Research Article

A Communication Framework in Multiagent System for Islanded Microgrid

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Microgrids are integrated energy systems consisting of interconnected loads and distributed energy sources which as a system can operate in parallel with the grid or in an island mode. By fault occurrence in the connected power system or geographical isolation, microgrids operate in the islanded mode. In the islanded mode, microgrids should be operated to meet a power balance between supply and demand without power trade. In recent years, multiagent systems have been proposed to provide intelligent energy control and management systems in microgrids. In this paper, we design a communication framework to control and operate distributed sources and loads in the islanded microgrids. The framework reliably delivers microgrid control frame between agents by employing wireless mesh network as an advanced topology of the wireless sensor network. From results of experiments, we show that our framework outperforms other conventional one, with respect to the rate of success on the transmission of frames among agents.

1. Introduction

A microgrid is an energy community having clean energy sources such as solar power, wind power, and fuel cells and energy storage devices such as batteries. The energy sources and energy storage devices are distributed in the community, and they are called distributed generation systems (DGs) and distributed energy storage devices (DSs), respectively. Recently, attention on the microgrid has been growing as an eco-friendly power system reducing climate change. Since Professor Lasseter proposed the concept of the microgrid in 2001 [1], many technologies such as power control [2–5], protection schemes [6, 7], simulators, and field tests [8–10] for microgrids have been studied. In addition, multiagent system applications have been studied for efficient and economic control and operation of microgrids [11–20].

The microgrid can be operated by two operation modes: the grid-connected mode and the islanded mode. In the grid-connected mode, a microgrid is connected to a power system, especially a distributed system. On the other hand, the islanded mode means an isolated operation mode from any power system for the case of fault occurrence in the connected power system or geographical isolation such as a small island. In the islanded mode, microgrids should be operated to meet a power balance between supply and demand without power trade. Whenever a power imbalance occurs, the output of DGs is decreased and load shedding is used to solve the power imbalance.

Since DGs and DSs are distributed geographically, microgrids can be operated and controlled using communication links such as the Internet, the power line communication (PLC), and fiber-optic lines [19]. In particular, in the case of geographically islanded microgrids located at an island, the PLC and the wireless sensor network (WSN) can be considered as economical communication links. The PLC is used for the pilot microgrid of Kythnos Island (Greece) [12]. However, the propagation problem and the limited data rates of the PLC are well-known problems. Besides, there
are many ways in which error has been introduced into the communication signals. Interference, cross chatter, some active devices, and some passive devices introduce noise or attenuation into the signal. When error becomes significant, the devices controlled by the unreliable signal may fail, become inoperative, or operate in an undesirable fashion. For this reason, the WSN was considered basically for a communication link in geographically islanded microgrids as explained in our previous work [15].

In this paper, we propose a communication infrastructure based on the WSN for geographically islanded microgrid operated and controlled by a multiagent system. As an advanced topology of the WSN, we employ wireless mesh network (WMN) that needs only a few access points for wireless connections among agents and also reduces the infrastructural costs. To improve the performance in terms of the success on the transmission of frames among agents, we customize the routing protocol for adjusting routes according to the link quality. Also, we verify that our protocol improves the success on the transmission irrespective of dynamics of link quality.

The remainder of this paper is structured as follows. Section 2 describes geographical islanded microgrid operation based on the multiagent system as backgrounds. Section 3 explains our communication infrastructure and discusses the proposed routing protocol. Following this, we verify the designed system by NS-2 simulations in Section 4. Finally, Section 5 summarizes our study results.

2. Islanded Microgrid Operation Based on Multiagent System

2.1. Islanded Microgrid Operation and Control. The microgrid should maintain a constant frequency such as 50 Hz or 60 Hz. In practice, some deviation such as ±0.2 Hz is allowed. The frequency affects a power balance between supply and demand. Figure 1 shows an operation scheme for power balance in the islanded microgrid [17]. The information of power supply, power demand, and status of storages is collected and a condition of power balance is checked. If the power supply is greater than the power demand, DSs are selected for charging. Otherwise, DSs decided to discharge and the load shedding is used.

Figure 2 illustrates the operation procedure of the microgrid simply where an operation plan prepared in the previous interval is implemented in the next interval. The operation is related to planning action for operational intervals and is composed of two steps: planning and implementation [15–19]. In general, the interval period is determined by microgrid operation rules, for example, a few minutes or a few dozen minutes. The planning action as a control reference is established in each interval. And then the control action is followed. Table 1 shows the features of the operation and control.

