Networking moves to home automation

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AFTER LANGUISHING FOR YEARS, HOME AUTOMATION IS SEEING A SURGE OF ACTIVITY AS NEW TECHNOLOGIES, EMERGING STANDARDS, AND THE NETWORKING OF CONSUMER DEVICES CONVERGE TO DEVELOP THE INTELLIGENT RESIDENCE.

The dream of an intelligent home that automatically controls the living environment and responds to individual preferences has been around since the advent of the microcontroller first suggested the possibility. High cost, reliability issues, limited capability, and a lack of standards have imposed major constraints on the market, however, keeping home automation more in the realm of imagination than practice. The advent of wireless technologies, the emergence of home-networking standards, and pull from both the entertainment and the energy markets are now revitalizing efforts to realize that dream, although industry participants are still hotly contesting the implementation methods.

The first attempts at home automation provided only simple remote control of basic functions, such as turning lights, fans, and appliances off and on. The X10 power-line-signaling technology, which Scotland's Pico Electronics first developed in 1975, is typical of these early attempts. The X10 control system sends data at 1 bit/8.33 msec, is limited to 16 commands, and can control a maximum of 256 devices in a single network. Despite these limitations, however, X10 products have enjoyed limited but continuous success in the market and are still available for consumer purchase and installation.

To provide more powerful and comprehensive control functions for home use, the EIA (Electronic Industries Association), now the CEA (Consumer Electronics Association), began in 1984 developing a set of standards for a common command language that would handle a variety of devices. The effort also defined communications methods for many media, including twisted-pair wiring, infrared, RF, and power-line signaling. The resulting CEbus standard, which the industry adopted in 1994 as EIA-600, targeted remote control, remote instrumentation, security systems, energy management, and entertainment coordination with other wiring that carried the entertainment content.

Unfortunately, the CEbus proved to be too much, too soon. It was costly to implement, appeared before the consumer market had been exposed to the Internet and the concept of networking, and did not gain widespread support. What support it had gradually faded. CEbus-product vendor Domosys Corp, for example, eventually abandoned the CEbus in favor of its proprietary PowerBus networking technology. The CEbus industry organization's Web page, www.cebus.org, is now inactive.

Other technologies arose for home networking, with one of the most successful being the LonWorks platform from Echelon. LonWorks targets not only home automation, but also industrial and au-

tomotive control, in which it has seen greater success. Several industrial and building standards, including ANSI/EIA709.1B for control networking, the European EN14908 building-automation standard, and even IEEE 1473-L for in-train controls, have incorporated the LonWorks platform along with its physical-layer signaling over power-line and twisted-pair wiring.

AT A GLANCE

- After languishing for decades, home-automation networking appears ready to move into the mass market.
- Technology improvements in power-line and wireless signaling have lowered costs, boosted data rates, and increased reliability.
- Although many standards exist, no technology or implementation approach yet dominates.
- A killer application may be emerging in the form of energy-management initiatives.

Despite such successes, however, neither LonWorks nor any other home-networking technology has taken off in the market. There are several reasons for the faltering of home automation. One is that no one technology offers all of the attributes that consumers demand in their technology. Another is the lack of a killer application to jump-start widespread adoption with its inevitable cascade of decreasing costs, increasing public awareness, and competition-fostered innovation.

A technology must possess many attributes to be successful in a consumer market such as home automation. These features include:

- **Affordability**: The technology must provide enough benefits with a low enough price that consumers become willing to invest in it.
- **Ease of use**: The technology should be simple enough to install that the average consumer can use it out of the box.
- **Reliability**: Once consumers install it, the technology should work as they expect without interruption and without their attention.
- **Flexibility**: Consumers expect to use technology where and how they wish without significant restrictions.
- **Long operating life**: Consumers expect their investment to pay dividends over months or years without fail. In the case of battery-operated devices, long battery life is essential for consumer satisfaction.
- **Interoperability**: Consumers expect to be able to purchase technology components from a variety of competing sources and have the components work together without effort.
- **Capability**: Consumers have come to expect that a newly adopted technology will provide several important benefits and useful features and that the technology's capability and features will steadily increase over time.

