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Agents with Power

The energy market is ripe for emergent IT tools that may simply transform the utilities sector.

THE POSSIBILITY OF USING THE ELECTRIC GRID FOR BOTH power and information transmission creates new business opportunities for utilities. The ongoing deregulation of the energy market and emergent information technologies are push-pull factors in this business transformation. Among the opportunities for utilities and their customers, we have improved usage of energy; improved production and better use of resources in industries; created new user-centric services; new business processes and new actors on the market; and smart equipment communicating on the electric grid.

It should be noted there are also some potential threats for the utilities to lose customers or lose market opportunities due to inability to upgrade or change their products or to change their market view from a monopoly to a highly competitive market.

Here, we describe project ISES (Information, Society, Energy, and Systems) in Sweden where these types of issues are addressed. The main business process of the energy sector has typically been around production and distribution of kiloWatt hours (kWh). However, the power grid can also be used as a data communication channel with increasingly higher bandwidth—over 1 Mb/s on parts of the grid—which creates new business opportunities. Another key technological driving force is the rapid development of technologies supporting design and implementation of smart distributed equipment communicating on the electric grid. Since the grid can be Internet accessible, we can foresee how we will one day phone our smart home from any place in the world and ask the refrigerator if it needs to download an agent to meet a new environmental regulation.

In a deregulated market, customers can easily change their kWh commodity provider, so the utilities will soon need to compete with added value for the customer. The deregulation also means that new players can enter the energy business field. For example, in October 1997, the Norwegian Statoil was the first petroleum company to enter the electricity market in Sweden. This petroleum company intends to gain market shares with low prices and knowledge of how to compete in a similar market, selling of gasoline to individual customers. The utilities have, due to regulated markets, often very limited knowledge of their customers' needs. Customers are usually regarded as "two holes in the wall."

In a follow-up project, these ideas of a change from commodity products of low value to value-added customer services are further developed. The theme is a sustainable society with a focus on smart housing and based on smart equipment communicating on the electric grid and with Internet access. The common idea is to go from product selling to function selling. Products could be kWh, home appliances, or cars; the functions might be comfort of living, secure homes, making a meal or transport. Besides utilities, we now have telecom companies, home appliance manufactures, and car manufactures working together in a new project supported by national Swedish funds.

A bottom line is that agent technologies will be key components in building necessary new types of *smart infrastructures*.

The ISES Project and Villa Wega Demonstrators

Our research group Societies of Computation (SoC) at the University of Karlskrona/Ronneby in Sweden, takes an application-driven approach to R&D on agent technologies and as a support in development of robust design methodologies.[1] After all, at the end of the day we must deliver reliable and purposeful software supporting people and businesses to get our technology accepted and used. The international R&D consortium ISES started in 1996 to investigate possibilities, and threats, for utilities facing deregulation and a possible two-way communication on the electric grid. The ISES project is coordinated by the R&D company EnerSearch AB.[2]

We selected load management on the electric grid as our first application. We also developed, in parallel, an R&D laboratory Villa Wega (Wega House), where we could build and test demonstrators. EnerSearch has also set up field tests in the residential area of Påtorp in Ronneby. Therefore, we have at our disposal a fruitful development and test environment in the form of Villa Wega demonstrators and Påtorp field tests. Energy savings based on communicating smart equipment have also been tested, with very promising results, at a paper and pulp industry in Ronneby. Most of the smart equipment we use is built from components, such as IBM's IDAM system, and Echelon LonWork technologies.

Load Balancing of HomeBots

Load balancing of the demand of energy has a large industrial value, since the utility can, for instance, avoid costly and sometimes environment-unfriendly generation of energy to meet peak demands. Furthermore, investments in expensive power generation and distribution equipment to take care of peak demand can thus also be trimmed. A win-win situation for utilities and customers can be obtained by trading energy allocation vs. price or customer value, thus agreeing on a suitable redistribution profitable for all parties.

We have modeled the load-balancing task as a multiagent system and introduced a computational market with auctions as an allocation mechanism (see [1] and the sidebar on Villa Wega demonstrators). The allocation of agents follows the topology of the electric grid.

