramatically, enabling the expectation of broadening effects on a scope for the application of wireless sensor networks. Battery-driven GW has not been considered on the right of **Fig. 1**, nevertheless GW are most often connected to sophisticated computers, the power supply is consequently considered to be readily available and batteries are most often not necessary to drive them. Furthermore, due to certain reasons, such as the collection of sensor data, traffic is anticipated to concentrate on GW. Electric power conservation achieved through the transitioning of nodes into sleep modes, sacrifices communication throughput, thus controlling the sleep mode at the nodes, such as GW, where traffic concentrates. This results in a reduced number of nodes where connections to networks can be made in terms of traffic. It is for such reasons that it is considered better not to use sleep mode controls on GW. We believe that a technology for controlling the sleep mode at the router nodes is therefore essential in order to make observations using wireless sensor networks driven by batteries, when the subject of observation is large in scale.

Further conservation of electric power in operating sensor nodes can enable them to operate using energy stored on secondary batteries, using sunlight, the opening and closing of doors or vibrations. Drive sensor nodes using such stored energy are feasible. These sorts of attempts are called energy harvesting sensor networks. Unlike wireless sensor networks that are driven by batteries and thus have limited observation periods, energy harvesting sensor networks can operate until a node fails, which facilitates a significant reduction in the maintenance costs for nodes. However, since electric power cannot always be secured it would be difficult for the sensors to operate at all times. On the other hand, by adopting the electric power conservation technology for sensor nodes, positive effects, such as an increased operating time of the nodes or broader time periods for sensor operations, can be expected. As a result we believe that the use of the electric power conservation technology on router nodes is effective for energy harvesting sensor networks as well.

Conventional research of electric power conserving communication protocols

Conventional research to conserve the electric power operations of router nodes is introduced in this section. The conventional technology for the Medium-Access Control (MAC) layer, which is relevant to the electric power conservation technology for router nodes, can be largely divided into two synchronous and asynchronous category types. The method referred to as the Sensor-MAC (S-MAC)[1], is widely known for the synchronous type. The operation of S-MAC is shown in **Fig. 2**. The S-MAC operation is basically a cyclical repetition of alternating periods of an activated period, during which wireless circuits are driven, as well as a sleep period, when the wireless circuits are in the sleep mode. The activated period is further divided into synchronizing and data transmitting periods. Packets are broadcast during the synchronizing period to notify neighboring nodes of the sleep schedule so that the receiving nodes can synchronize an active period with the sending node of the synchronizing packet, to achieve a synchronization of the activated periods of the sending and receiving nodes. In this manner the activated period of the nodes are synchronized with the S-MAC operation to eliminate packet reception errors that may occur due to sleeping. The transmission of data packets is performed during the data transmission period in the activated period. Transmissions are performed during this period, with contentions avoided due to the Carrier Sense Multiple Access. Synchronization on a larger scale is an issue for S-MAC, but once the length of the activated and sleep periods are determined as operating parameters, the duty ratio of the nodes are uniformly determined according to the ratio of the period lengths. This brings about a characteristically less apparent difference in the life of the batteries, even when communication loads are different between nodes.

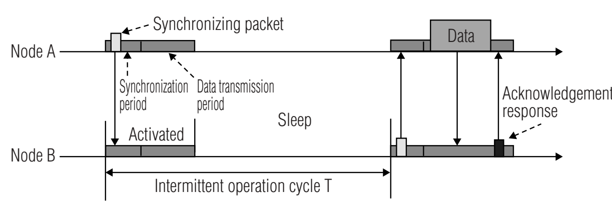

Fig. 2 Mechanism of electric power conservation with S-MAC

*1) ZigBee is a registered trademark of Koninklijke Philips Electronics N.V.

The method often used for the asynchronous type is known as Low Power Listening (LPL) with relevant methods proposed, such as Berkeley-MAC (B-MAC)[2] and X-MAC[3]. Other asynchronous electric power conserving methods that perform beacon transmissions, such as Receiver Initiated CyclEd Receiver (RICER)[4] and the like have also been proposed. The basic operation of the B-MAC is comprised of sensor nodes that turn on a wireless device to the activate status for a few milliseconds in intervals of a specific operating cycle with a duration of T seconds, while maintaining the sleep status for the remainder of the time. Carrier signal sensing is conducted during the activated period to determine whether or not the available channel is in use. If the channel is in use the node remains in the activated status and waits for the reception of packets. If the channel is not in use it returns to the sleep status. As the node waits for the reception of packets it returns to the sleep status after successfully receiving packets or when a timeout is reached. The sending node on the other hand, sends out packets with a preamble that is longer than the T second operating cycle. Since the receiving node always checks the channel every T seconds, the nodes can be transitioned into a packet reception standby status while the sending node is sending out a preamble. Data may be received following the transmission of a preamble. A similar feature can be accomplished by sending continuously extremely short control packets that request the startup of the destination nodes, rather than sending a long preamble. This method simplifies the operation during activated periods, making it possible to shorten the duration of an activated period. However, this method has problems, such as generating additional costs since additional signals must be sent for the T seconds prior to sending data and because nodes that exist within one hop, whether they are destination nodes or not, are all activated.

