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F. T. H. den Hartog, M. Balm, and C. M. de Jong, TNO Telecom
J. J. B. Kwaaitaal, Technische Universiteit Eindhoven

ABSTRACT

A new OSI-based model is described that can be used for the classification of residential gateways. It is applied to analyze current gateway solutions and draw evolutionary paths for the medium to long term. From this it is concluded that particularly set-top boxes and broadband modems, as opposed to game consoles and PCs, have a strong potential to evolve toward gateways that deliver network services to the home on all OSI layers, although they probably will not converge. In the context of our model, we have not found any compelling reasons for the residential gateway industry to support concurrent multiple broadband access network connections on a single residential gateway in the near future.

INTRODUCTION

The term *residential gateway* (RG) is not strictly defined and is widely used for many different devices. A general consensus can be observed if an all-encompassing definition is used — "A residential gateway is one or more devices that connects one or more access networks to one or more home networks and delivers services to the home environment." But a great variety of options are possible within the framework of such a definition. Some examples are digital subscriber line (DSL) modems with Dynamic Host Configuration Protocol (DHCP) server and IP routing, set-top boxes, home telephony switches, cable modems with a separate router, and remote metering equipment.

The industry generally agrees that some convergence will take place in the not too far future. For broadband network operators, a detailed vision of RG evolution is crucial to anticipate new tasks to be fulfilled in the future, such as service packaging, remote management, and network storage provision [1]. This article attempts to derive some evolutionary paths for RGs for broadband networks by first stating a set of user requirements to which future gateways should comply, and then assessing a number of current solutions and their roadmaps in the framework of an RG classification model. Special attention is given to the question of whether or not RGs are going to support concurrent multiple access network connections. This issue is of particular interest to service providers who want to be able to deliver services based on the characteristics of different networks.

RG CLASSIFICATION AND REQUIREMENTS

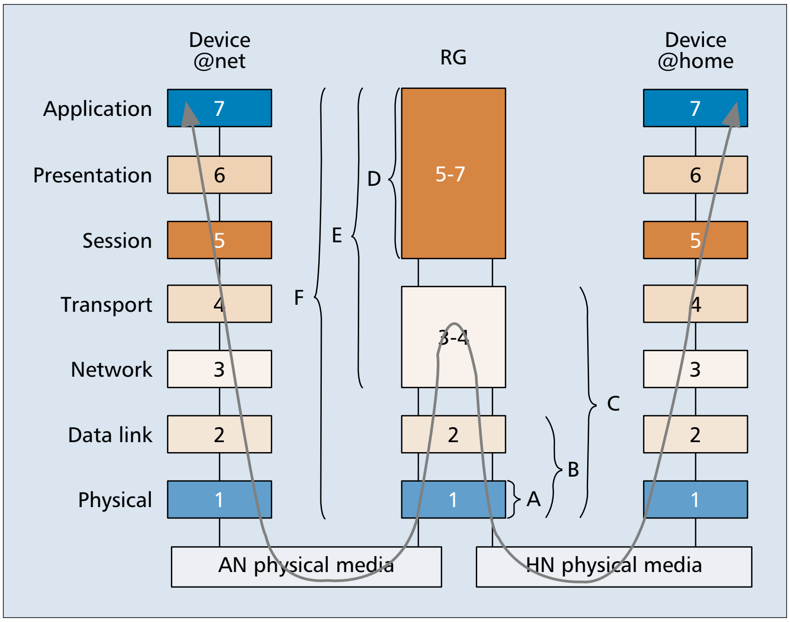
RG CLASSIFICATION BASED ON OSI

Various ways of classifying RGs have been proposed in literature. Parks Associates [2] distinguished gateways mainly based on the number of access networks terminated and number of services supported. The main disadvantages of such a classification are the assumption that RGs will terminate multiple access networks eventually and denial of distributed or modular RG solutions. The case of multiple gateways for one user and the fact that other devices in the home network can also provide typical gateway functions should be taken into account. Another classification was made in a paper by BTexact Technologies [3]. They distinguish modems, routers, RGs, and services gateways in order to describe RG evolution. The main disadvantage of classifying RGs in this way is in the nomenclature. In literature, the term is generally also used for devices BTexact calls routers or services gateways. Furthermore, the classification model does not take into account distributed RG architectures that consist of, for example, a broadband modem and a separate device running router software and a firewall.

