HOME AREA NETWORK TECHNOLOGY ASSESSMENT FOR DEMAND RESPONSE IN SMART GRID ENVIRONMENT

Md. Zahurul Huq
Dept. of Electrical and Computer Engineering
Curtin University of Technology
Perth, Western Australia, Australia
E-mail: mdzahurul.huq@student.curtin.edu.au

Prof. Syed Islam
Dept. of Electrical and Computer Engineering
Curtin University of Technology
Perth, Western Australia, Australia
E-mail: s.islam@curtin.edu.au

***Abstract--* Modern electricity network will increasingly rely upon a set of intelligent communication and control technologies like home area network. Within the smart grid network, Home Area Network (HAN) help develop the demand response and demand side management. Renewable Energy opportunities such as Rooftop PV systems is also closely linked to the development of HAN and Demand Response. Several communication technologies are available in the market to implement HAN, but it is very important to choose the right one. Simply installing tools for implementing smart grid does nothing to influence customer energy usage behaviour. In this paper, we analyse the opportunities to improve demand management in a home for peak load curtailment and implementing the dynamic pricing policy. Wet also propose the comprehensive assessment of different technologies available for HAN and develop an approach for selecting suitable technologies, which contribute to demand management.**

***Index Terms-* Home Area Network, ZigBee, Z-Wave, HomePlug, Wavenis, M-Bus, Wi-Fi**

I. INTRODUCTION

Smart grid is an auto-balancing, self monitoring power grid that integrates various generation concepts and technologies [1]. It allows users to optimise the use of energy sources and minimize the negative impact on environment. Home Area Network (HAN) extends smart grid capabilities into the home using different networking protocols. HAN technology enables one to remotely connect to and control many automated digital devices throughout the house. Integration of smart meter with HAN helps to communicate peak energy use times to digital devices. For example, on a hot day, a smart controller would send a signal that would operate the HVAC system based on preferences.

One of the differences between residential environment and commercial/industrial environment is the level of sophistication and customer participation that can be assumed in configuring networks to achieve interoperability of Smart Grid communications. Many homes have one or more data networks linking computers or consumer electronics devices. However, this does not reflect all consumers. Moreover, even in homes those have data networks; consumers may not have the expertise for configuring a home network or may not want to spend time or money setting up a machine as clothes dryer to communicate through home network.

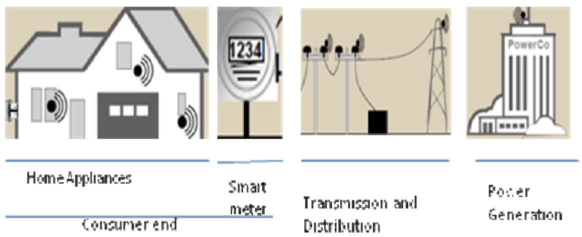


Fig 1 Smart Grid Framework

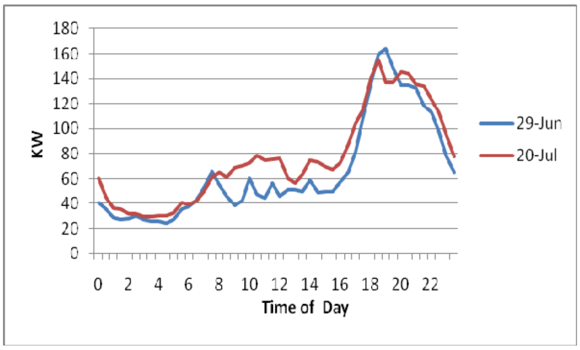
There are several technologies available or currently under development for HAN technologies. However not all are suitable for HAN implementation. One of the objective of this paper is to compare these technologies for HAN.

The paper is organized as follows: firstly we will look for the opportunities of demand management in a home, which can help the reader to understand the technologies role in demand management. Then, we focus on the opportunity of the more usable tariff structure introduction. After this, we go through the technologies presently available in the market and finally, we analyse and compare the different technologies, based on some selected characteristics.

II. OPPORTUNITY OF DEMAND MANAGEMENT IN HOME

Load behaviour significantly affects utility planning and strategic corporate objectives (improve earnings and cash flow, reduce risks, etc.) [2]. To achieve these business objectives, generic load shape changes are often necessary, such as clipping, valley filling, load shifting, energy conservation, load growth and reliability. So, an investigation of energy consumption, in conjunction with the general shape of its load and the variation of this shape during the year [3], is necessary.