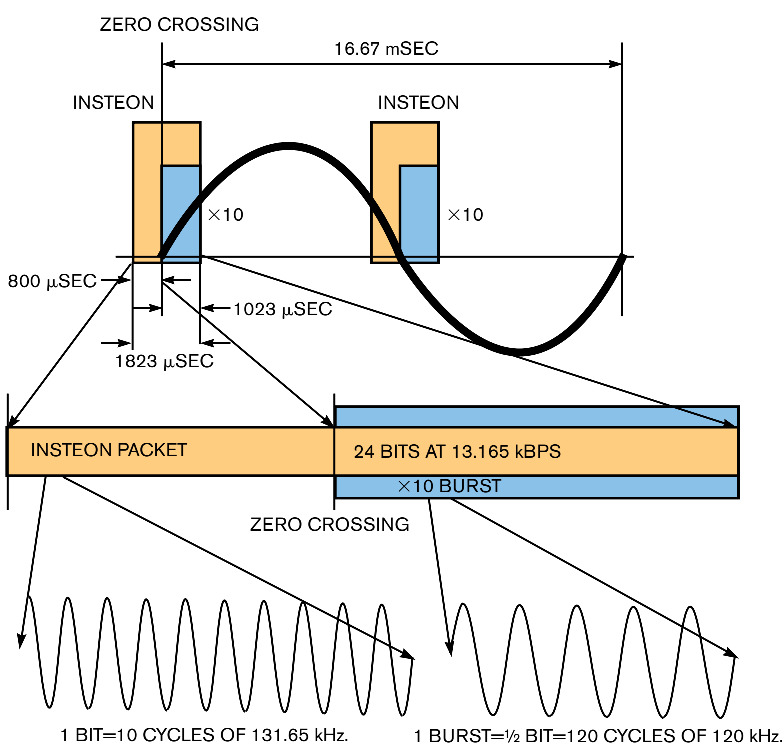


Figure 1 Insteon's power-line-signaling approach uses high-frequency bursts at the zero crossing to encode data bits, giving it a higher data rate than the older X10 technology, and it still retains interoperability (courtesy SmartLabs).

Currently, every available home-automation technology falls short in one or more of these areas, although proponents are continuously working to address these shortcomings. Sometimes, the shortfall arises purely from the communications medium. Home-automation systems use one or more of three media: wire and cable, power line, and wireless, typically RF. Each approach has its advantages and drawbacks.

Wire and cable media for home automation include twisted-pair wiring, coaxial cables, and optical fiber. These media have an advantage in their high data capacity and ability to provide a relatively noiseless communications channel for network signaling. Their major drawback is cost. Estimates for the installation of cable in construction range from $65 per linear foot for residences to nearly $300 per linear foot in industrial settings. Costs are lower when installation occurs during new construction but still remain too high for most consumers.

A second drawback of wire and cable media is inflexibility. Consumers are not free to relocate controls or endpoint equipment as they wish. The location of the installed cabling restricts placement, and the cost of new cabling is prohibitive.

POWER-LINE SIGNALING

In response to the drawbacks of cabling, home-automation technologies seek to use one type of wiring in every residence: the power line. As a networking medium, a power-line connection has two advantages. One is that they are

in place and run to nearly every location where endpoint devices exist. The second is that endpoint devices need no external power source, such as a battery. Both help satisfy the low-cost and ease-of-use requirements of a consumer technology.

Power-line networking has its challenges, however. The medium is noisy, carrying a variety of voltage spikes that arise as lights and motors switch on and off, loads change, and disturbances on the power grid propagate into the home. As a result of this noise, power-line-networking technologies have either restricted their signaling bandwidths or employed sophisticated and expensive noise- and error-reduction strategies.

The X10 standard serves as an example of the first approach: restricted bandwidth. To avoid noise, X10 signaling occurs during the zero crossing of ac power. A burst of 120 cycles at 120 kHz, repeated at the next zero crossing for basic noise immunity, signals a one, and its absence signals a zero. The result is a raw data rate of 60 bps, with synchronization, framing, and addressing bits adding overhead to reduce the achievable data rate by 60%. This low data rate prevents the network from handling any but the most basic control and sensing functions and adds considerable latency when implementing a string of commands.

The SmartLabs' Insteon offers a similar approach (**Figure 1**), transmitting a packet of 24 bits at the zero crossing, each bit encoded as 10 cycles of 131.65 kHz. It achieves a sustained bit rate of 2880 bps, greatly improving its utility and latency compared with X10. Yet, the similarity in technique allows Insteon networks to control X10 devices, providing a measure of the interoperability attribute that consumers demand.

