Beyond the Smart Grid: Building Networks

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Abstract— **Most effort to date on the "Smart Grid" has focused on what is possible in the near term, with today's technology and paradigms, for the most part on how to bring the power of information technology to existing functionalities. This is absolutely necessary, but a parallel effort is required to assess and design what is needed in the long term). The long term will bring more capable hardware, new paradigms of communication and control, and different needs and expectations of human beings. This paper presents some key design goals and considerations that our future "building networks" should have, their relationship to the meter and grid, and some proposed architectural principles. It also outlines key near-term research needs so that we can develop and demonstrate early versions as soon as possible. Some key principles are distributed intelligence, the meter as a "narrow waist", people as nodes on the network, local control (ceding to central authority as needed) and universal interoperability.**

I. INTRODUCTION

The last few years have seen a surge of interest in activities around the "Smart Grid" and in particular, for the potential of bringing the power of Information Technology (IT) to saving energy within buildings. Smart Grid activities are overwhelmingly dominated by the goal to deploy hardware in the near term and to best meet the needs of the grid. While this is appropriate, there is a need for a parallel effort for technologies that will only be available in the long term; the term "building networks" is proposed for these.

The premise of this paper is that revolutionary change in building communication is needed [1][2], or rather, that it will definitely happen whether planned or not. The questions at hand are when this will occur, and how helpful it will be to saving energy. The answers to these are in our hands.

There are many analogies to the Internet to what we face with buildings. A simple example is email addressing. Originally, the paper mail scheme was adopted in which addressing was a product of the administrative domain involved (usually the country) and there was no consistency between these. This required complicated gateways between domains which was cumbersome for people and computers. Eventually it was realized that a new scheme was needed, one that took universal interoperability and consistency as a key goal. The new system also relied on technology development, in the form of the Domain Name System. Once available, the new system of "user@domain" addresses quickly relegated the old UUnet, MCImail, and BITNET addresses to the dustbin of history. The original scheme was a necessary stage to go through, but one to use for as little time as feasible. In addition, care was required to assure that the long-term solution was designed exceptionally well, universal, and as simple as possible.

Put another way, the Smart Grid and Building Network approaches are not so much in opposition, but for different points in time. Similarly, at one time fax machines were a key method of distributing information, but have since been mostly replaced by the Internet.

The Internet transformed our relationship to the information world. Building networks will transform our interaction with the physical world.

The rest of this paper is organized as follows. Section II presents the concept of a building network. Section III contrasts this with how communications technologies are generally conceived of in the Smart Grid. Section IV delves deeper into key design goals for building networks, and Section V reviews recommendations for key research areas and other next steps.

II. BUILDING NETWORKS

This section describes key characteristics and considerations in developing and operating building networks.

A. *What*

A building network extends the power of the Internet from solely the information domain, into the physical world, in the context of a building (or other space) with a common administrative domain. It is a communications network that:

- enables arbitrary communication between any two or more devices in a space.
- provides for location awareness so devices understand their own location, and their relation to others.
- logically contains people as nodes on the network, albeit with a different set of standard interfaces.
- provides a common data model, to enable interoperability among devices and people.
- embraces "universal interoperability" as a core goal.

The definition of a building network will evolve over time, but the above can serve as a starting point. A building may be a house, apartment, retail structure, office building, or light industrial facility. A car is also a building in this context, as they are simply 'buildings on wheels' (cars are already becoming more densely networked than other building types).

Building networks will begin with IT products (which will often serve as the user interface to others), and grow to include all energy-using devices (e.g. lights, thermal sources, ventilation, displays, sensors, and appliances), as well as some that don't use energy (e.g. windows, doors, and people).

It seems inevitable that meeting the design goals of building networks requires universal use of standard Internet protocols, as defined by the Internet Engineering Task Force (IETF). While some accommodations may be needed in that structure (e.g. as being accomplished by the CORE working group [3]), these can be isolated from higher layers. Most buildings today already have many data and network physical layer technologies, and so we can expect all future buildings to have a variety of both wired and wireless physical layers. However, with appropriate network switches and routers, this diversity is not a problem.