There are two very distinct load curves – one for summer and one for winter. In actual fact the load curve for an extremely hot summer day is quite different from a mild summer day (i.e. air conditioning), as it is for a very cold and mild winter's day (i.e. heating). The graphs below show us how power is used on different days in one of the suburban substation in WA.



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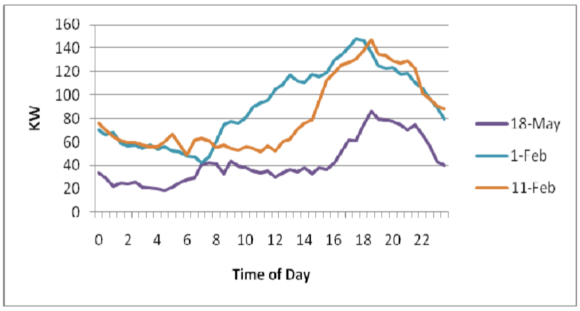

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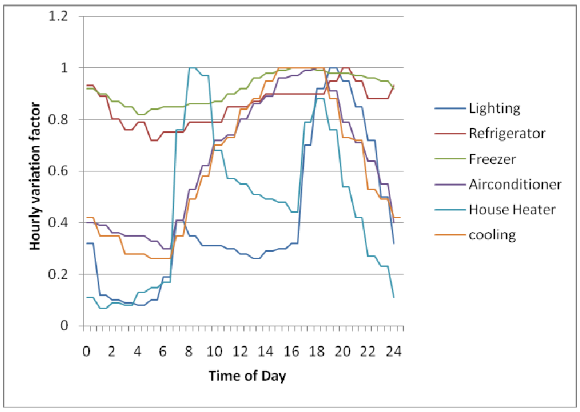


(c)

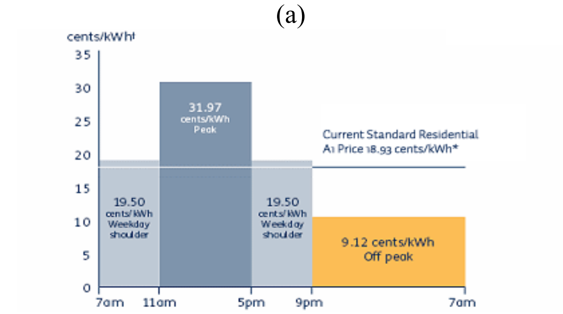
Fig 2. (a) Summer Load curve (b) Winter and Middle summer load curve (c) Hourly variation factor of home appliance (*Data source: a,b – Western Power*)

If we go through the above load curves and hourly variation factor we find that the heating and cooling system is the maximum contributor to develop the peak demand. The appliances that coincides with the system peak are candidates for smart equipment implementation.

III. Opportunity of Tariff Structure Improvement

One of the major benefits of smart grid environment is that it can enable the opportunity to introduce time-varying pricing of electricity. In Australia, the Time of Use (ToU) tariff policy is introduced for the consumers, who uses smart meter. In this policy, different tariff is applied for weekdays and weekends. Three time slots- peak, off-peak and shoulder time for metering are introduced [4]. The following figure shows the smart meter tariff of WA; All other states also uses similar policy but the time of peak, shoulder varies along with prices.

(a)



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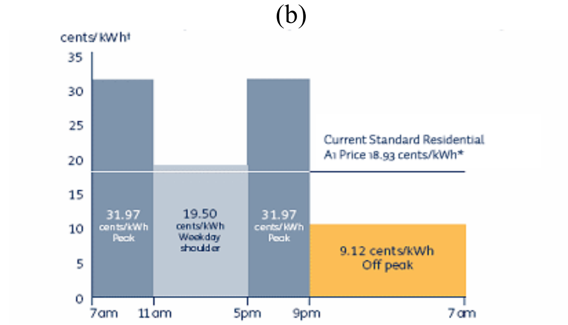

(c)

Fig 3. Smart Meter Tariff of WA (a) Weekends (b) Summer Weekdays (c) Winter Weekdays (*Data source: Synergy*)

The introduction of effective time-varying pricing largely depends on the bundling of different networks and consumer awareness. In this level, there is a scope to evaluate more effective time-varying pricing policy[5]. Because, when most of the consumers are integrated with smart metering, every consumer intends to move to off-peak period which can shift the peak to other time slots (a new peak is created), and also the critical peak period (which only happen for a fraction percentage of the whole year) may not be controlled.