Device agents, we call them HomeBots in this case, intermediate Service agents, and the Utility agent are the participants of the auction. The natural hierarchy of agents induced by the network topology allows us to design and implement highly efficient distributed auction algorithms. Figure 1 shows a simulation of the multiagent system illustrating that after a change in price by the utility agents, total demand and redistribution of energy is done in just a few steps [9, 11, 12].

Our approach has a number of desirable general features:

- *Scale.* Large numbers of equipment components can be dealt with in this approach; thousands, even millions, of devices can be handled simultaneously by the market mechanism.
- *Flexibility.* The overall goal of load balancing is achieved by coordination between many small programs with local information and intelligence, rather than by a single point of control that has to "know and steer everything." This gives a much more flexible and natural architecture in highly distributed applications.
- *Adaptability.* The present approach deals well with the (common) situation whereby the environment of the system is changing dynamically, with loads entering or disappearing at unknown and irregular times.
- *Customizability.* The approach gives ample room to

[1] SoC at the University of Karlskrona/Ronneby: www.sikt.hk-r.se/~soc/
[2] EnerSearch and the ISES project: www.enersearch.se/

cater individual customer requirements and preferences in interaction styles.

- *Wide applicability.* Although we have sketched only a restricted scenario for load management, the market programming concept can be used for many different applications and scenarios. The basic ideas and procedures remain the same.

A very high degree of automation is achieved in finding the optimum situation in large-scale distributed energy management. Information exchange and problem-solving methods appear to be computationally fast, robust, and efficient. Simulations and field experiments confirm the feasibility of the HomeBot agent and electronic market approach. It succeeds in reducing peak demands, as well as the overall costs of power delivery and consumption.

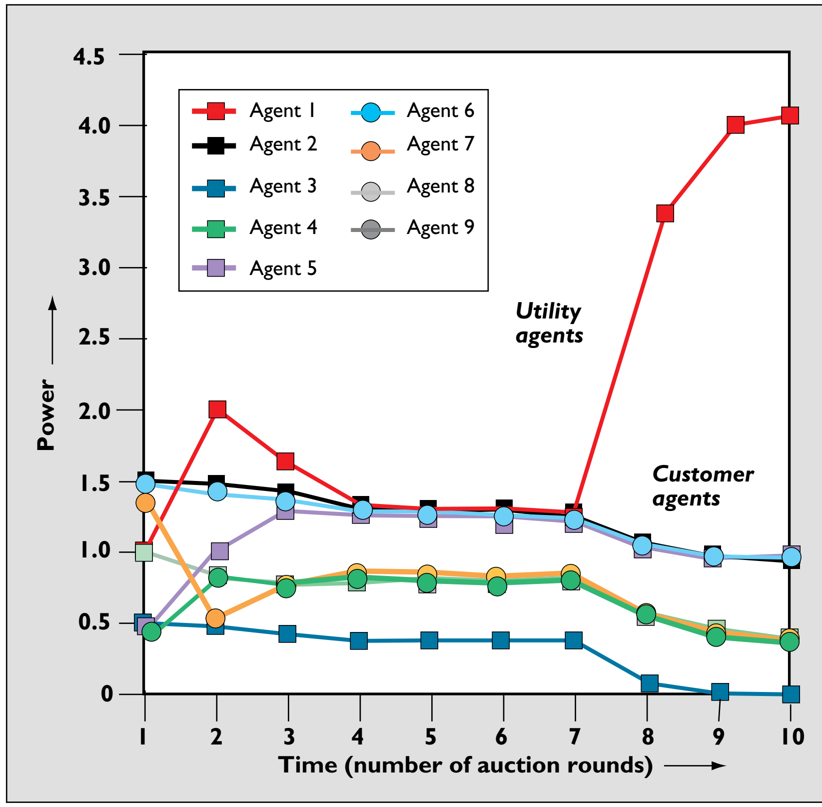

Figure 1. Simulation of an auction for load management. A time point 7, agent No. 1 (representing the utility) attempts to buy back power in a load management action by raising its bid price. It is seen that all customer agents sell and thus reduce power use in a balanced way. The optimal situation (market equilibrium) is reached at time point 10, that is, in only three negotiation rounds.