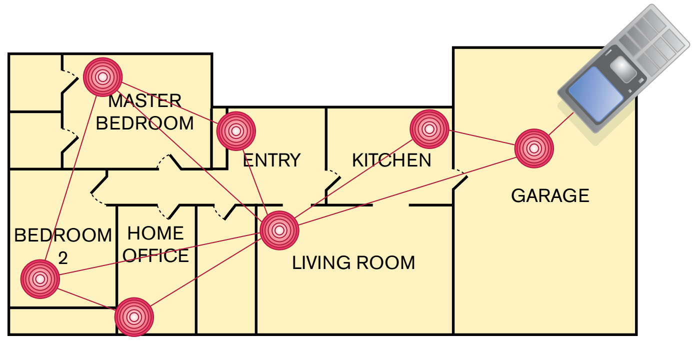


Figure 2 Enough nodes to provide multiple links in the mesh can handle the limited range of wireless signaling (courtesy Z-Wave Alliance).

A third variation, the Universal Powerline Bus, comes from Powerline Control Systems. This system imposes 40V-dc spikes on the power line at the zero crossing, using pulse-position modulation to encode 2 bits per zero crossing. Filtering prevents the spikes from generating excessive EMI on the power lines. The data rate is on the order of 100 bps.

These low data rates, however, limit what the network can achieve, thus failing to provide much of the capability attribute that consumers expect of technology. Yet, achieving higher data bandwidths using the power-line approach requires a more sophisticated signaling approach and protocol. Echelon's PL3120 power-line transceiver, for instance, includes a DSP-enhanced processor for data recovery and noise reduction, achieving a sustained data rate as high as 5.4 kbps.

Dramatically higher rates have become available over the last few years. The HomePlug Powerline Alliance's new HomePlug AV standard, using technology from Intellon, employs orthogonal-frequency-division multiplexing to generate signals that attain data rates as high as 200 Mbps. This speed is fast enough for the network to go beyond simple control of lights and power and serve as a communications channel for entertainment media, such as IPTV (Internet Protocol television). It remains

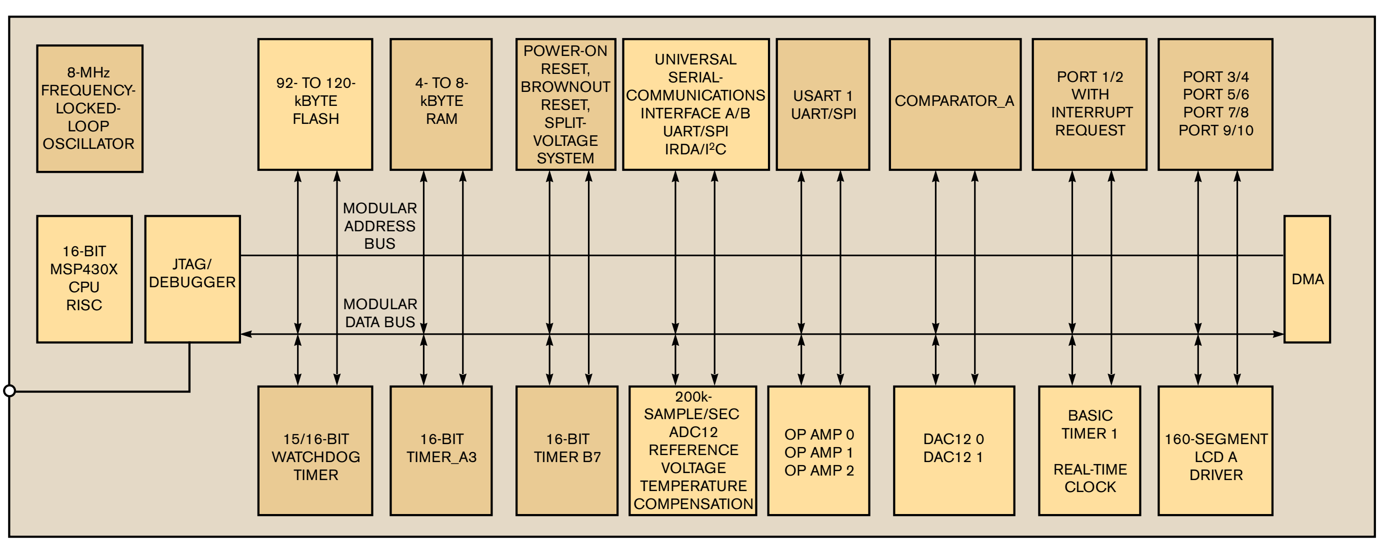


Figure 3 Making the peripheral functions of the microcontroller capable of acting without CPU supervision helps save power and extends the battery life of home-automation nodes (courtesy Texas Instruments).