IV. HOME AREA NETWORK TECHNOLOGIES

Home Area Network extends smart grid capabilities into the home using different networking protocols. HAN is the backbone of the communication between smart meter and home appliances.

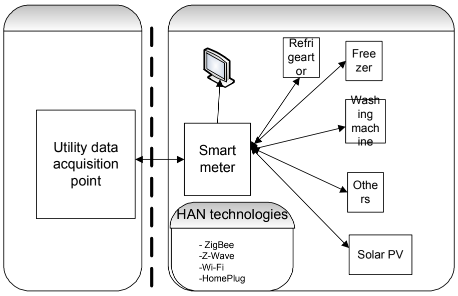

Fig 4. Typical HAN Structure

In a home area network, multiple components interact to provide a wide range of capability. The basic components of a home area network are:

1. The network portal or gateway that connects one or more outside information services to the home area network
2. The access point or network nodes that form the wired or wireless network itself
3. The network operating system and network management software
4. The end points such as thermostats, meters, in home display devices, and appliances

In this paper, we evaluate different technologies used in HAN technologies like – *ZigBee, Wi-Fi, Ethernet, Z-Wave, HomePlug, Wireless M-Bus, Wavenis* etc.

ZigBee[7]:

- Wireless mesh proprietary networking solution (from Layer 3 to the application layer) built on the IEEE 802.15.4 media standard.
- In a mesh network, nodes are interconnected with other nodes so that at least two pathways connect each node. Connections between nodes are dynamically updated and optimised. Mesh networks are decentralised in nature; each node is self-routing and able to connect to other nodes as needed. The characteristics of mesh topology and ad-hoc routing provide greater stability in changing conditions or failure at single nodes.
- The low power network must exclusively be made of devices interconnected by IEEE 802.15.4 links.
- The raw, over-the-air data rates are:
  - 250 kbps per channel in the unlicensed 2.4 GHz band (Worldwide)
  - 40 kbps per channel in the unlicensed 915 MHz band (Australia and US)
  - 20 kbps in the unlicensed 868 MHz band (Europe)
- Distance covered is 10-100 metres point to point, typically 30 metres indoors; unlimited with mesh networking.
- Low cost allows wide deployment in wireless control and monitoring applications;
- Low power-usage allows longer life with smaller batteries (up to 10 years) and the mesh networking provides high reliability and broader range.
- Provides secure connections between devices through 128-bit AES encryption.

Z-wave[8]:

- Z-Wave is a proprietary wireless communications standard designed specifically to remote control applications in residential and light commercial environments.
- Due to an impressive eco-system community Z-Wave is widely spread although it is not open and is available only to Zensys customers. Zensys is now a division of Sigma Designs.
- The Z-Wave Radio uses the unlicensed 900 MHz ISM (Industry, Scientific and Medical) band. 900MHz is unlicensed radio frequency band used in Australia, Israel and North America, while 2.4Ghz is unlicensed band used worldwide including Australia. Generally, 900MHz solutions provide significantly longer range and lower power than those operating in 2.4GHz.
- Distance covered is approx 30 metres point to point open-air, reduced indoor; unlimited with mesh networking and bandwidth 40kbps.
- Optimized for low-overhead commands such as on-off (as in a light switch or an appliance) and raise-lower (as in a thermostat or volume control), with the ability to include device metadata in the communications.
- The freedom from household interference (WiFi, Microwave, Cordless Phone) allows for a standardized low bandwidth control medium that can be reliable alongside common wireless devices.

HomePlug[9]:

- HomePlug is a power line communication technology. It uses the existing home electricity wiring to communicate.
- To create a network, a user connects two or more adapters to the power outlets in the home. The user can then connect devices to the network via the adapter.
- Alternatively, devices may already have HomePlug adapters built in, and therefore it is just a manner of connecting the devices to the home power outlet to enable network connectivity.
- Several HomePlug specifications exist. HomePlug 1.0 supports speeds up 14 Mbps

while HomePlug AV supports speeds up to 200 Mbps. A standard also exists currently in draft: IEEE P1901.
- Security with HomePlug AV is provided via 128-bit AES Encryption.
- HomePlug Command & Control (HPCC) is an alternative to the AV version and is designed for lower speed, very low-cost applications.
- Supports a number of protocols including IP.
- Setup and configuration may take a level of skill.

