Power consumption reduction for wireless smart networks

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Recently, a new social infrastructure known as smart community[1] that integrates information, energy, transportation and public systems is attracting much attention. Connection of photovoltaic power generators, electric cars and other wide variety of environment/energy related equipment is envisioned in a smart community, and communication between the equipment is expected to be wireless. However, due to the wide distribution of the equipment, direct wireless communication may not always be possible prompting the need to use other intermediate equipment as transit stations. This article defines such a wireless multi-hop communication for the smart community as a smart network.

We are studying the large-scale connection of wireless communication nodes which make up the smart community[2]. One of the major objectives of the smart community is efficient energy use. Therefore, the smart network itself must not consume vast amounts of energy. That makes reduction of network power consumption an important technical issue.

This article describes a way to reduce the power consumption of a network while suppressing the degradation of communication performance by improving the network configuration method we previously developed. We will also provide results of a simulated performance evaluation which show 30% to 50% reduction in power consumption when compared with the conventional method.

Related Studies

In the smart network we envision, each wireless node has a transit function and forms a mesh-type network as shown **Figure 1**. Each node exchanges route information with the surrounding nodes and determines where to forward packets. The forwarding process is repeated to allow communication between nodes that cannot communicate directly.

There have been several studies related to power-savings in a wireless multi-hop network. The past studies are presented below, and the differences between those studies and the current study are described.

Since majority of the nodes in a sensor network will be battery-operated, the need is high to reduce power consumption of all nodes to ensure their lifespan. Although transmission power may be small for short-range wireless, great deal of power is consumed to operate wireless devices in microcomputers, and reception stand-by power use is almost the same as during actual reception. For these reasons, intermittent operation, which periodically powers down wireless devices in nodes and powers them on only during communication, is mainly used to reduce power consumption, and various methods have been developed[3].

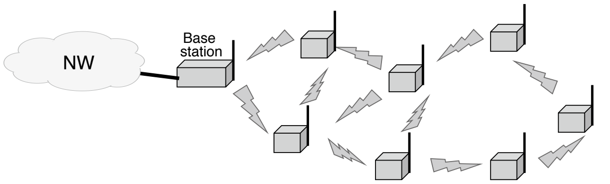

Figure 1. Example of a Smart Network

Results of past studies can be utilized to reduce power consumption of each node. However, a power-saving node cannot communicate while in sleep mode. Therefore, throughput of the communication passing through a power-saving node greatly drops and also increases delay. Especially in a multi-hop network, power-saving causes wait-time to occur at each transit point significantly deteriorating the communication performance.

A smart network is expected to control devices connected to a node, measure power consumption and supply power to target devices as well as many of the other nodes. The power-saving objective of the node is not to extend battery life, but to reduce power consumption of the entire wireless network. This way, there is no need to equalize the power usage of individual nodes, and unnecessary power use can be reduced after communication performance is secured.

Therefore, we developed a method to balance communication performance and power consumption by operating certain nodes, which have low-impact on performance, in power-saving mode while the other nodes are operated in normal mode.

To achieve such a behavior, it is necessary to determine the operating mode of individual nodes. Due to changes that occur in the wireless communication environment, communication status and installation status, it is not realistic to manually set the operating mode of individual nodes. Each node must autonomously determine its own operating mode based on the surrounding condition and communication status.

Automatic Selection of Power-Saving Nodes

From the background presented above, we set out to develop a method to automatically select power-saving nodes. First a method to determine the power-saving operation of the each node was developed. This was followed by a method to determine the network configuration that will provide the greatest power-saving effect.

• Selecting Power-Saving Nodes

Communication in a smart network takes place between the base station (connects to external networks) and nodes, and communication between nodes is considered rare. In this situation, communication is carried out along the paths of a tree structure with the base station as the root. We are developing a method that assumes such a network, and the fundamental portion of the routing utilizes a previously developed method [2].

A node at the end of the tree structure (termination node) only sends and receives data related to itself, therefore traffic volume is low. Hence, to maintain communication performance, only the termination nodes are made to operate in power-saving mode. With this method, there is no need to measure actual traffic, and operation mode can be determined simply from the status of the network connection.

• Improving Networking Method

Power-saving using the above method requires building a tree structure with numerous termination nodes. Typical networking methods do not take into account the number of termination nodes.

When configuring a tree-type network, each node only selects its parent node. Previously, a cost was set for each link (link cost), and paths were generated so the cost sum of all links used from the base station to each node (path cost) would be the smallest. In this method parent nodes are selected to minimize cost, and no consideration is given to the number of termination nodes.

The newly proposed method defines cost that considers the increase in the number of transit nodes when a parent is selected (cost of selecting parent node n: C (n)). Each node calculates C (n) for all surrounding nodes it can directly communicate with and chooses the node with the smallest cost as its parent. This makes it possible to configure a network that not only considers the shortest transmission path, but also considers reducing the number of transit nodes.