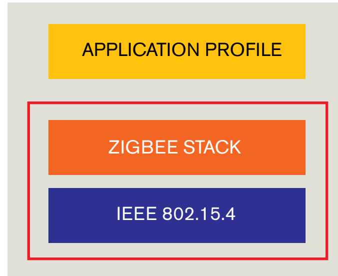


Figure 4 Compatibility may have many meanings in ZigBee devices, because the standard defines different levels for just the radio and the stack, for devices with custom application software, and for products conforming to a public-application profile (courtesy ZigBee Alliance).

to be proved, however, that the cost for this sophistication will drop to the levels needed for widespread adoption.

Power-line signaling also has other drawbacks that can impact its long-term success. In US homes, for instance, power comes to the house as two out-of-phase, 120V feeds with a neutral line. This arrangement allows the wiring of 240V power for demanding appliances, such as furnaces and dryers, and allows regular household power to run at the safer 120V level. The result, however, is that the power lines in the house split among the two phases, and power-line signaling cannot reliably cross between the phases without the help of either a bridge node or a high-frequency shunt between phases. This step adds complexity and cost that consumers may not tolerate to the implementation of a home network.

Power-line signaling also has a limitation to its installation flexibility: It requires that power lines be present at every node in the system. This situation imposes restrictions on the placement of control nodes, such as light switches and thermostats. Ideally, consumers would want to locate anything anywhere with no restrictions.

This level of flexibility is one of the main benefits of the wireless-RF medium. Several wireless-home-automation-network technologies have arisen, including Z-Wave and ZigBee. In addition, home-networking technologies such as Echelon's LonWorks, SmartLabs' Insteon, and the European KNX have adopted wireless signaling in addition to power line to gain the added flexibility.

Until recently, however, RF-based networking has faced significant reliability challenges. To avoid licensing issues, RF-based networks typically work in one of the open-frequency bands for products such as microwave ovens, portable phones, and the like. The Z-Wave approach, for instance, operates in the 900-MHz ISM (industrial/scientific/medical) bands, which differ between the United States and Europe. ZigBee also operates in this band but is concentrating future development in the 2.4-GHz spectrum, in which frequencies are usable worldwide, allowing design of universal radio devices. In either case, however, the presence of other users in the open bands has the potential of creating a severe interference problem.

Supporters of the RF approach have been addressing the issue of interference and now appear to have solved it. Reports from ZigBee Alliance members Ember, Freescale, Microchip, and Texas Instruments, for instance, all agree that the latest revision of the specification, ZigBee 2006, ensures robust operation even in the presence of in-band interference from other users, such as Wi-Fi. Components based on ZigBee 2006, which saw release in December, should soon be available to home-automation-product designers.

Software, too, can play a role in resolving interference issues and ensuring reliable network operation. Officials at ZigBee-application-software vendor Airbee Wireless note that the ZigBee-protocol implementation can impact the network's performance in a dirty RF environment. Airbee's software, for instance, includes network-management functions that allow measurement of signal strengths and can actively respond to interference sources through channel selection and message routing. Fixed routers can also use signal strength to triangulate and identify interference sources and alert the user.

Still, other issues exist. Supporters of the power-line approach point to the limited range of RF devices and their potential need for battery power as significant drawbacks of the RF approach. Because the RF-home-automation networks use self-configuring mesh architectures, however, their supporters claim that range is not an issue. Simply adding nodes with message-relay capability in appropriate locations will ensure that everything connects (**Figure 2**).

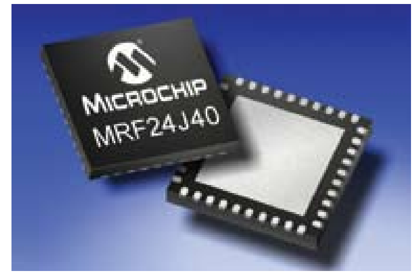
Battery life is more of a concern to RF-home-networking suppliers. An RF-based home network can potentially contain several hundred nodes, many of which are battery-powered. Consumers do not want to change dozens of batteries every few months to keep their systems operating.

Several approaches for maximizing battery life now exist. The Z-Wave approach, for instance, allows nodes to remain inactive most of the time to conserve power. They wake when an event such as a button press requires a response and periodically to see whether any network traffic is addressed to them, remaining in a low-power state the rest of the time. ZigBee nodes offer a similar approach. The underlying IEEE 802.15.4 radio standard works at low duty cycles, transmitting energy only in bursts. In both cases, relay nodes need to remain continuously active to maintain links, but those nodes typically are not battery-powered.

