

## From the Information and Communications Technology Perspective

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Information and communications technology (ICT) has enabled the integration of computer and audio-visual networks, leading to unprecedented exchange of data between various users and entities. By providing the infrastructure to coordinate millions of distributed assets within and across buildings, including variable loads, distributed energy resources, and energy-storage, ICT has the potential to lead to a similar convergence across building and grid domains. This paper illustrates obstacles to a broad application of ICT, lists steps to resolve these barriers, and explains how applying ICT to the building and grid domains, as well as the interface between those two domains, could provide new value to stakeholders by facilitating an exchange of services.

### Overview

As the accompanying papers discuss, there is an underlying need for highly interactive control technologies that enable a host of benefits, such as more efficiently providing transactive energy, demand response (DR) and ancillary services to electric grid markets. In principle, aggregations of residential and commercial buildings are a significant, but largely untapped source of services for transactive energy, DR and other ancillary services like spinning reserve, voltage regulation, and frequency control. In practice, the design of reliable and robust aggregation systems is hampered by the inter-domain, buildings domain and electric-grid domain challenges and barriers, all of which require unique solutions before nationwide energy, economic, and environmental benefits can be realized from buildings-grid integration. Services by buildings to the grid can only be achieved if there are commensurate benefits to the participating buildings.

ICT continues to transform our economy and society. ICT is the enabling technology that underlies affordable and practical

advanced systems to harness electrical loads in buildings as a resource for providing DR and ancillary services to electric power systems. ICT depends on computer and networking technology to deliver automation and communication for interactions among physical components and humans (i.e., between machines, between humans and machines, and between different humans). As such, ICT will provide the essential foundation upon which a transaction-based system for the electric grid could be built. ICT will enable data exchange, decision support, energy services, physical transactions, and financial settlement of transactions. The volume of transactions and the speed at which transactions must take place will require automatic processes built on an ICT infrastructure.

In a strict sense, ICT is used to refer to the convergence of communications, which represents the integration of data, voice, and information exchange and associated technologies. Throughout this section, ICT is used synonymously with the data exchange and communication infrastructures, including hardware, software, and underlying theory and principles, but it does not include the application software that resides on top of the infrastructure (e.g., analysis and visualization software tools). It encompasses the transmission, exchange, storage, retrieval, and management of data in support of interactions among components of the grid, buildings, renewable generation and storage installed on or in buildings, and neighborhoods and communities.

Broadly speaking, highly interactive, distributed control requires ICT in three different domains—smart electric grid, building automation, and the interface between the two. Because different companies provide technology to different users/decision-makers and different standards already exist or are being developed for the smart grid and for buildings, it is quite possible that smart grid and building automation may not converge, but instead will remain separate. Furthermore, the needs in each of these sectors differ. For example, the priorities in buildings are to provide comfort and other amenities to owners and occupants and to minimize occupants' complaints, while for the electric power grid, keeping the grid operating reliably is of paramount importance. Therefore, the interface between ICT systems represents a critical third ICT 'domain' that straddles buildings and the grid.

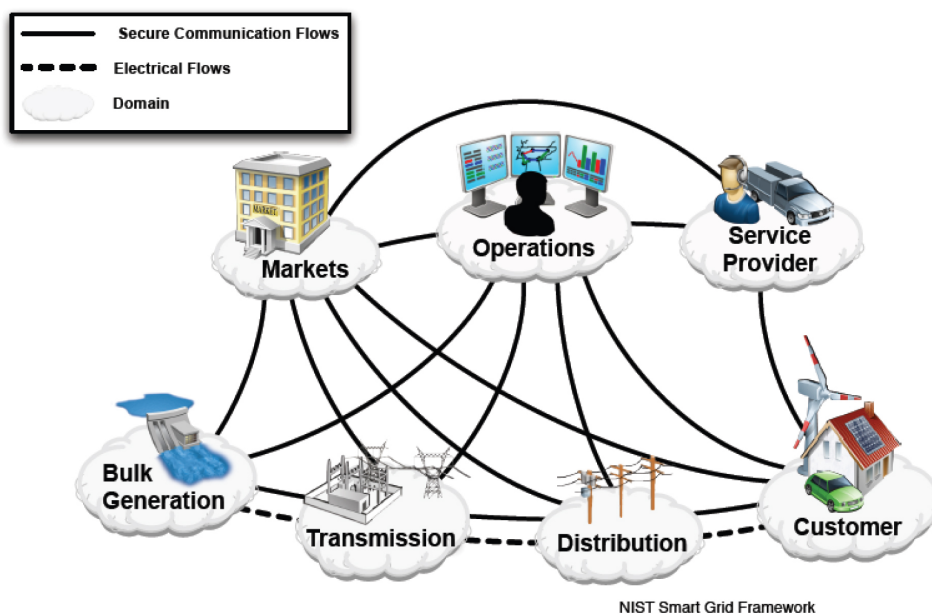
The Smart Grid is essentially an integration of the power infrastructure with an information infrastructure, combining the maturity of the electric grid with the efficiency, connectivity, and cost gains brought by ICT. A transaction-based system will require exchanges of value among participants both on the grid side and the end-user side. It will be a network of networks comprising many systems and subsystems with various ownership and management boundaries interconnected to provide end-to-end services between and among stakeholders, as