B. Why

People use today's networks because they enable doing activities more efficiently, effectively, or conveniently, or because they enable doing things not possible before the network was in place. People will extend their networks to devices with physical-world relevance for the same reasons. Occasionally this will be done for explicit reasons of saving energy, but for most applications, that will not be the primary purpose. In many cases, the networking of physical-world devices will enable energy savings not otherwise possible, even when that was not the driving purpose.

The key purposes of the building network are to be able to discern with the greatest possible fidelity, the needs and wants of the occupant(s) of a room or building, and to provide, as close as possible to those preferences, services in the form of heat, light, sound, etc.

C. How

We should expect a great diversity of physical media in building networks. Partly this is due to the varying needs and capabilities of connected devices. Some will be powered by batteries or energy harvesting, and want sparse and highly efficient transmission. Others will be data intensive and need high speed and low latency (at least some of the time). Others may have multiple network connections, shifting between them to meet different operational goals. Also, many objects in buildings are long-lasting, on the order of decades, so more accommodation of backwards-compatibility will be needed than with electronic products with shorter useful lifetimes. In any case, so long as all devices can communicate with IP packets, the diversity does not matter.

A key way that building networks will work is that devices will start from a state of managing their own behavior and operation. They will communicate with others to coordinate and improve what they do, but can function on their own. This bottom-up networking facilitates devices being moved within and between buildings, and eliminates requirements for configuration before use. Central devices will mostly coordinate rather than control, though some elements of central control will exist in most buildings, particularly for HVAC systems that are fundamentally centralized, and for temporal concerns such as emergency conditions.

With the goal to make devices as responsive as possible to the people and other devices in their immediate vicinity, decision-making is kept as local as possible. Actions taken as a result of these decision will usually also be accomplished locally.

D. Preferences

Devices in building networks will "harvest" preferences to know how to best behave. First, they will be shipped from the factory with default preferences, appropriate to typical use and expectations of a device. A person who buys it and brings it into a space may alter the default configuration. A system of inheriting preferences from central sources in the building may adjust them, and this may be dynamic. Other devices in the space may also have preferences of their own. Finally, a user or users in the space (or nearby spaces) may have preferences, static or dynamic, that need to be taken into account.

Clearly, implementations of this could be so unwieldy as to be unworkable in most instances, so a key research question is how to structure the system of preferences to have it be as simple and transparent as possible, while retaining needed power and robustness.

Any system which lacks a rich system of preferences will then lack correct information about what the building occupants and managers desire, and so guarantees less than optimal operation, and likely wasted energy.

E. Price Responsiveness

A special case of preferences is the degree to which devices can change their behavior in response to the price of electricity. It is assumed that all buildings will pay electricity prices which vary on an ongoing basis in response to the supply and demand conditions the grid is experiencing. How often the price changes – every 15 minutes, or every second – is not important. What *is* important is that devices be able to acquire the current price and price forecast (most likely for the subsequent 24 hours) as often as they would like to do so (possibly varying with usage context and price changes). The device then uses all the information it has at its disposal to decide how to operate. The only communication "upstream" past the meter is the current electricity demand of the building.

A particular building may choose to alter the grid price, to account for environmental externalities, to reflect conditions of local generation or storage that are present, or other reasons. Devices then use the local price.

This system envisions no coordination between the building and the grid. An exception may be vehicle charging, as the size and prevalence of this load may otherwise break the ability of very local grid infrastructure to reliably operate. This should be understood as an exception to the general architecture, not something to drive its core design.

Building networks do not require the grid to be present. A building with local generation or even just storage can have an entity that sets a price and adjusts it to equilibrate supply and demand [4]. A particularly useful application is for buildings that are usually grid-connected but have some generation or storage that can engage when the grid is not available. The off-grid price is likely to be much higher and so devices will automatically reduce their aggregate demand.

F. *Security*

Security is a concern in nearly any aspect of networking today, and building networks are no exception. Keeping information and decisions more local should avoid some security issues.

III. CONTRAST WITH THE SMART GRID

There are many different articulations in the literature of what constitutes the "smart grid", and how communication within buildings is defined and assumed. Thus, the discussion below is necessarily simplistic, but serves to help clarify key differences in approach and result from that which arises with building networks. Some smart grid proposals share some characteristics with the building network approach, and that should be encouraged.

A. *Scope*

The Smart Grid extends from power plants to end use devices, including all infrastructure in between including transmission, distribution, and the meter.