Compared to existing methods for load management, our market approach has a number of specific advantages. Indeed, it provides an integrated strategy for many different loads and contracts. Executable business scenarios may vary from low-level contracts allowing the utility to switch off loads for certain periods to high-level services, such as indoor temperature control. It enables a natural decomposition, from both a software design and a computational perspective. All local characteristics are encapsulated by agents, communicating only through prices and demands, while performing local optimization computations. It uses highly natural and understandable abstractions: price and demand. It provides the utility with a compact and uniform estimate of the energy system characteristics (present and future) in terms of prices and demands. It allows to obtain a local estimate of the value of the load management contract. This enables the utility to do continuous online cost/benefit analysis of every load management contract in the entire system.

The metaphor of local agents negotiating their way to market equilibrium is a very natural and attractive one that simplifies the understanding of the principles of the system. This naturalness is also important from the software engineering perspective. The estimate of energy system characteristics in terms of prices and demands it allows is highly relevant to utilities. Well-known concepts from economics, such as price elasticity, apply directly. Finally, the local evaluation of load contracts for every load in the entire system is a useful feature inherent only in a market approach. Accordingly, the market design tightly fits the real-world situation conceptually.

Due to different capabilities of the HomeBots and Utility agents, different auction schemes can be implemented [7, 9–11]. We have developed different specifications of agent capabilities, in terms of characteristics of user demands and utility resources, that can be implemented in very efficient algorithms. We can also model and test different trade-offs between local reasoning capabilities of the agents vs. communication bandwidth. Furthermore we can have resource-oriented or price-oriented auctions. Time critical, anytime algorithms auctions, as well as multicommodity markets, are also quite well understood and implemented [12]. Finally, we have modeled the auction dialog in a high-level agent communication