<sup>1</sup> This report is being disseminated by the U.S. Department of Energy (DOE). As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by DOE.

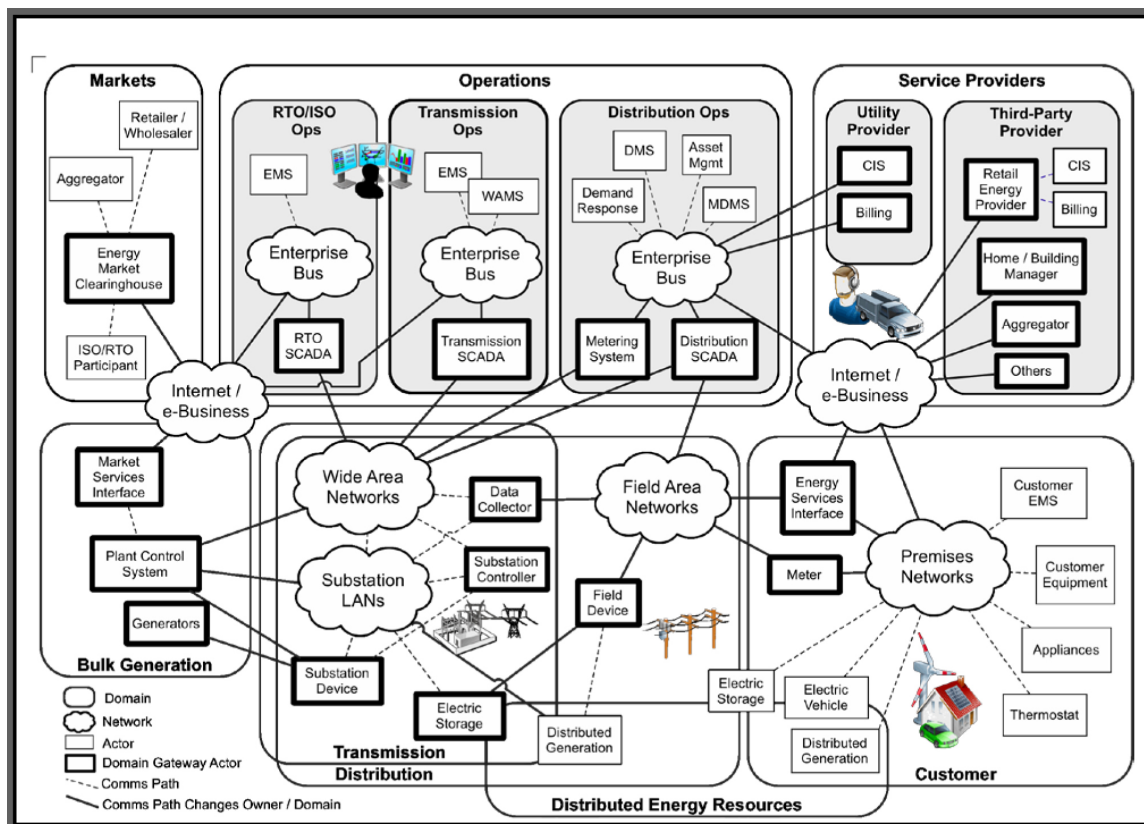
well as between and among intelligent devices representing stakeholders. ICT is essential for monitoring and managing distributed energy resources, including storage, automated DR, and the coordination and control required for operational stability of electric grid.