Building networks include the "half" of the meter that is inward-facing, which may be a source of price information, and measures aggregate demand from the building. From the building network perspective, the grid ends at the meter. Fig. 1 shows a common conception of the integrated Smart Grid [5].

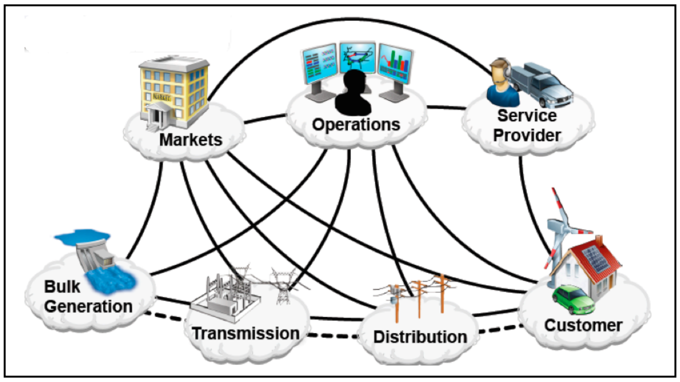

Figure 1. Schematic of Smart Grid (NIST [5])

B. *Focus and the role of People*

The Smart Grid takes energy (electricity) as the primary goal of the system. Communications within buildings are assumed to be different in different building types (e.g. Home Area Network, etc.). People are not present or at the periphery.

Building networks take functionality for people as the primary goal (the electricity system is one of several secondary goals). Network architecture is consistent across houses, any commercial building, cars, and even spaces between buildings. Industrial energy and some sensor networks are out of scope, because they lack the close connection to people at the core of building network design and operation.

C. *Primary control strategy*

The Smart Grid approach takes traditional building controls, digitizes them, and layers on specific new functionalities needed for better grid operation. This results in structure that is primarily top-down. The primary tool for action is the command, accomplished through control.

Building networks start from a *tabula rasa*, much as the Internet did, presume smart end-point devices, and introduce central control only when truly needed (this by devices voluntarily ceding authority). The primary tool for action is changing preferences or conditions with the network.

D. *Paradigm*

The grid is oriented to Production, and how to shape the behavior of devices (and ultimately people) to serve the needs of that system. The grid is a single system.

The building network is oriented to Consumption, the provision of useful services to people (most of which will involve energy use), taking into account the grid through price. The electricity system is composed of two separate parts, with a "narrow waist" connecting them at the meter.

E. *Interoperability*

For the Smart Grid, interoperability is embraced within the grid, but not between building types and not between countries.

Building networks assume "universal interoperability" across all building types, globally, and for all people.

F. *Role of electric utilities*

For the Smart Grid, utilities are the key driver of changing end-use device behavior to meet grid needs, and have visibility into buildings through two-way communications with devices past the meter.

In building networks, the only role of the utility is as a source of prices (and not necessarily the vehicle for communicating those prices). It has no visibility into the building (excepting the vehicle charging special case). There is no financial relationship that contributes to grid stability other than the current and forecast prices. The users (possibly including a "building manager") are in complete control.

G. *Design timeframe*

The Smart Grid is intended for deployment immediately, or in the coming few years. Building networks are designed for the long-term future, though they will overlap in use for many years.

H. *Summary*

The Smart Grid and Building Network approaches are dramatically different. We need both, as each provides insights and technology directions that the other cannot.

IV. DISCUSSION

A. *Domains*

Central to the concept of a building network is that it is a finite administrative "domain", with rich interaction internally but limited interfaces to the outside.

An analogy to the question of domains can be seen in vehicle transport. In the U.S., we have local streets that network individual buildings to each other, and interstate (and other) highways that network metropolitan areas to each other.

These two domains do allow many of the same vehicles to transit across them (think electrons), but the similarity mostly ends there. Differences include: topology, applicable laws, controlling governmental authorities (for installation and policing), design considerations, functional purposes, the role of buildings, and the role of people. The two domains are separate from each other except at well-defined interfaces – freeway exchanges – the demarcation point where the rules all change (think the meter). It is important to keep these separate.

B. *Robustness*

Building networks, with their self-configuring and bottom up nature, are inherently robust and resistant to single-point failure. Centralized control, on the other hand, is generally more fragile and prone to disruption when conditions change.