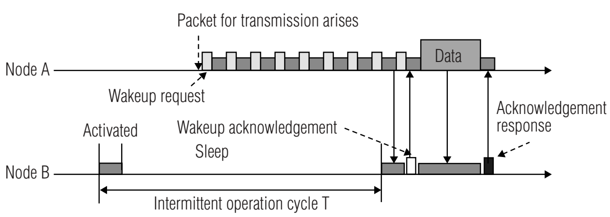

Fig. 3 Mechanism of electric power conservation with X-MAC

X-MAC is an expanded version of the B-MAC method. The operation of this method is shown in **Fig. 3**. Node A sends data repeatedly transmitting, as wakeup request packets, control packets that contain the addresses of the destination nodes. Node B, which is intended for receiving data, sends out a wakeup acknowledgement packet after receiving a wakeup request. Once an acknowledgement is received node A then undergoes the operation of sending out data packets. Since the wakeup request is simply repeatedly sent out until an acknowledgement is received from the destination nodes, the problem relating to the necessity of sending out a preamble that takes T seconds when sending data packets, has been improved with B-MAC, making it also possible for all nodes that are not intended for receiving data, which can be determined from address information provided in wakeup requests, to resume the sleep status without waiting for data packets to arrive. This has resolved the problem of turning all the nodes together with destination nodes within one hop, into an activated status.

The method known as RICER involves the sending out of beacon signals, even though the RICER is extremely similar to the LPL in mechanism. The operation of RICER is shown in **Fig. 4**. The RICER operation involves the intermittent transmission of beacon signals. Node B periodically sends out beacon signals and thereafter remains in a packet reception standby status for a certain length of time. When a packet for transmission arises at node A, node A enters the reception standby status and waits for the reception of a beacon from node B, which is the intended node for transmission. If node A immediately sends out data when a beacon signal is received from node B, then the data packets are sent while node B is in the reception standby mode, immediately after the transmission of beacon signals from node B. In this manner, asynchronous communications are possible for sensor nodes while entering the sleep status.

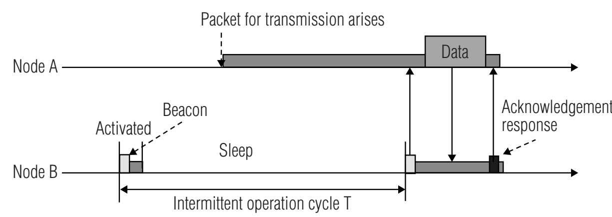

Fig. 4 Mechanism of electric power conservation with RICER

The methods of the asynchronous type introduced in this paper require no synchronization and as a result present superior scalability. Since the load on the sending node is high in comparison with that of the receiving node, an issue can arise pertaining to the gap in the amount of electric power consumption between nodes, depending on the traffic pattern.

Although many proposed technologies are available for conserving electric power consumed by routers on a research level, as introduced in this section, none have so far been standardized. Currently, when the conservation of electric power at the router nodes is necessary, the requirements are satisfied through the adoption of a proprietary electric power conserving protocol.

Development method: Autonomous distributed communication timing control

The autonomous distributed communication timing control method[5] is an available method we developed for the conservation of electric power. This method involves the sending of control packets by each node at fixed intervals and sending data packets immediately following the sending of the control packets. This means that control packets inform neighboring nodes of a node's timing for the sending of data. When a control packet is received the gaps in timing for the transmission of control packets with neighboring nodes are calculated. The transmission timing of the node's own control packets is autonomously decided by the node, ensuring that the transmission timing does not overlap with the timing of other nodes, according to gaps in the timing of transmissions. A characteristic of this method is the autonomous adjustments that are made based solely on local information.

This method has been developed with the intention of avoiding a collision of packets, as soon as the communication timing control has converged, the communication timing between the nodes becomes steady and forecast timing of the transmission can be performed by individual nodes. This means that since each node is aware of the timing by which packets intended to the node are sent, the power supply to wireless devices can be shut down during the period in which no communication occurs, without risking packet reception failures. The operation is shown in **Fig. 5**. Since node A is aware of the transmission timing at nodes B, C and D through the exchange of control packets, its wireless device can be turned into an activated status synchronized to such timing. Node A enters the activated status in time for the control packet sent by node B. The control packet sent by node B contains a number of subsequent packets to be transmitted, aside from the information pertaining to the timing control. Node A can therefore enter into the sleep status once data packets are received from node B. The same is true for the reception of packets from node C. When a data packet is not available for sending, the node simply receives a control packet and then transitions into the sleep status. Timing control for the transmission of packets is necessary in order to avoid collisions due to hidden terminals for nodes located two hops away, such as node D, but since no direct communications are performed, node A enters into the sleep status when the data is timed to be sent from node D.

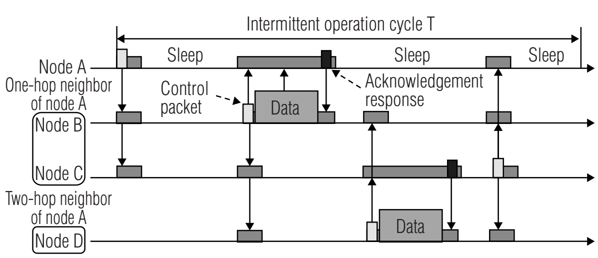

Fig. 5 Electric power conservation by autonomous distributed communication timing control

The characteristics of the autonomous distributed communication timing control are different from other electric power conserving methods in that the problem of packet collisions has also been resolved. Traffic during activated periods is concentrated with other electric power conserving methods, as sleep is controlled. A slight increase in traffic can easily cause packet collisions. The use of our method, however, would make it possible to respond to a high volume of traffic while using sleep control.

Conclusion

This paper introduced problems associated with conserving electric power consumed by the router nodes of wireless sensor networks and the conventional technologies available, followed by an explanation of the electric power conservation at router nodes using the method we developed, the autonomous distributed communication timing control. Technologies pertaining to the conservation of electric power consumed by sensor nodes are vital technologies that impact the application of wireless sensor networks by broadening the scope or leading to the creation of energy harvesting sensor networks.

We are planning to conduct further developments for electric power conserving methods and consider improvements to delays that occur due to sensor nodes entering into the sleep status, as well as make evaluations using prototypes.

References

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