Villa Wega Demonstrators Load Balancing and Energy Savings

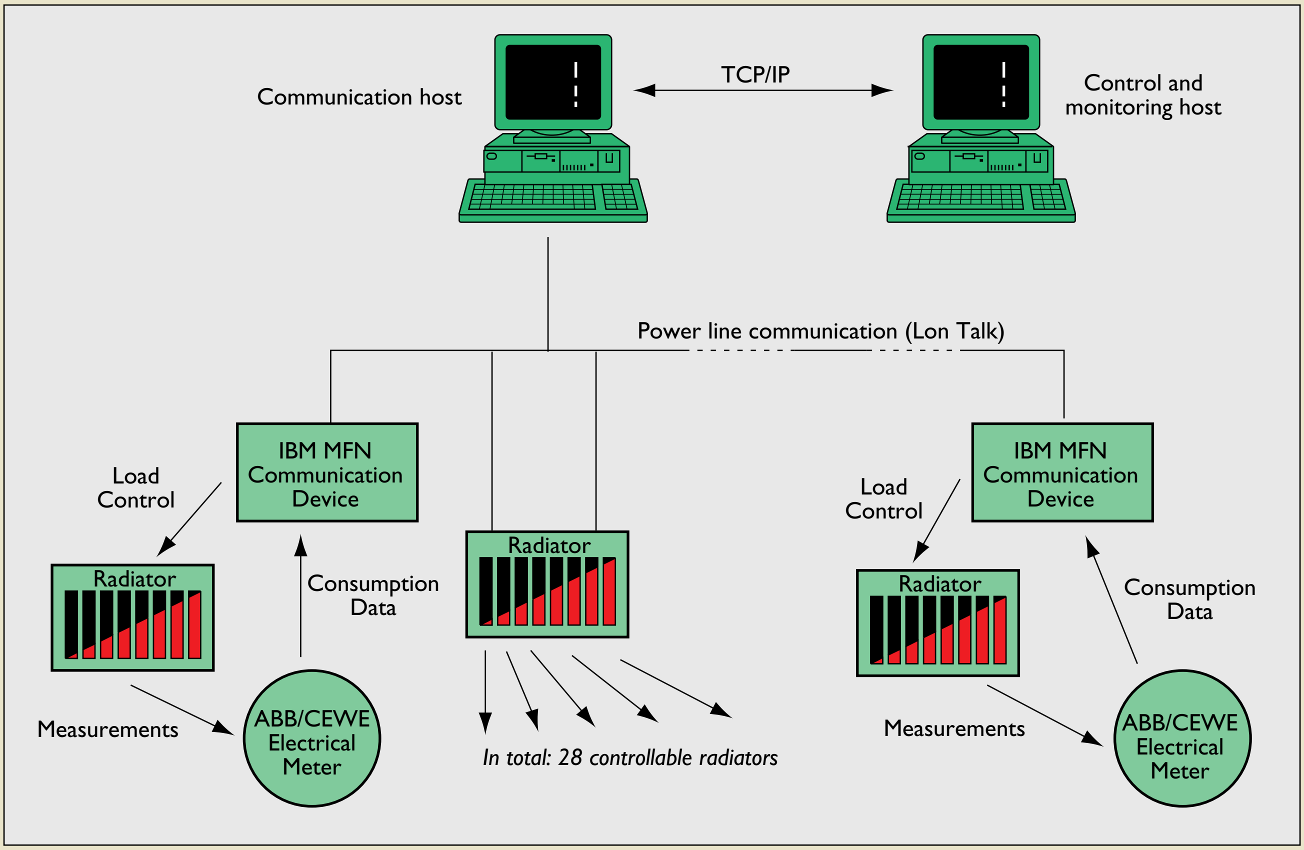

Figure a. The setup of the Villa Wega field tests.

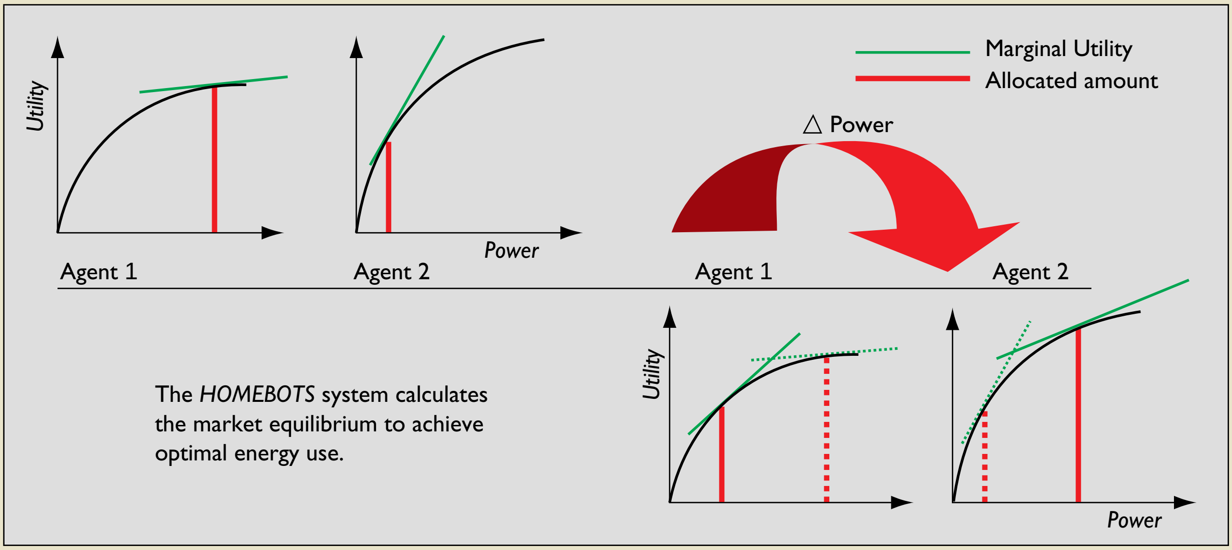

Figure b. How the electronic market works. The power allocation to the HomeBot agents is adjusted in each auction round by considering their different bid prices. Bid prices are visible as the slopes of the utility functions (that is, the marginal utilities). When the overall allocation has become such that all bid prices are equal, a market equilibrium occurs. No agent will gain more by buying or selling; the load management auction as a market process is complete.