2.2. Multiagent-Based Islanded Microgrid. An agent is considered as an intelligent agent which senses the changes of environment and acts by its design purpose. A multiagent system is composed of multiple agents. In our previous works [15–19], a multiagent system for microgrid was defined as follows:

$$\text{Ag = } \{\text{Ag}_{\text{MGOCC}}, \text{Ag}_{\text{DG}}, \text{Ag}_{\text{DS}}, \text{Ag}_{\text{L}}\},$$

where \(\text{Ag}_{\text{MGOCC}}\) is the Microgrid Operation and Control Center (MGOCC) agent, \(\text{Ag}_{\text{DG}}\) is a set of DG agents (\(\text{Ag}_{\text{DG}}\)), \(\text{Ag}_{\text{DS}}\) is a set of storage device agents (\(\text{Ag}_{\text{DS}}\)), and \(\text{Ag}_{\text{L}}\) is a set of load agents (\(\text{Ag}_{\text{L}}\)). The MGOCC agent manages entire operation and control in the microgrid. Each agent operates and controls its DG, DS, and load. The agents communicate with the agent communication language (ACL) and share their knowledge for cooperation. An example of the message for communication among agents is as follows:

\(<\text{performative}>: \text{from <agent name>>: to <agent name>>: content <OAV type data>),\n
where OAV (objective attribute values) type data is composed of an object, an attribute of the object, and the value of the attribute. Table 2 is the communication protocols and Tables 3 and 4 are the designed performatives for the protocols [17]. Here, P1 is used for interactions between the MGOCC agents and the DG agents and P2 is used for between the MGOCC agents and the Load/DS agents.

3. WSN-Based Communication Infrastructure

3.1. Design of WMN Structure. As an extension of the WSN, the WMN has been recently developed to provide high-quality services and applications over wireless personal area networks, wireless local area networks, and wireless metropolitan area networks [21]. Its applications and services include wireless home Internet access, community and neighborhood networking, public safety and security surveillance systems, intelligent transportation systems, and emergency and disaster networking. The WMN has a hybrid network infrastructure with a backbone and an access network. It is operated in both ad hoc and infrastructure modes with self-configuration and self-organization capabilities.

The WMN is the ideal solution to provide both indoor and outdoor broadband wireless connectivity in urban, suburban, and rural environments without the need for extremely costly wired network infrastructure [22]. The WMN has been envisioned as the economically viable networking paradigm to build up broadband and large-scale wireless commodity networks. Installing the necessary cabling infrastructure not only slows down implementation but also significantly increases installation cost. Therefore, the wired architecture is costly, unscalable, and slow to deploy. On the other hand, building a mesh wireless backbone enormously reduces the infrastructural cost because the mesh network needs only a few access points for connection. This reduction of network installation cost ensures rapid deployment of a metropolitan broadband network even in rural or scarcely populated urban areas. Thus, we employ the WMN to design communication infrastructure for the multiagent system.
The WMN is a group of mesh clients and routers interconnected via wireless links. Mesh clients (MCs) can be various devices with wireless network interface cards such as PCs and laptops. In this paper, a MC represents an agent. Hereafter, MC and agent are exchangeable for convenience. Agents have limited resources and capability in terms of processing ability, radio coverage range, and so on. Mesh routers (MRs) are usually powerful in terms of computation and communication capabilities and have continuous power supply. They normally stay static and act as access points to supply network connections for the agents. Due to limited radio coverage range and dynamic wireless channel capacity, message from an agent usually is transmitted through a multihop path to its destination. Ad hoc mode interconnections of the MRs construct the wireless mesh backbone network. When a new or existing router joins or leaves the backbone, the network self-organizes and self-configures accordingly. In a wireless mesh access network, there are usually one static agent and a number of sensors.

Our WMN structure is illustrated in Figure 3. On each MR, one wireless channels is assigned for access network communication, while the other channel is assigned for the backbone network interconnection. Adjacent access networks should be set to operate on separated channels in order to avoid interference with each other. In the backbone, when directed traffic travels towards the destination, the backbone provides redundant paths between each pair of MRs significantly increasing communications reliability, eliminating single points of failure and potential bottleneck links within
Table 3: Performative for P1.

| Performative          | Meaning                                      | Remark                      |
|-----------------------|----------------------------------------------|-----------------------------|
| Request Information   | Request for Information about available      | Between AgMGOCC and AG1/AGS |
|                       | storage capacity and charged amount          |                             |
| Receive Information   | Receive information                          |                             |
| Inform Load           | Inform load amount                           |                             |
| Receive Load          | Receive load information                     |                             |
| Request Load          | Requests for load shedding                   |                             |
| Inform Storage        | Inform available capacity and charged         |                             |
|                       | amount                                        |                             |
| Receive Storage       | Receive storage information                  |                             |
| Request Charge        | Request for charge                           |                             |
| Request Discharge     | Request for discharge                        |                             |
| Report Load           | Report load shedding                          |                             |
| Shedding              |                                              |                             |
| Report Storage Action | Report action of storage device              |                             |