Ethernet:
- Ethernet is a very common communication technology standard primarily used within the LAN but can also be used on the WAN.
- Devices can connect to the Ethernet network in a variety of ways including copper "twisted-pair" cabling or fibre optics.
- Predominantly, copper cabling is used in Home LAN's. With the copper cabling connecting to a hub or switch in a star topology. This hub or switch may also serve as a gateway providing DSL/Cable/3G access to an ISP.
- A variety of speeds can be achieved including: 10 Mbps, 100 Mbps, 1000 Mbps and 10000 Mbps. 100 Mbps is the most common speed found in the Home LAN although 1000 Mbps is making an appearance as high bandwidth media such as Video and Network Attached Storage (NAS) becomes more prevalent. The NBN proposes 100 Mbps.
- The majority of network attached devices today come with Ethernet interfaces, including personal computer, laptops, servers, printers, AV equipment, media console, game consoles.
- Being standards based setup and configuration is very easy.
- Ethernet may not be appropriate for connecting all devices in the HAN (especially appliances) due to the high cost and power requirements plus the need for separate cabling back to a central point.

Wi-Fi[10]:
- WiFi is a popular wireless technology used in home networks, mobile phones, video games and other electronic devices.
- Based on mature IEEE 802.11 standards:
- 802.11n (~ 300 Mbps); 802.11b (11 Mbps); 802.11g (54 Mbps); 802.11a (54 Mbps)
- Support is wide spread with nearly every modern personal computer, laptop, game console and peripheral device provides a means to wirelessly access the network via WiFi.
- WiFi is generally upper layer protocol agnostic with IP being the most predominate protocol.
- Setup and configuration may take some level of skill.

IP:
- IP is a protocol used for communicating data within a packet switched internetwork. It is responsible for delivering data from source to destination based on a IP address.
- IP is the foundation on which the Internet is built and communication is achieved.
- IP is a single layer within a multi-layer suite known as the TCP/IP stack. Due to this abstraction, IP can be used across a number of different heterogeneous network technologies, including: Ethernet, WiFi, HomePlug without translation.
- The design of IP infuses the view that the underlying network is inherently unreliable and therefore is a "best effort" delivery mechanism. It is the responsibility of the upper layer protocols to provide reliability.
- Due to the ease of interoperability, ubiquitous nature, wide spread adoption and work being performed to create a lightweight interface (6LoWPAN), IP is being seen as essential to the success of HAN and Smart Grid development.
- It supports networking over power lines, phone lines and coaxial cables.
- Expected data rates up to 1Gbps.
- Provides secure connections between devices through 128-bit AES encryption. Authentication and key exchange is done following ITU-T Recommendation X.1035.
- G.hn natively supports popular protocols like Ethernet, IPv4 and IPv6 and as a result G.hn-based Energy Management networks can easily be integrated with IP-based SmartGrids.
- Availability of G.hn-compliant chips is expected during CY2010.
- Key advantages are ability to connect to any room regardless of wiring type, consumer self-install, built-in diagnostic information and self management as well as multiple equipment suppliers.

Wireless M-Bus[11]:

M-Bus (Meter-Bus) is a European standard for the remote reading of gas or electricity meters. M-Bus is also usable for other types of consumption meters. The M-Bus interface is made for communication on two wire, making it very cost effective. A radio variant of M-Bus (Wireless M-Bus) is also specified in EN 13757-4. The M-Bus was developed to fill the need for a system for the networking and remote reading of utility meters, for example to measure the consumption of gas or water in the home. This is suitable for- large number of connectable devices, possibility for network expansion, Fail-safe characteristics / robustness, minimum cost, minimum power consumption in the meters and acceptable transmission speed.

Wavenis[12]:

Wavenis is designed for ultra-low-power energy consumption and long-range transmission of small amounts of data and low traffic communications. Wavenis operates in the major license-free ISM bands around the world and complies with following regulatory standards - 868 MHz (EU EN300-220) with strict duty cycle regulation, 915 MHz (US FCC15-247, 15-249) with mandatory signal spreading, 433 MHz as straightforward extension (with no duty cycle restriction). While Wavenis maximizes the link budget to achieve the longest possible wireless range, the technology is not recommended for use in the 2.4GHz ISM band due to less efficient propagation conditions at the higher frequency. Wavenis data rates are programmable, from 4.8 kbits/s to 100 kbits/s. Most Wavenis applications communicate at 19.2 kbits/s.