Communication standards will be critical to successfully develop and deploy a highly interactive network supporting transactions. The National Institute of Standards and Technology (NIST) is providing leadership in this area. The *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0*, identifies seven domains within the Smart Grid: transmission, distribution, operations, bulk generation, markets, customer, and service provider.<sup>2</sup> A domain is a high-level grouping of actors (e.g., organizations, buildings, individuals, systems,

devices, or other actors) with similar objectives and relying on, or participating in, similar types of interactions and transactions. The various actors are needed to transmit, store, edit, and process the information required by the smart grid. To enable smart grid functionality, the actors in a particular domain often interact with actors in other domains, as shown in Figure 1 and Figure 2.



**Figure 1.** Interaction of actors in different smart grid domains through secure communication<sup>3</sup>



**Figure 2.** Conceptual reference diagram for smart grid information networks<sup>4</sup>

<sup>2</sup> National Institute of Standards and Technology. 2012. NIST Special Publication 1108R2. Available from NIST at: [http://www.nist.gov/smartgrid/upload/NIST\\_Framework\\_Release\\_2-0\\_corr.pdf](http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf)

<sup>3</sup> Reproduced from NIST, 2012. *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0*, page 42. Available from NIST at: [http://www.nist.gov/smartgrid/upload/NIST\\_Framework\\_Release\\_2-0\\_corr.pdf](http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf)

<sup>4</sup> Ibid., page 43.

The conceptual models presented in Figure 1 and Figure 2 provide high-level, overarching perspectives on a few major relationships that are developing across the smart-grid domains. The figures also represent possible communications paths in the Smart Grid and useful ways for identifying potential intra- and inter-domain interactions, as well as the potential applications and capabilities enabled by these interactions. The conceptual reference diagram in Figure 2 shows many communication paths between and within domains. These paths illustrate key information flows between applications that reside both within and between domains. For example, monitoring information originates in the home, the transmission and distribution networks, and the bulk generation facilities. This information is then supplied into the operations and business applications. Command and control traffic originates in the operations applications and flows through the communication network to transmission, distribution, and residential facilities.

Commercial buildings over 100,000 square feet (about 2% of all commercial buildings and 35% of total floor space<sup>5</sup>) often are served by a building automation system (BAS) composed of controllers (both supervisory and local), sensors, actuators, and relays. The sensors provide the state information of the equipment and systems under control. The controllers take the sensor data and compute the control actions needed to move the output of the systems toward desired states (e.g., a space temperature that will provide comfort or a flow rate inside a system), and also send signals based on the computed control actions to the actuators and relays. The actuators and relays implement the control action to change the operation of the physical systems.

In large buildings, there is typically a network, commonly known as a building automation network, which connects the sensors, actuators/relays, and controllers. Figure 3 shows a schematic diagram of a typical building automation network with a primary bus where the human machine interface, data archiving, and other applications with which the building operators interact, reside. The secondary bus generally networks controllers that connect to the sensors and actuators/relays, which interact with the physical systems (e.g., conditioned space, and building HVAC and lighting equipment).