Smart Home Services

The devices are either sensors or actuators. The sensory devices we use are temperature, light intensity, presence (detects whether there is activity in a room or not), and an active badge system. It is possible to include other types of sensors, like fire detectors. The active badge system makes it possible to know which persons are in each room at any moment. The actuator devices differ from the sensory devices in that it is possible to change the state of the device (in order to change the state of the building).

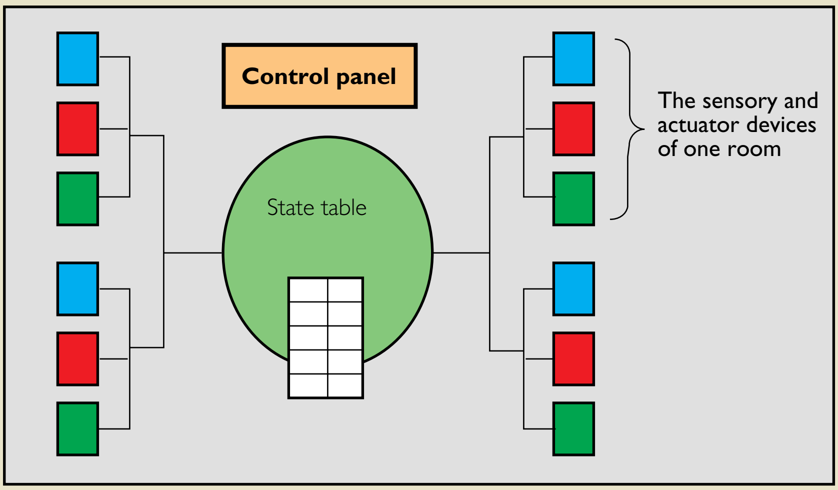

Figure c. The conceptual structure of the multiagent system. Interaction with the devices at the hardware level is facilitated by an infrastructure based on LonWorks technology. Each electrical device in the system is connected via special purpose hardware nodes to the LonWorks sytem, allowing the exchange of information over the electrical grid. All the information received from the devices is recorded on a control panel. This information reflects the state of the devices (and therefore, the state of the environment) and is stored in a special attribute-value table.

When a person's movement is detected by a badge sensor and forwarded to the Badge Server Agent via the control panel, the Badge Server Agent informs the appropriate Personal Comfort agent about this. The Personal Comfort agent informs the appropriate Room agents, such as the agent of the room the person is leaving and the agent of the room the person is entering. The Personal Comfort agent also provides the Room agents with the personal preferences. The Room agent decides, based on these preferences and on energy saving considerations, the new desired environmental conditions and passes them on to the Environment Parameter agents. The Environment Parameter agents then try to achieve and keep the values decided by the Room agent by monitoring the relevant sensors and sending commands to the relevant actuators via the control panel. Eventually, the House agent might be consulted concerning overall goals and constraints as well as solving some local conflicts.

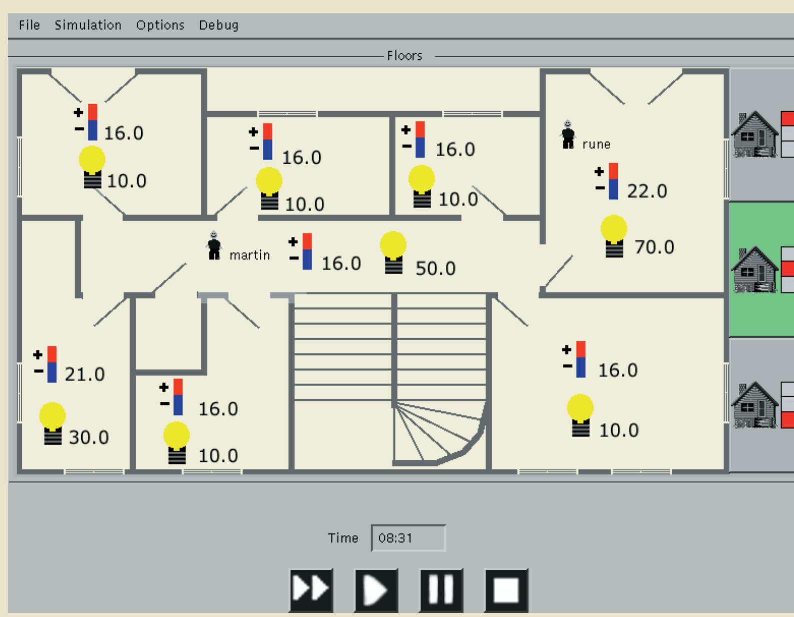

Figure d. A snapshot of this GUI visualizing the state of the building in terms of temperature, light intensity of the rooms, and the persons present in the rooms.

language by using methodologies from knowledge engineering [2].