For our purposes, we propose a model for RG classification derived from the Open Systems Interconnection (OSI) model (Fig. 1). The RG is represented as an entity connecting the access network (AN) physical media with the home network (HN) physical media, and comprising a number of protocol processing units that deliver services to the home environment. For example, an RG containing only the protocol processing units numbered 1 and 2 in Fig. 1 is a device that delivers just physical layer conversion and layer 2 (L2) services to the home network. The units are connected with solid lines to show that an RG can be a single integrated device, have a modular architecture, or consist of a number of separated systems distributed in the network (mostly the home network). Any end-user device in the home network is named device@home in our model, and is represented by separately connected single-layer units to symbolize that the device can be a single device or some sort of subnetwork. The same counts for the stack called device@net in Fig. 1, which can be a server directly connected to the access network or any set of collaborating devices in the Internet. The double-headed W-shaped arrow represents the data flow and processing activity for a communication session between a device@net and a device@home through an RG that connects the access network with the home network, and delivers only bridging and routing functions to the home network. Six types of RGs are distinguished, hereafter called types A to F (see braces in Fig. 1). Other combinations of processing units are theoretically possible. However, such devices are never called residential gateways; just media converter, switch, router, proxy, and so on. Types A and D are hardly ever called residential gateways either, but nevertheless are included here for completeness.

RGs of type A are just physical layer converters and are transparent on L2. Current examples of such RGs are integrated services digital network (ISDN) network terminations and Ethernet optical/electrical (O/E) converters. RGs of type B also terminate L2 of the access network and provide L2 services to the home network. Current examples are DSL modems with a Universal Serial Bus (USB) interface, many cable modems, virtual local area network (VLAN) supporting L2 switches with O/E converters on the WAN side, home telephony switches, and a distributed RG consisting of a bridge or switch plus any RG of type A. Voice over broadband hardware also falls in this category. RGs of type C have integrated router functions and deliver L3 services (mostly IP) to the home environment. Commonly used examples are DSL or cable modems with integrated IP router and DHCP server, ISDN routers, and a distributed RG consisting of a router plus any RG of type B.

RGs of type D are often PCs or dedicated consumer electronic devices that act as service platforms to other devices in the home. Examples are personal video recorders (PVRs), many set-top boxes, game consoles, home servers, and also the PC included in the RG used in the Dutch KPN HomeServices trial in 2001 [4]. RGs of type E are like type D, but include router functions and deliver L3 services (mostly IP) to the home environment. The best examples here are the PCs running Linux and router software, used by many early adopters of broadband access to act as a firewall (among other services) between the broadband modem and the home network. Also, many Open Service Gateway initiative (OSGi)-enabled services gateways with Ethernet WAN interface belong to this category [5]. Of course, RGs of types D and E also contain L1–2 functions, but they generally do not process and offer



■ **Figure 1.** *RG classification model based on OSI.*

L1–2 services to the home environment. Examples of such processing would be bridging of different home networks, VLAN switching, Ethernet quality of service (QoS) support, filtering of overlay technologies, and so on, not just offering connectivity. Finally, RGs of type F include all OSI layers. Examples are any RG of type C with integrated firewall and Web-based management services, or combinations of RG type B or C with separate devices of type E or D.

Requirements that Drive RG Evolution

In this section a number of user requirements are postulated that are thought to drive the future evolution of current RG solutions. The list does not pretend to be complete, but merely summarizes the criteria used in the following section to draw evolutionary paths. Future type F RGs should:

Req. 1: Be always switched on and operational

Req. 2: Be fairly reliable, (i.e., system crashes no more often than about once per year)

Req. 3: Be manageable, preferably remotely

Req. 4: Have a depreciation time longer than three years

Req. 5: Be priced affordably (under a few hundred euros) and/or deployable by means of subsidized business models

Req. 6: Serve multiple peripherals (devices@home), most likely on multiple home networks

Req. 7: Support various services, including security services such as firewalls and virus scanners

Analysis of Current Solutions

Set-Top Boxes

The primary function of digital set-top boxes (STBs) is to enable an analog television to receive digital television (DTV) broadcast signals. Nowadays, a typical STB contains one or more microprocessors for running the operating

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system and parsing the Moving Pictures Expert Group (MPEG) transport stream. It also includes random access memory (RAM) and MPEG video and audio decoding and processing functions. Such STBs are good examples of type D RGs.

The major manufacturers have developed STBs for cable, satellite, terrestrial, and xDSL connections, and envision the incremental change of the STB into a full-fledged type F RG [6]. The first step should be creating a type E gateway with high-speed two-way data connectivity across the home. The next step is to expand the STB with modules, application programming interfaces (APIs), and drivers for new services. More sophisticated STBs already contain a hard drive for storing recorded television broadcasts (PVR function) and downloaded software, and for other applications provided by the DTV service provider. Also, the integration of gaming functions is foreseen.

Nowadays, additional cable telephony services and broadband cable Internet access are provided via separate devices. TV, telephony, and broadband data services require different specific hardware. It is expected, however, that these technologies will converge in future STBs. Although STBs are now mostly attached only to the television set , they can also act as an Internet gateway and be connected with other peripherals such as PCs and voice over IP (VoIP) hardware (*Req. 6*). Current STBs are equipped with interfaces such as IEEE1394, 10/100bT, RS232, and USB2, but in the future this will most likely be extended with phoneline, powerline, and wireless-based protocols.