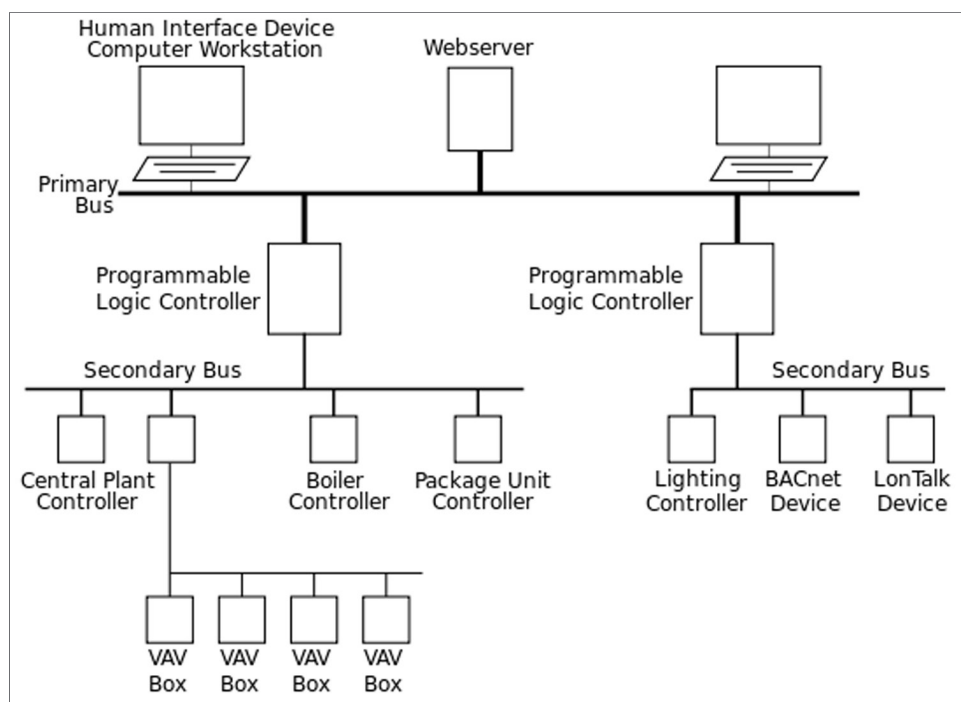


Figure 3. Architecture of a building automation network<sup>6</sup>

Most buildings, however, do not have BASs, and their systems operate independently. Lighting is generally not controlled other than by wall switches in homes and small/medium commercial buildings. Typically, standalone thermostats control heating and cooling. Even buildings with BASs that provide central monitoring suffer from poorly designed and implemented controls, manual overrides of automatic controls, poorly maintained system and equipment, and alarms that trigger too frequently and must be dealt with by operations staff (alarms are then, in many cases, silenced by overrides). This lack of good infrastructure needs to be addressed to enable buildings to participate successfully and economically in a transaction-based energy system.

Advanced ICT applied across the grid and the building domains has the potential, in principle, to connect and harness millions of distributed assets within buildings, including variable loads, distributed energy resources, and energy-storage for providing services that not only help in managing the grid, but also provide value to building owners in exchange for the services they provide to the grid through transactions.

An example of leveraging ICT to enable transactions between buildings and the grid comes from the EcoGrid EU project piloted on the Danish island of Bornholm with 2,000 residents and commercial users. Using smart meters and a Web-based app that runs on smartphones, tablets and PCs, consumers can

<sup>5</sup> Energy Information Administration (EIA). 2006. *Commercial Building Energy Consumption Survey*, Tables A1 and C1A. <http://www.eia.gov/consumption/commercial/index.cfm>

<sup>6</sup> Reproduced from Wikipedia, "Building Automation", accessed January 27, 2014. Available at: [http://en.wikipedia.org/wiki/Building\\_automation](http://en.wikipedia.org/wiki/Building_automation)

schedule when to purchase electricity online and at what price. Consumers will be at the forefront of this project with smart controllers being installed in all of the participating homes. These will be used to automate select appliances such as dishwashers, heat pumps and electric water heaters as energy prices adjust in five-minute increments.<sup>7</sup>

## Technical Challenges and Barriers

Realization of a highly interactive control network that supports transactions faces significant ICT challenges. It must handle different kinds of data for different purposes at different speeds. For example, traditional (i.e., slow) DR may require a response within a time frame on the order of a day or hours, while ancillary services may require a response within minutes or seconds. Financial settlement, in contrast, likely will be completed over a longer time interval. For distribution, there are many standards and protocols that present a complex challenge for integration.<sup>8</sup> The transaction system needs to support decisions at the lowest level of distribution (e.g., enabling buildings to make decisions regarding where to connect to the market and register). Then, the building does not need information about the rest of the market. The grid level at which the building is connected provides the resources and context for building-level decisions. In the case in which individual building devices participate in transactions directly, information from the grid must be provided to the devices themselves.

Primary challenges to realizing seamless buildings-grid integration include:

1. *Improving Scalability.* The system should be highly scalable, accommodating increases in the number of devices and services in the future both within a building and between buildings. It must also scale cost-effectively from the largest buildings to the smallest.
2. *Increased Operational Visibility.* Feedback data from end-users (e.g., at the neighborhood aggregate level to the building level or down to the individual building device level) to the grid are needed. This includes visibility to humans but also visibility of machines to the necessary conditions in other parts of the system.
3. *Cybersecurity.* Security and privacy to meet both utility and customer needs and expectations are required to keep the electric grid secure against attacks and release of proprietary operations data and keep personal data of customers private.