Table 4: Performatives for P2.

| Performative          | Meaning                                      | Remark                      |
|-----------------------|----------------------------------------------|-----------------------------|
| Announce task         | Announce to start a new task                 |                             |
| Receive task          | Receive a new task                           |                             |
| Bid                   | Bid for power supply                         | Bid price and supply amount |
| Receive Bid           | Receive a bid                                |                             |
| Award                 | Award contracts                              |                             |
| Receive Award         | Receive Award                                |                             |
| Report                | Report the contract                          |                             |

3.2. Routing Protocol Customized to the Islanded Microgrid. Open standard radio technologies are essential for industry because they bring down the cost of equipment and ensure interoperability. For this reason, several IEEE standard groups are actively working to define specifications for WMN. IEEE 802.11s [23] extends the IEEE 802.11 architecture and protocol for providing the functionality of an extended service set (ESS) mesh. IEEE 802.11s defines a default mandatory routing protocol (Hybrid Wireless Mesh Protocol, or HWMP) [24], yet allows vendors to operate using alternate protocols. HWMP is inspired by a combination of an on-demand AODV [25] and a proactive tree-based routing. The proactive mode requires one MR to be configured as one root MR and we configure the MR connected with MGOCC as the root MR. The root MR constantly propagates routing messages that either establish and maintain routes to all MRs in the mesh or enable MRs to initiate a path to it. In Figure 4, MR K uses the root MR C to establish an initial path (dotted arrow) to MR J. Once
the link quality with no route-flaps. According to the relative
extend HWMP to adjust the route between MRs according to
frequent packet reordering and increases packet loss. We
link, and the process repeats. This route-flap problem causes
their previous link. The switch results in unloading the new
link, traffic congests the link, while the previous link becomes unloaded.
Then, the MRs detect the status change and switch back to
their previous link. The switch results in unloading the new
link, traffic congests the link, while the previous link becomes unloaded.
We extend HWMP to adjust the route between MRs according to
the link quality with no route-flaps. According to the relative
link quality, each MR chooses a new link in a statistical manner for delivering the traffic load to its destination.
The MR detects the degradation of the link quality of its
current link \(i\) when the link cost \(c_i\) is larger than a certain threshold \(c_{th}\). Then, the MR selects a new link as follows:
the MR calculates \(\Gamma(c_i)\) of its links whose \(c_i\)s are smaller than \(c_{th}\). \(\Gamma(c_i)\) is the min-max normalization function of \(c_i\). The
normalized link cost represents the relative link quality levels among them. As \(\Gamma(c_i)\) of a link is smaller, the link quality of the link is better, compared to the other links having larger values. Given \(\Gamma(c_i)\), the MR sorts \(\Gamma(c_i)\) in an ascending order
and we denote \(\{\Gamma(\Gamma(c_1)), \Gamma(\Gamma(c_2)), \ldots, \Gamma(\Gamma(c_k))\}\) as the sorted \(\Gamma(c_i)\). Then, with probability \(p\), the MP selects link \(i\) as the new
link as long as \(p\) satisfies the condition as in the following equation:

\[
\Gamma(c_{i-1}) \leq p < \Gamma(c_i).
\]

4. Performance Evaluations and Discussions

To quantitatively evaluate the performance of the proposed routing protocol, we use NS-2 network simulator [28]. Our WMN delivers the microgrid-related command between agents in a reliable manner. We evaluate the rate of success on the transmission of frames as a performance metric.

In a 1500 m by 1500 m grid, we deploy 20 MCs that is, agents and 36 MRs. The MCs are randomly placed and MRs are equally spaced. The root MR sends a control message every 0.5 seconds. MCs exchange 1024-byte CBR packets with randomly selected other MCs through MRs every second. Table 5 is the list of the parameters as well as the selected values of the physical (PHY), MAC, and HWMP layer applied for the simulation environment. The values for the PHY layer are those for the Extended Rate PHY (IEEE 802.11g). The RTS/CTS mechanism of the MAC layer is disabled by the default settings of the IEEE 802.11 standard. The total simulation time is 3600 seconds.