In this method, all nodes periodically send information about themselves in a control packet. These control packets include parent ID, number of child nodes, number of child nodes that are transit nodes, and path cost.

C (n) is determined as follows:

$C(n) = k \times (P(n) + L(n)) + S(n)$

$P(n)$: Path cost of node n

$L(n)$: Link cost between node n

$S(n)$: Power-saving cost when node n is selected

k: Shortest path priority

Coefficient k is decided in advance and is used to adjust the balance between reduction of power consumption and average number of hops. If k is made sufficiently large, it will virtually invalidate the power-saving cost giving priority to the shortest path and lead to the same result as using the previous method. On the other hand, reducing k will increase the influence of power-saving cost, and priority will be given to minimizing power consumption even if it increases the number of hops.

Power-saving cost adds a penalty cost when a selected parent node increases the number of transit nodes. Power-saving cost will vary depending on the number of connected child nodes.

• Operational Example

Figure 2 shows an operational example of the method. The shaded nodes represent transit nodes, and the number on each node indicates the number of hops to reach the base station. When a new node is added, the number of transit nodes temporarily increases to four, but eventually comes down to two nodes, which less than the initial number. This is the result of allowing detour paths, and hop number of the lower left node in **Figure 2** has increased from 2 to 3.

Figure 3 is an example of a network with 100 nodes configured using the past method (equivalent to always setting the power-saving cost to 0). **Figure 4** shows an example of the newly developed method applied to the same node deployment as in **Figure 3**. The upper left

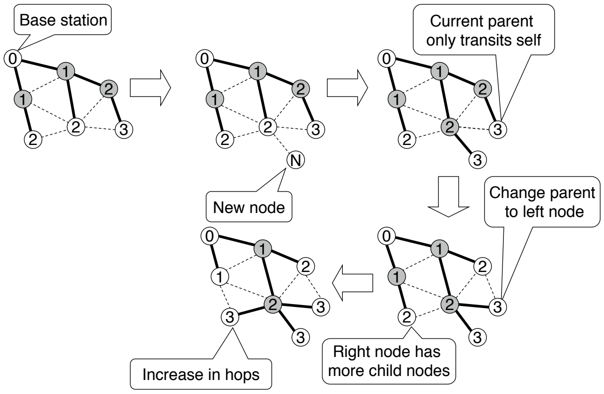

Figure 2. Operational Example of Newly Developed Method

node designated as 0 is the base station, the squares connected with bold lines are transit nodes, and the circles are termination nodes. Number appended to each node denotes the number of hops to the base station. In **Figure 3**, priority is given to minimizing the number of hops resulting in a congregation of transit nodes near the base station while in **Figure 4**, distance between transit nodes are farther apart reducing the number of transit nodes. Number of transit nodes in **Figure 3** is 42 and 21 in **Figure 4**, so power consumption has been cut in half.

However, the nodes at the lower right in **Figure 3** require eight hops to reach the base station whereas in **Figure 4**, the transit path for the nodes have been lengthened and require nine hops.

Performance Evaluation

A simulation was performed to test the new power-saving method using node density and shortest path priority as variable parameters. Keeping node deployment constant, only the network configuration methodology was changed to evaluate the power-saving characteristics of each method. Evaluation was started after ensuing there were no broken links and sufficient time has elapsed for the network to stabilize. The use of the 920MHz wireless band was assumed, and communication rate was set at 100kbps[4]. Results are shown in **Figure 5.** The vertical axis is the power consumption with consumption normalized to 1 when none of the nodes are in sleep mode. The horizontal axis shows the node density and the results of varying the k value. Legend in parentheses is the k value. It can be seen that high density deployment of nodes significantly reduces power consumption even before the proposed method is applied.

Results show that applying the proposed method to any of the node densities leads to power-savings of 30% to 50%. Furthermore, raising the shortest path priority in regions with low node density increases the number of transit nodes and in turn increases power consumption. In the case of high node density, change in shortest path priority has little effect on power consumption. This can be attributed to the fact that when node density is high, degree of freedom in network configuration is also high, and configuration close to that of the shortest path can be achieved even though shortest path priority is low.