<sup>7</sup> R. Ambrosio, IBM, presentation at the “Buildings-To-Grid Technical Meeting”, Dec. 12-13, 2012, at the National Renewable Energy Laboratory (NREL). More information on the meeting available from DOE at: <http://energy.gov/eere/buildings/buildings-grid-integration>

<sup>8</sup> See Institute of Electrical and Electronics Engineers (IEEE) 802.11 (IEEE 2012), and IEEE 802.15.4 (IEEE 2006), available from <http://www.ieee.org/index.html>; ASHRAE BACnet, Official Website of ASHRAE SSPC 135, available from: <http://www.bacnet.org/>; LonWorks (ISO/IEC 2012), available from: <http://www.echelon.com/technology/lonworks/>

4. *Seamless Interoperability.* Standardization of communications, including lexicon, taxonomy, and protocols, for interoperability among all entities in the system is necessary to realize a market with interactions at different time scales. A way of communicating is needed that is independent of the physical medium used, the manufacturers of the equipment, and the types of devices. Interfaces, messages, and work-flows must interoperate. If multiple standards must coexist on the system, it must bridge the different standards. Application Programming Interfaces (APIs) will be needed for readily integrating devices from different manufacturers. Open standards will be required to support equipment from multiple vendors and different providers of services to end-users (buildings), supported by open APIs, which will enable third-party development of software applications that add functionality and enhancements to the system. APIs for the system should be “technology agnostic, lightweight and future proof.”<sup>9</sup>
5. *Data Integration.* The system also should support data from various sources—information services, devices from different vendors, and utilities—to provide easy-to-access situational awareness and understanding.

These challenges need to be addressed within buildings, between buildings, and between buildings and the grid. Timely management of building-level loads to service grid requests requires an efficient and reliable communications infrastructure that enables widespread deployment of systems and devices to perform building-to-grid interactions. The key to achieving ubiquitous deployment in this area is to successfully leverage the large-scale investments done in ICT in the Internet and related technologies, which have demonstrated significant progress toward seamless, widespread deployment and adoption.

Application requirements for successful operation of buildings-to-grid integration should be considered carefully, and technology solutions that will satisfy those requirements are needed. Specific barriers to deployment of buildings-to-grid interactions include:

- *Adequacy of Physical Infrastructure.* The infrastructure will likely consist of a mix of wired and wireless infrastructure, requiring that standards for both be accommodated by the transaction system. For buildings with existing building automation infrastructure, low-cost, easy-to-commission hardware is required for rapid integration with buildings/grid infrastructure. For example, issues related to wireless networks include network coverage, bandwidth availability for high sampling rates, lack of installation expertise available, etc.

<sup>9</sup> SK Tan, M. Sooriyabandara, Z. Fan. 2012. “M2M Communications in the Smart Grid: Applications, Standards, Enabling Technologies, and Research Challenges,” *International Journal of Digital Multimedia Broadcasting*, vol. 2011, Article ID 289015. <http://www.hindawi.com/journals/ijdmb/2011/289015/cta/>

- *Communications Performance Requirements.* The four fundamental parameters for deploying networks include latency, throughput, reliability, and security. The four parameters are independent of each other and application requirements (for buildings-grid integration) have to be carefully considered to design the network for reliability from both the grid and building perspectives.
- *Data Model and System Architecture.* The structure of the data, irrespective of the specific physical infrastructure, needs to be determined. This includes standards for data and information exchange between building equipment, various buildings, and utilities. The system architecture must be flexible and accommodate existing and future buildings-grid interactions through components and systems.
- *Relationship between Building Controls and Grid Transaction Network.* The network must be flexible to meet the needs of end-user decision-making, such as supporting different models of decision-making regarding transactions with the grid. For example, companies may make decisions for the entire enterprise that governs control of buildings or companies may decide to have those decisions passed down to individual departments, groups, teams, or even individuals. The degrees of centralization and decentralization in the building control system must be resolved and an infrastructure developed to support them. Building control systems must integrate the end-use loads and systems within the building itself (e.g., HVAC, lighting, metering, etc.) to provide optimal response to grid conditions and/or signals. For the grid to be able to rely on the response of buildings for various services, building control systems must reliably respond with known behaviors and associated power demand reductions. Furthermore, they must be able to respond in the time frames necessary to provide the grid with different types of services. This will require that the building control system ‘knows’ which building systems can participate in providing the different services. The addition of new capabilities to an existing control system in a building often overloads the bandwidth of the physical network. This issue must be addressed to support new functions associated with participating in buildings-to-grid interactions. As applicable, the building control system must, in addition to supporting demand management, support effective integration and control of onsite renewable generation and energy storage.