V. FACTORS AFFECTING HOME AREA NETWORK TECHNOLOGY SELECTION

In this section we propose a set of criteria that could be used to identify and shortlist technology options for the HAN implementation in home. A number of issues influence the Smart Grid infrastructure development:

- Pace of technology innovation – Emerging standards are rapidly evolving along with the demand-side management applications that leverage these standards.
- Upgradability – Although consumer devices, such as in-home displays and programmable communicating thermostats, deliver demand-side benefits immediately, making them upgradeable over time requires increasing firmware and hardware resources.
- Consumer choice – Customer choice is a critical component in consumer adoption, and choice requires simultaneous sustained product innovation and attentiveness to existing technologies.
- Device ownership – The increasing variety of products and product types resulting from technology innovation that leverages Smart Grid communication capabilities are redefining the relationship between consumers and utilities.
- Market diversity – Fueled by product innovation, consumers and utilities are facing a mix of retail, direct-to-consumer and services markets that influence and are influenced by device ownership aspects of the HAN.
- Interoperability – The ability of devices and systems to work together is critical for the applications that deliver value to consumers, utilities, retail energy providers, load aggregators, and other stakeholders.
- Total cost – A variety of cost models may apply depending on the HAN gateway architecture chosen, and the Smart Grid business case must account for this.
- Performance – System level performance of applications can be hindered or enhanced by different architectures. This makes it vitally important to assess the risks, objectives, and current state-of-the-art in technology.

The availability of compatible appliances or appliance interface is also a major decision factor for the technology selection. A standard interface should be designed and implemented, so that appliances of different manufacturers can be connected with HAN. But in the current market scenario, limited commercial availability of ZigBee smart energy application profile compliant devices, on the other hand Z-wave compliant products present in the market for around three years. Now HomePlug and ZigBee working together with some major utilities, product vendors and technical experts to develop the acceptable standards in HAN automation [13]. The ZigBee Smart Energy Profile 2.0 specification will remove the dependency on IEEE 802.15.4. Device manufacturers will be able to implement any MAC/PHY, such as IEEE 802.15.4(x) and IEEE P1901, under an IP layer based on 6LowPAN.

Some of the above factors can be considered in more detail (more specific aspects), like- impact on other appliances or network, openness for future development, standardization, security, manageability, upgradability, scalability, extensibility, self-healing, interactivity. Following table shows a basic comparison of the different type technologies:

TABLE I
COMPARISON OF DIFFERENT HAN TECHNOLOGY

	Zigbee	Z-Wave	WiFi	HomePlug	Ethernet
Connectivity	Wireless	Wireless	Wireless	Wired	Wired
Max Speed per Channel	250 kbps (2 4 GHz) 40 kbps (915 MHz)	40 kbps (915 MHz)	11Mbps 300Mbps	14Mbps 200Mbps	10 Mbps – 1000 Mbps
Reach	10 -100 m (30 m typical)	30 m open-air, reduced indoor	100m (Indoors)	300m	100m (Twisted-Pair Cable)
Standards	IEEE	Proprietary	IEEE	IEEE P1901	IEEE 802.3

	802.15.4		802.11		
Adoption Rate	Widely adopted	Widely adopted	Extremely High	Medium	Extremely High
Security	128-bit AES encryption	128-bit AES Encryption	802.11i (WPA2)	56 bit DES encryption technology	
Others	Low cost, low power- usage, longer battery life	The freedom from household interference (WiFi, Microwave, Cordless Phone) allows for a standardized low bandwidth control medium that can be reliable alongside common wireless devices. IP support through IP-Wave product which will remain backwards compatible to existing Z-Wave products while adding compliant IP services to Z-Wave nodes	Support is wide spread with nearly every modern personal computer, laptop, game console and peripheral device	Designed for lower speed, very low-cost applications. Supports a number of protocols including IP. Setup and configuration may take a level of skill	Standards based setup and configuration is very easy. May not be appropriate for connecting all devices in the HAN (especially appliances) due to the high cost and power requirements plus the need for separate cabling back to a central point.

VI. CONCLUSIONS

HAN is an integral part of smart grid technology in developing demand response management at the distribution and substation transformer levels. HAN plays a critical role to control the home appliances, proper use of electricity and lowering the gas emission. The success of smart grid largely depends on the bundling of different network and consumer participation. Proper HAN technology selection is a critical part to involve the consumer in this process. In this paper, some of the factors are considered for the selection of HAN technologies, and also identify issues should be considered. A framework can be developed further for the selection of technologies.

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