C. *Simplicity*

Making products useable, particularly when they have rich functionality, is a difficult process. A key is to drive for simplicity whenever possible (but no more). Apple is widely recognized for accomplishing this in products, as is Google for web pages. However, many companies sell products that fall far short on this account. Quality design is doable, but is not the usual outcome.

Building networks have a significant design component in them, and so working toward the best design result must be a priority and will be well worth the effort, for energy and functionality.

D. *The Law*

A key document in contemporary Smart Grid policy is EISA, the Energy Independence and Security Act of 2007 [6]. EISA has a list (section 1301) of ten goals "which together characterize a Smart Grid". Of these ten, seven are mostly or entirely about actions that take place within buildings, and the remaining three are generic in application to the grid and buildings. Thus, EISA sees what goes on within buildings as not only part of "the grid", but arguably the most important and interesting part.

E. *Role of Meter*

The electricity meter on any building is a "narrow waist". In the OSI network model, the Internet Protocol is a narrow waist. There is great diversity in lower layers, and in upper layers, but at the IP layer itself, a striking degree of simplicity. For the electricity system, we have much complexity in the grid, and also within buildings, but the meter is a place with a minimum of wires and information that passes through.

In future, the meter will continue to perform its traditional function of measurement, and little else (albeit perhaps every minute or second instead of once a month, and bi-directionally for excess local generation). Price information (the current and next 24 hour forecast price series) needs to be made available to the building; this could come through the meter, or some other avenue. The only obvious case today in which two-way communication may be warranted is for vehicle charging.

F. *Role of Prices*

Not charging real marginal prices leads to using too much electricity and paying too little.

The Smart Grid is largely burdened by today's 19th century billing approach of fixed prices. Thus, demand response has to arrange financial rewards that work around fixed prices and so associate specific actions with demand response signals. The complexity this induces is simply a by-product of the original bad pricing model.

While changing to dynamic prices itself is not sufficient to attain widespread dynamism in end-use loads, it is a necessary condition.

V. RESEARCH NEEDS AND PATH FORWARD

Building networks cannot be implemented today because we lack several core technologies and a shared view of the whole architecture. The sooner we begin to create these, the sooner that test networks can be deployed in tests in real buildings to refine the design and demonstrate the real energy savings potentials and other benefits.

Deployment of building networks will highly leverage existing IT networks. Early deployment may make wide use of "dumb" but communicating end-use devices, that use highly capable proxies that serve as a sophisticated face to the rest of the network. This enables quick upgrading and graceful inclusion of legacy devices. Following are some critical research topics.

A. *Universal Interoperability*

Perhaps no concept is as central to building networks as universal interoperability. While this is an unattainable ideal, determined effort should get us suitably close — and lack of effort guarantees large amounts of non-interoperability, and thus energy waste and inconvenience.

Universal interoperability means that "Any device should work with all other objects in any space":

- Across building types: residential, commercial, vehicles, …

- Across geography: countries, language, …
- Across time: worthy of durability
- Across end uses: for coordination, cooperation
- Across people: age, disability, culture, activity, context, …

Accomplishing this leads in several directions, including the user interface, and data model, but it also has important implications for policy, in seeking to minimize differences in networks across building types.

B. Network architecture

Many aspects of building networks hinge on the overall architecture of the network, much as the OSI model grounds modern networking in the information world.

One foundational assumption is to build off of standard Internet technology up through layer 4 (transport). It is difficult to imagine what buildings will need that is not already present or will be shortly. The costs of being non-standard will always be much greater than any potential benefits. Other key elements are the common data model, and user interfaces. Eventually there will be application-layer protocols.

C. Common information model

Interoperability is not possible without devices on the building network sharing a standard "language" for describing the world that they share. The need for a common information model (CIM) is often noted, but usually only in a limited way. A "dictionary" needs to be rich and extensible, while enabling simplified expressions when required. It must include "nouns" (physical objects), "verbs" (actions), "adjectives" (characteristics), as well as more abstract concepts such as prices, schedules, and presence.

A typical approach to creating a CIM is to design it around the needs of the devices that use it. For building networks it must be designed around the needs of people, to ensure that the terminology, concepts, and organization are readily understood. The user interface should be the starting point for design. While it is not required that terminology used in technical documents match that used by ordinary people, it helps minimize confusion. We also need standard translations for all languages. The CIM needs to identify the meaning (semantics) of the information. How it is encoded or represented internally can be specified elsewhere.