Figures 5–7 show the probability of success on the frame transmission between MCs. The probability is mostly affected by the frame error rate (i.e., the probability of success on the transmission of frames), data rate, and threshold \(c_{th}\) [26, 27]. The numbers in each legend of Figures 5 and 6 present how to set the value of the \(c_{th}\). For example, “Our

| Table 5: Simulation parameters. | Parameter | Value          | Parameter | Value          |
|--------------------------------|-----------|----------------|-----------|----------------|
| Slot time                      | 9 \(\mu\)s| Max PREQ retries| 3         |                |
| SIFS                           | 10 \(\mu\)s| Net diameter   | 35        |                |
| Signal extension time          | 6 \(\mu\)s| Diameter traversal time| 0.2 s |                |
| Preamble duration              | 20 \(\mu\)s| PREQ min interval| 0.1 s |                |
| Data rate                      | 54 Mbit/s| PERR min interval| 0.1 s |                |
| Transmission range             | 250 m     | Path and root timeouts| 5 s  |                |
| Radio-propagation model        | Two Ray Ground | Root PREQ interval | 1 s |                |

**Figure 4: HWMP route selection scheme.**
Figure 5: Experimental results obtained by varying frame error rate with standard deviation of Gaussian distribution $N(0, \sigma_1)$.

Figure 6: Experimental results obtained by varying data rates.

Figure 7: Experimental results obtained by varying $c_{th}$ threshold.

The number of delivered frames between MCs is not large, for example, one frame for each second, the performance improvement is not large. Figure 7 indicates the performance with varying the $c_{th}$. As seen in the figure, the performance of HWMP is not affected by the $c_{th}$. In our protocol, as the $c_{th}$ is changed between 10% and 90%, the performance is changed up to 6%. When the $c_{th}$ is small, our protocol is too highly sensitive to the dynamics of the link cost and the overhead of changing the route increases. When the $c_{th}$ is large, the protocol becomes dull and the benefit of adjusting routes according to the link quality decreases. From the results, we conclude that the performance is good when the $c_{th}$ is 30% or 40%.

5. Conclusions

In this paper, we designed a communication infrastructure for multiagent-based islanded microgrid. There are several contributions in our design: we designed the infrastructure to deliver grid control frame between agents by employing WMN. In order to deliver the frame reliably, we extended the traditional HWMP to adjust the route between MRs serving agents according to the link quality. For the development, we selected a new link in a statistical manner to avoid the route-flap problem. In addition, we showed the feasibility of our protocol from the comparison of our protocol with HWMP. From the comparison, we can conclude that the performance of our protocol is better than that of HWMP with respect to the rate of success on the transmission of the frame.

In our protocol, one of the factors affecting the performance is the threshold $c_{th}$. To optimize the performance, we need any threshold decision scheme in time-varying environments. We will consider developing the scheme as a future research direction. In addition, when the islanded microgrid needs to be connected to the external network, for example, the Internet, our infrastructure uses one or more MRs to connect the external network. As another research direction,
we will develop the load-balancing scheme between the MRs to avoid the traffic concentration.

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References

[1] R. H. Lasseter, “Microgrids,” in Proceedings of the IEEE Power Engineering Society Winter Meeting, pp. 146–149, January 2001.

[2] J. Y. Kim, S. K. Kim, and J. H. Park, “Contribution of an energy storage system for stabilizing a microgrid during islanded operation,” Journal of Electrical Engineering and Technology, vol. 4, no. 2, pp. 194–200, 2009.

[3] J. Y. Kim, J. H. Jeon, S. K. Kim et al., “Cooperative control strategy of energy storage system and microsources for stabilizing the microgrid during islanded operation,” IEEE Transactions on Power Electronics, vol. 25, no. 12, Article ID 5580122, pp. 3037–3048, 2010.

[4] C. K. Sao and P. W. Lehn, “Control and power management of converter fed microgrids,” IEEE Transactions on Power Systems, vol. 23, no. 3, pp. 1088–1098, 2008.

[5] R. Majumder, A. Ghosh, G. Ledwich, and F. Zare, “Power management and power flow control with back-to-back converters in a utility connected microgrid,” IEEE Transactions on Power Systems, vol. 25, no. 2, Article ID 5340642, pp. 821–834, 2010.

[6] H. L. Jou, W. J. Chiang, and J. C. Wu, “A simplified control method for the grid-connected inverter with the function of islanding detection,” IEEE Transactions on Power Electronics, vol. 23, no. 6, pp. 2775–2783, 2008.

[7] D. M. Vilathgamuwa, P. C. Loh, and Y. Li, “Protection of microgrids during utility voltage sags,” IEEE Transactions on Industrial Electronics, vol. 53, no. 5, pp. 1427–1436, 2006.