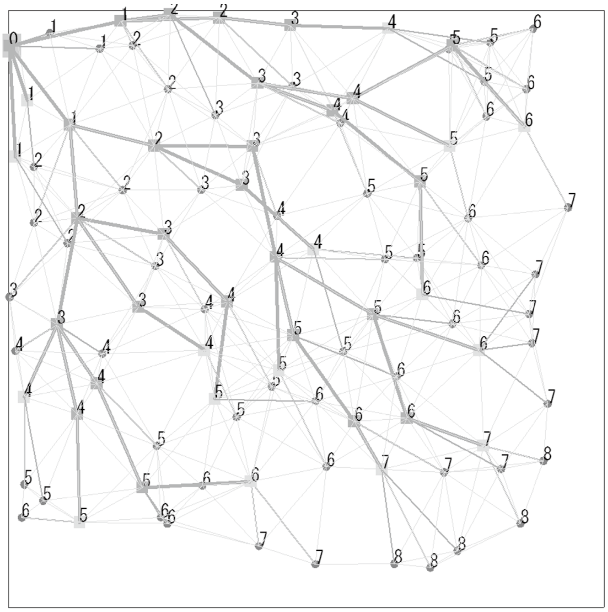

Figure 3. Network Configuration using Previous Method

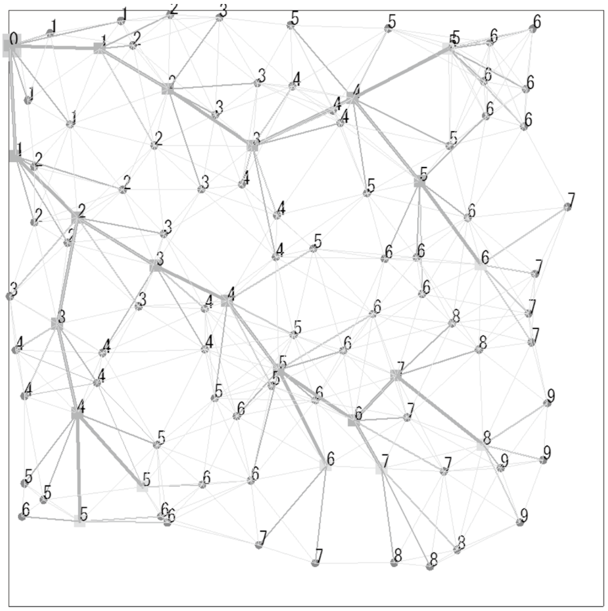

Figure 4. Network Configuration using New Method

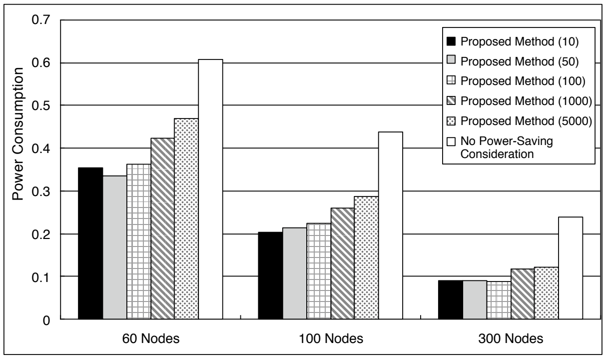

Figure 5. Comparison of Power-Saving Effects

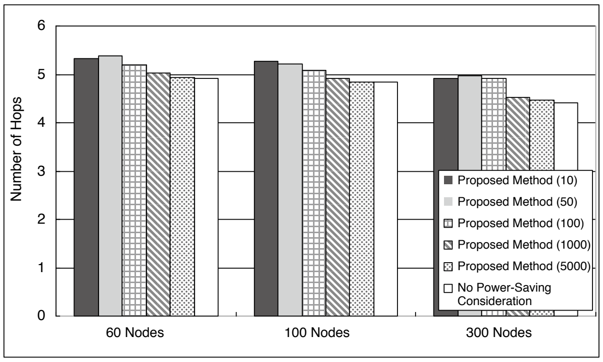

Figure 6. Comparison of Average Number of Hops

The proposed method reduces the number of transit nodes which may result in longer paths. To examine this effect, the average number of hops for each method was determined. The simulation conditions were the same as those for the power consumption test.

This time, the network is assumed to be for communication between the base station and each node. Only nodes that correspond to the termination of the communication path are operated in power-saving mode, hence they will not affect the delay of the overall network (delay will only increase for the downstream communication directed at the terminal nodes). If the effect of broken links is excluded, communication delay is essentially proportional to the number of hops. Therefore, evaluating the hops is basically equivalent to evaluating the communication delay. **Figure 6** illustrates the changes in the average number of hops. The effect is the opposite of the power consumption test, and the proposed method increased the average number of hops compared with the case when power-saving was not considered. Communication paths are detoured as power consumption is reduced. When the shortest path priority is set low, hops increase, and when the priority is set high, the hops decrease. The small changes seen with high node density is similar to the power consumption test. The increase in the average number of hops resulting from a low shortest path priority holds at about 10% which is a small effect compared with the 30% to 50% reduction achieved in power consumption. Furthermore, the effect of increased hops on communication performance, such as delay, is dependent on traffic volume. Thus, balancing reduction between hops and power consumption using shortest path priority will enable adjustment in network configuration to respond to various situations.

Summary

In order to reduce power consumption and ensure communication performance at the same time, a network configuration method using power-saving effects has been proposed. Simulation conducted to evaluate performance revealed that 30% to 50% reduction in power consumption can be achieved compared with the past method.

Acknowledgement

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Note: Titles and organizations are current as of March 2012

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