The CIM will include: Building elements (energy using or not) such as lights, climate control devices, windows, displays, rooms, sensors, appliances, and people; Ideas like presence, schedules, prices, events, and preferences; Characteristics such as physical location, power levels, and light levels; and Actions like dim, open, or go to sleep.

1) Standard concepts

Standard concepts are already familiar around the globe, so seeking to create them for building networks is not without solid precedence. The standards are variously *de facto* and *de jure*; that distinction is not important – what is is the quality and wide usef of them. User interfaces have standards around cars, both for internal controls and on road signs, and the tape transport words and symbols are nearly universal (play, pause, stop, fast-forward, eject, …).

Other sources of standard concepts are in document conventions (fonts, margins, headings, columns, …), web page conventions (forward, back, navigation, links, …), and data and file formats (ASCII, PDF, HTML, …).

Note that these standards have manefestation in both communications between devices, as well as those between devices and people.

D. Other research priorities

Academic research is needed on key difficult topics such as: presence, authority, security, user interfaces, network architecture, failure modes, emergencies, and protocol design. There is a need to review lessons from Internet development.

Building networks are focused on functionality, but we also need development in how we distribute power. Unlike building networks, power distribution may be amenable to a more evolutionary development, but again, working from the bottom-up is key. An approach to this for "nanogrids" is described in [4].

E. Institutional needs

Building networks will require an extended family of technology standards, even considering only higher layers. A key question is then where to host them. No existing standards organization seems an obvious fit. Organizations tied to a particular physical layer technology seem unsuited to something which must be independent of lower layers. Organizations too closely tied to a single country or region also seem unsuitable for standards which need to be global. The Internet Engineering Task Force must be considered for this, but the building network needs, while closely related, seem not a good fit for the individuals and topics that the IETF has today. A possible alternative is a new organization that is a sibling to the IETF (that is, also a project of the Internet Society), but focused solely on the topic of building networks – perhaps the Building Networks Task Force (BNTF).

Another issue is the transition from traditional demand response programs, to the era of building networks. Demand response is largely contingent on signals distinct from generic instant price signals that reward behavior change in buildings economically.

F. Market structure

As with Internet technology and many existing building standards (e.g. AC electricity, plumbing, and lumber), non-proprietary standards are critical, and they must be global.

Once we have a solid foundation/infrastructure for devices to exist and interoperate, we can think about concepts as "Apps for buildings" or for rooms, or individual devices. The functionality native to a device should be a floor, not a ceiling, for its utility to people (and to saving energy).

VI. SUMMARY

There is a urgent need to establish a second track to "Smart Grid" efforts targeted to long-term building network architecture. Key steps are an overall roadmap, initiation of research on critical topic areas, and adoption of core principles of system design.

A first step is for people to acknowledge the possibility of buildings that are much more functional, in ways we don't readily imagine or understand that we may need. This requires accepting revolutionary change, with quantum leaps in technology, not incremental adaptations of existing ways of using buildings.

Assumptions driving these conclusions include that building networks will largely be installed for purposes of functionality first, and energy only secondarily; networking will generally be incremental in installation, and highly dynamic; the vast majority of decisions about how devices in building networks.

Some core principles are using a distributed architecture, universal interoperability, embracing standard Internet technology, using price to mediate demand, and learning from development of Internet. Design of the architecture must keep the grid and its needs out of the picture. High functionality, simplicity and robustness are also key needs. Finally, necessary to see people as nodes on the building network, and the center of its design.

While the technology approach of building networks is revolutionary, deployment will necessarily be incremental. We need to be ready to throw away early technology (both hardware and standards) when it fails to meet our needs. Once really useful new functionalities become available, they will quickly move from being seen as luxuries to becoming necessities.

Perhaps the greatest danger is that the actual benefits of bringing power of networking to physical world (buildings) will be underestimated and so insufficient effort will be put to developing and deploying this technology.

When the modern utilities of electricity and indoor plumbing were introduced to buildings, many activities in residences and commercial buildings were fundamentally transformed. The introduction of networking to how we use buildings should be expected to have a similar effect. We need infrastructure for applications we can't even imagine today.

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