A next step is to integrate load balancing into other user-oriented services. Of course, the load balancing mechanisms are a value-added service for both the utility and the customer. As such, it can be a building block for other services for added value to all parties involved.

The Benefits of Intelligent Buildings

In this application, we study home services, such as energy saving, comfort of living, and safety. We have developed a system consisting of a collection of software agents that monitor and control an office building. It uses the existing power lines for communication between the agents and the electrical devices of the building, such as sensors and actuators for lights, heating, and ventilation. The objectives are energy saving and increased customer satisfaction through value-added services. Energy saving is realized by such abilities as lights being automatically switched off and room temperature being lowered in empty rooms. Increased customer satisfaction is realized for example, by adapting temperature and light intensity according to each person's personal preferences. We have initial results from simulation experiments of an office building and its staff. Different user profiles are modeled in terms of their energy consuming behavior, for example, their tendency to turn off the light when leaving a room, and to adjust the temperature when leaving and entering the building. The energy consumption when using the system is compared to that of not using the system. Our simulations indicate that significant savings, up to 40%, can be achieved.

The application is modeled as a system of agents that monitor and control Villa Wega Device-agents (see the sidebar). We have also introduced high-level Room agents and Service agents that can communicate to meet customer needs [3, 8].

The agent-based approach allows for a structure-preserving mapping of the design entities of the application and the distributed smart equipment of the implementation. This methodology has advantages extending those of traditional object-oriented modeling and programming [4, 6]. It also provides the advantage of an open architecture in the given context, that is, agents can be easily configured and even dynamically reconfigured. Furthermore, it is possible to add new agents at run-time without the need for interrupting the normal operation of the system. Such changes reflect changes in the infrastructure of the building or in the staff. Finally, in contrast to the traditional object-oriented approaches, which are limited to reactive behavior, the multiagent system approach provides a straightforward way of modeling and implementing proactive behavior. Sometimes the goals of the Room agents and the Personal Comfort agents are conflicting. The sidebar notes that the Room agents are maximizing energy savings and the Personal Comfort agents are maximizing customer value. Another type of a conflicting goal situation would be the adjustment of temperature in a meeting room in which people with different preferences regarding temperature will meet. We are currently investigating the use of decision modules to address this problem with possible extensions of using the notions of group utility and norms for dealing with problems arising from agent negotiations.

The agent-based approach allows for a structure-preserving mapping of the design entities of the application.

According to our simulations, this approach will consume 221.8 kWh during an average week, whereas the approach using the multiagent system consumes only 136.2 kWh. That is, we save almost 40% energy by using the agent approach.

We can also make use of the electronic diaries in order to heat up the rooms to the preferred temperature in advance. Our simulations show this is only slightly more energy consuming, 137.0 kWh, but will probably lead to greater customer satisfaction (on the other hand, it also requires individuals to keep their electronic diaries updated).

We have evaluated only the energy-saving performance. The evaluation of customer satisfaction is equally important. However, it is difficult to make such evaluation based only on computer simulations; it is necessary to let real people use the system.

As a further step we will combine the services of both Villa Wega demonstrators. We then have to design the interface between the multiagent systems and the physical devices of the building to use and reuse the same data from the control panel, but for different services. In addition, we are experimenting with more complex functionalities, such as when a person enters the building in the morning, his or her monitor is switched on and the coffee machine starts brewing.

To enable integration of societies of multiagent systems we will use and extend methodologies of components and service-oriented architectures.

Lessons Learned

The ISES project has been a fruitful arena for assessing possibilities of multiagent technologies as well as of new business processes in an important industrial sector [1, 5, 8]. The following two concerns are often expressed by application owners or by their software development teams.