[8] J. H. Jeon, J. Y. Kim, H. M. Kim et al., “Development of hardware-in-the-loop simulation system for testing operation and control functions of microgrid,” IEEE Transactions on Power Electronics, vol. 25, no. 12, Article ID 5594649, pp. 2919–2929, 2010.

[9] Y. Li, D. M. Vilathgamuwa, and P. C. Loh, “Design, analysis, and real-time testing of a controller for multibus microgrid system,” IEEE Transactions on Power Electronics, vol. 19, no. 5, pp. 1195–1204, 2004.

[10] J.-H. Jeon and S.-K. Kim, “Development of simulator system for microgrids with renewable energy sources,” Journal of Electrical Engineering and Technology, vol. 1, no. 4, pp. 409–413, 2006.

[11] A. L. Dimeas and N. D. Hatziargyriou, “Operation of a multi-agent system for microgrid control,” IEEE Transactions on Power Systems, vol. 20, no. 3, pp. 1447–1455, 2005.

[12] S. J. Chatzivasiliadis, N. D. Hatziargyriou, and A. L. Dimeas, “Development of an agent based intelligent control system for microgrids,” in Proceedings of the IEEE Power and Energy Society 2008 General Meeting, pp. 1–6, July 2008.

[13] A.L. Dimeas and N.D. Hatziargyriou, “Agent based control for microgrids,” in Proceedings of the IEEE Power Energy Society General Meeting, pp. 1–5, June 2007.

[14] A. L. Dimeas and N. D. Hatziargyriou, “Control agents for real microgrids,” in Proceedings of the 15th International Conference on Intelligent System Applications to Power Systems (ISAP ’09), pp. 1–5, Curitiba, Brazil, November 2009.

[15] H. M. Kim, T. Kinoshita, Y. Lim, and T. H. Kim, “A bankruptcy problem approach to load-shedding in multiagent-based microgrid operation,” Sensors, vol. 10, no. 10, pp. 8888–8898, 2010.

[16] H. M. Kim and T. Kinoshita, “A multiagent system for microgrid operation in the grid-interconnected mode,” Journal of Electrical Engineering and Technology, vol. 5, no. 2, pp. 246–254, 2010.

[17] H. M. Kim, T. Kinoshita, and M. C. Shin, “A multiagent system for autonomous operation of islanded microgrids based on a power market environment,” Energies, vol. 3, no. 12, pp. 1972–1990, 2010.

[18] H. M. Kim and T. Kinoshita, “A new challenge of microgrid operation,” Communications in Computer and Information Science, vol. 78, pp. 250–260, 2010.

[19] H. M. Kim and T. Kinoshita, “Multiagent system for Microgrid operation based on power market environment,” in Proceedings of the 31st International Telecommunications Energy Conference (INTELEC ’09), Incheon, Korea, October 2009.

[20] Z. Xiao, T. Li, M. Huang et al., “Hierarchical MAS based control strategy for microgrid,” Energies, vol. 3, no. 9, pp. 1622–1638, 2010.

[21] F. Huang, Y. Yang, and L. He, “A flow-based network monitoring framework for wireless mesh networks,” IEEE Wireless Communications, vol. 14, no. 5, pp. 48–55, 2007.

[22] R. Bruno, M. Conti, and E. Gregori, “Mesh networks: commodity multihop ad hoc networks,” IEEE Communications Magazine, vol. 43, no. 3, pp. 123–131, 2005.

[23] Draft Amendment to Standard for Information Technology—Telecommunications and Information Exchange Between Systems—LAN/MAN Specific Requirements—part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Amendment: ESS Mesh Networking, IEEE P802.11s/D3.0, March 2009.

[24] G. R. Hiertz, D. Denteneer, S. Max et al., “IEEE 802.11s: The WLAN mesh standard,” IEEE Wireless Communications, vol. 17, no. 1, Article ID 5416357, pp. 104–111, 2010.

[25] C. Perkins, E. Belding-Royer, and S. Das, “Ad hoc on demand distance vector (AODV) routing,” IETF RFC 3561, 2003.

[26] Y. D. Lin, S. L. Tsao, S. L. Chang, S. Y. Cheng, and C. Y. Ku, “Design issues and experimental studies of wireless lan mesh,” IEEE Wireless Communications, vol. 17, no. 2, Article ID 5450658, pp. 32–40, 2010.

[27] R. C. Carrano, L. C. S. Magalhães, D. C. M. Saade, and C. V. N. Albuquerque, “IEEE 802.11s multihop MAC: a tutorial,” IEEE Communications Surveys and Tutorials, vol. 13, no. 1, Article ID 5473885, pp. 52–67, 2011.

[28] “The network Simulator ns-2,” http://www.isi.edu/nsnam/ns/.