Other important barriers include the following:

- Open-standards based sensing and control integration to existing buildings should be done in a way that will drive down costs by encouraging “non-traditional suppliers” into the market by increasing market size and potentially improving

competition and the rate of innovation. This will require end-users to support early adoption of open-standards-based approaches and for startup companies to take advantage of new opportunities to innovate in this sector created by open ICT standards.

- Application-level requirements for utility services have to be carefully considered for deploying a highly interactive (e.g., transactive) electricity network. For example, voltage regulation has to be performed in minutes versus frequency regulation, which occurs in the order of milliseconds, and load shedding, which occurs in the order of hours. Responses of building loads have to be characterized to accommodate successful automated interactions.

## Technical Opportunities

Key opportunities for ICT-based advancements to help realize the national-scale benefits associated with the DOE transactive energy vision include:

- *Communications Network Infrastructure.* The networks in the electric distribution system and inside buildings must be standards-based, open, secure, scalable, reliable, and adequate in bandwidth (or data throughput), have acceptable latency and guaranteed quality of service, and provide adequately for privacy. The network must support end-to-end interoperability to seamlessly integrate utility and building protocols while still satisfying the application requirements. The network also must support an end-to-end security infrastructure for transaction processing supporting the existing efforts in smart grid.
- *Building Data Protocols and Controls Infrastructure.* Improved building controls, data exchange infrastructure, and monitoring are needed to enable buildings to reliably and securely participate in interactions with the grid. This infrastructure must not only ensure that interactions (including transactions) can be executed but that the building systems/equipment that deliver on contractual (transaction) obligations (e.g., the curtailment of a specific amount of electric load for a specific time period) are in adequate condition and states that enable them to do so. This level of performance will require proper control of building systems and equipment, and also knowledge of their condition at all times. Furthermore, to maximize the benefit to the building, its occupants, and the rate payer(s), these systems should support high-quality, likely condition-based and predictive maintenance based on advanced technology such as automated fault detection, diagnostics, and self-healing. Current controls and approaches to maintenance are not up to this challenge; advancements are needed.

- *Buildings-Grid Data Exchange Infrastructure.* The interface between the building and grid must be able to accommodate differences in ICT infrastructure inside and outside buildings. It must support transactions and other interactions at the different levels (boundaries) in both directions between buildings and the grid, and support decision-making by building owners regarding where to connect to the grid market. These points could include the buildings-to-grid boundary, selected controllers in the building, selected devices with which occupants interact (e.g., thermostats) or some other set of points at which interactions would take place inside the building. Utilities must have the ability to know, in real time, the potential building response to grid needs at a whole-building or neighborhood level. Data exchange and transactions must be supported at any of these points.
- *Automated Decision-Making and Interaction Management.* Some interactions between buildings and the grid will require round-trip response times at the second or even sub-second time scales. This will require that machines communicate directly with one another and execute interactions automatically on behalf of the parties they represent (e.g., a building owner or a utility). Each interaction will be directed by goals established by the human party it represents, but at such time-scales, humans cannot be involved actively in every interaction. Machines must act on their behalf. Advances in machine-to-machine communications, machine decision-making and interaction execution, and effective communication of human goals to machines for purposes of such interactions will be needed.
- *Specification of ICT Requirements.* To ensure that the ICT infrastructure can adequately support the data communication needs (e.g., bandwidth, limitations on latency, etc.), the specific kinds of interactions and the data they require must be identified and characterized. These needs drive the required characteristics for the network infrastructure in the grid, in buildings, and at the grid-building boundary to support adequate communication in both directions.