"We are interested in solutions, not agents!"

The use of agent and agent systems in industrial applications will be invisible mostly in the sense that industry just wants systems that do what they are supposed to do and have good product characteristics throughout their life cycles. We can, however, already see how a multiagent approach to system design and implementation has clear benefits, especially when we have to plan for system adaptation and system integration. Another strength of an agent-based approach is that it allows for a high-level system design, including business aspects, [1, 4, 6].

"Where do agent societies fit in?"

In order to gain industry acceptance, it is important to adopt emerging industry standards as much as possible. In our case, we closely follow the advancements by distributed objects and components as well as design patterns and software architectures.

Such technologies as service-oriented software architectures and design patterns are key components of a common framework for agent methodologies and more traditional software engineering methodologies. As we see it, agent technologies have a natural place in the usual three-tier application model. Firstly, as wrappers of legacy systems or as embedded smart systems; secondly as middleware agents gluing together applications from distributed components, allowing horizontal integration, or adaptations, of applications. Finally, as interface agents supporting user interactions.

Finally, ultimate success depends on nontechnical issues such as user acceptance and profitability. These issues are also addressed in the ISES project. ■

References

1. Akkermans, J.M., Ygge, F., and Gustavsson, R. HOMEBOTS: Intelligent decentralized services for energy management. *Knowledge Management: Organization, Competence and Methodology.* J.F. Schreinemakers (Ed.). Ergon Verlag, Wuerzburg, Germany, 1996.
2. Akkermans, J.M., Gustavsson, R., and Ygge, F. An integrated structured analysis approach to intelligent agent communication. In *Proceedings XVth IFIP World Computer Congress, Information Technologies and Knowledge Systems Conference.* (Vienna/Budapest, Aug. 31–Sept. 4, 1998). Austrian Computer Society/IFIP, Vienna, 305–318.
3. Boman, M., Davidsson, P., Skarmeas, N., Clark, K., and Gustavsson, R. Energy saving and added customer value in intelligent buildings. In *Proceedings of the Third International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology* (PAAM'98), 505–517.
4. Gustavsson, R. Multi agent aystems as open societies: A design framework. In *Proceedings of ATAL-97, Intelligent Agents IV, Agent Theories, Architectures, and Languages.* Springer Verlag, 1998, 329–337.
5. Gustavsson, R. Requirements on information systems as business enablers. (Invited) *Proceedings of DA/DSM DistribuTECH'97.* PennWell, 1997.
6. Hägg, S. A sentinel approach to fault handling in multi-agent systems. In *Proceedings of the Fourth Pacific Rim International Conference on Artificial Intelligence.* Springer-Verlag, 1996.
7. Sandholm, T.W. and Ygge, F. On the gains and losses of speculation in equilibrium markets. In *Proceeding of the 15th International Joint Conference on Artificial Intelligence IJCAI-97* (Nagoya, Japan, August 23–29, 1997). Morgan Kaufmann, San Francisco, 1997, 632–63; www.enersearch.se/~ygge.
8. Sweet, P. Interactive business processes and high-precision market development: Implications for the power industry. In *Proceedings DistribuTech DA/DSM 97 Europe* (Amsterdam, Oct. 14–16, 1997). PennWell Energy and Utility Group, Utrecht, NL.
9. Ygge, F., and Akkermans, J.M. Power load management as a computational market. In *Proceedings Second International Conference on Multi-Agent Systems.* (Kyoto, Japan, Dec. 10–13, 1996). AAAI Press, Menlo Park, Calif.
10. Ygge, F., and Akkermans, J.M. Making a case for multi-agent systems. *Multi-Agent Rationality.* Springer-Verlag, Berlin, 1997.
11. Ygge, F., and Akkermans, J.M. On resource-oriented multi-commodity market computations. In *Proceedings Third International Conference on Multi-Agent Systems.* (Paris, July 3–7, 1998). IEEE Computer Society, Los Alamitos, Calif. 1998.
12. Ygge, F. Market-Oriented Programming and its Application to Power Load Management. Ph.D. thesis; www.enersearch.se/~ygge.

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