The other new approach to battery life is the design of microcontrollers and other ICs for implementing home-networking nodes that have active power management. Vendors such as TI's ultralow-power-MSP430-microcontroller division have come up with microcontroller devices that minimize power consumption by keeping active only the functional blocks needed at any given time. TI divides its MSP430FG461x family microcontrollers, for instance, into multiple functional blocks (**Figure 3**) that can carry out their tasks without involving the core processor. This situation minimizes power draw and allows nodes to operate on batteries for years without replacement.

INTERNATIONAL BODIES ARE ATTEMPTING TO CREATE WORLDWIDE STANDARDS TO TIE TOGETHER ALL THE MANY ASPECTS OF HOME NETWORKING.

Technological advances have thus brought a variety of home-networking approaches to levels that will allow the dream of intelligent houses finally to become reality. Two roadblocks still remain, however. One is interoperability. Many companies base their approaches on proprietary technology, which limits the number of suppliers from which consumers can choose. The other roadblock is the lack of a compelling application to jump-start the market.



The availability of single-chip radios and microcontroller/radio combinations is lowering the cost of wireless home networking (courtesy Microchip Technology).

To solve interoperability issues, vendors of home-automation technologies have turned to standards and trade associations. Echelon's LonWorks technologies have the support of the Digital Home Alliance, providing a broad base of suppliers and certifying interoperability among devices. The Z-Wave Alliance provides a similar function for the Zensys Z-Wave technology. The HomePlug Powerline Alliance supports Intellon's HomePlug technology. Other industry groups include the UPnP (Universal Plug and Play) Forum and the ZigBee Alliance, both working to ensure interoperability and to refine their standards.

On a higher level, international bodies are attempting to create worldwide standards to tie together all the many aspects of home networking. The ISO/IEC JTC (International Standards Organization/International Electrotechnical Committee Joint Technical Committee) has formed the JTC1/SC25/WG (Working Group) 1 to define a set of standards creating a single network for all of a home's electrical and electronic devices. The scope of the proposed standards ranges from heating and air conditioning to appliances and home entertainment, with ties to home computers and the Internet. Work is still ongoing in this definition effort, although several standards have already seen release.

Developers should examine the levels of certification that standards call for and trade organizations provide, however, to ensure that they are appropriately targeting their designs. In the case of ZigBee, for example, several levels of compliance exist, and not all ensure interoperability in a home-networking application. The ZigBee protocol lies above the IEEE 802.15.4 radio standard, with application software sitting above the protocol stack (**Figure 4**). ZigBee Platform Certification ensures that the compliant device will interoperate in a network but says nothing about its application. Certification of a manufacturer-specific platform ensures that the device will not interfere with other ZigBee devices but does not ensure application-level interoperability. A device must achieve certification to a public profile for a given application, such as home networking, to guarantee the kind of interoperability that consumers demand.

Even with the ambiguities and competing standards, however, the field is now ready to begin delivering some of the wildest dreams of home-automation proponents. The range of media choices ensures that flexible and low-cost installation options are available. Data rates are high enough to allow distribution of entertainment and data as well as control over the networks. RF-signal-strength triangulation will allow systems to monitor and adapt to user locations, turning lights on before entering and off after leaving a room and switching music from room to room as the user moves. And developers are creating links to the Internet for remote operation of the systems as well as downloading media for many of the home-automation approaches in the market.

THE KILLER APP?

As exciting as these possibilities seem, however, from the consumer's viewpoint they represent just the gravy. Alone, they will not fuel the market. The meat of home automation, the killer application, must command widespread acceptance of the technology.

Such an application may be emerging. Power companies in both Southern California and Texas are looking to technologies such as ZigBee to help them implement load control and demand-based pricing in the home. With a ZigBee link from the meter into the home, these companies hope to provide customers with real-time feedback on energy use and cost as well as adjust user demand by remotely turning thermostats up or down, turning off water and pool heaters, and the like.

As energy costs continue to rise, such uses of home-automation technology can become compelling and may become mandatory. It's a humble beginning and less exciting than an intelligent home that conforms itself to your presence and preferences, but it may be all the home-automation industry needs to gain entry to the consumer's home. From there, the approaches that best satisfy the many requirements of consumer technology can see the kind of opportunity growth that the PC industry enjoyed in the late 20th century. EDN

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