One of the issues that still has to be settled, however, is how decoding functions should be distributed in the home network. Should the decoding happen centrally, resulting in analog in-home distribution of the TV signals, or should every TV have its own decoder? Excellent papers have been written on this question (e.g., [7]), but no definite conclusions could be made.

Although the convergence of broadcast and broadband data services into one device makes the STB a good candidate to evolve into a type F RG (*Req. 7*), cable operators are not rushing to abandon today's units yet. Virtually all of the 14.7 million digital STBs sold in the United States during 2000 were low-end models. However, recently conducted surveys indicate a shift of consumer interest from the PC to new apparatus such as DVD players and high definition TV (HDTV). The STB would definitely seem to be a similar device in consumer perception. Therefore, with strong marketing strategies offering good pricing (*Req. 5*) and content, a type F STB can be a "must" for every consumer.

Game Consoles

The gaming industry has grown into a big business with tough competition. Three vendors are currently developing game consoles: Microsoft Corporation, Sony Corporation, and Nintendo. For the time being, Microsoft's Xbox, released in November 2001, is technically the most advanced. The console contains a processor, a hard drive, and an Ethernet WAN port. It can also function as a normal DVD player (*Req. 7*). Recently, multiplayer gaming via the Internet has been realized. As an RG, it would classify as Type D.

In the future, consoles will be equipped with or connectable to a large variety of peripherals. However, all game consoles are mainly proprietary technology, with the exception of some standard USB and IEEE 1394 connectors on the home network side. As a result, peripherals and software cannot be exchanged among the different game consoles (*Req. 6*). Standardization is not likely to happen due to the harsh competition: the manufacturers make a profit by selling relatively expensive games. One of the advantages of such a business model is that game consoles can easily be sold for a price close to production costs (*Req. 5*).

Although the hardware and location in the living room may be similar to that of an STB, the game console has more similarities with a PC from a purely functional point of view. The core of the console is the processor. The quality of a game console depends on the processor speed. Fast moving graphics need to respond to the interaction of gamers. The increasing speed of new processors requires that gamers buy newer and faster game consoles regularly, since processor speed can be decisive for victory or loss, and new games only run on the new releases. This relative fast rotation of game consoles and their inherently proprietary technology make them less suitable for use as a type F RG (*Req. 4*).

Next-generation game consoles are expected to be more than just game consoles. Microsoft and Sony foresee a device with added functions such as PVR and Internet browsing. This could be a viable step toward a type F RG.

PCs

At first sight, the PC seems to have a very good chance to evolve quickly into a type F RG. In some households, the PC already functions as a type D, E, or even F RG. Many advantages of using a PC as an RG arise from its modular architecture. The PC is easy and relatively cost effective to upgrade (*Req. 5*). Specific hardware can be added as separate units and is usually widely available. The PC has strong multitasking properties and can run many different applications (*Req. 7*). Nowadays, a PC can be a true multimedia machine with soundcard, CD driver, and DVD (re)write-able. All these properties make the PC architecture very suitable for RG development, which is why embedded PCs are now often taken as a starting point for the design of new gateways.

More commonly, however, PCs are sold as end-user devices for use on a desktop, with desktop-oriented operating systems and applications installed. There are hardware-software combinations on the market that can turn the PC into a PVR, similar to an STB, by using the PC's hard drive. Unexpectedly, it has never really taken off. United States sales figures indicate that PC-based PVRs represent a small percentage of all other video recording technologies. Pricing and unawareness of PVR are said to be the main reasons for the low sales. PVR on STBs may be more successful, because STBs can more easily be sold within subsidized business models than PCs (*Req. 5*). Another reason for the relatively low popularity of PC-based PVRs might be the fact that in most (European) households the desktop PC is placed in any room but the living room. Therefore, the consumer requires either cabling or a wireless connection between the TV and the PC (*Req. 6*). Other disadvantages of desktop PCs serving as RGs are the poor reliability of some operating systems (*Req. 2*) and the many reasons for (European) consumers to switch PCs off after use (*Req. 1*), such as power consumption and noise nuisance and, related to these, the poor (remote) manageability (*Req. 3*).

In some households, such as student accommodations, the desktop PC and TV are installed in the same room. For this market, Microsoft and PC manufacturing partners NEC Corporation, Hewlett-Packard Company (HP), and Samsung have introduced a new class of PCs powered by Microsoft's Windows XP Media Center Edition (alias Freestyle). Compared to ordinary PCs, these media center PCs are equipped with a very large screen that can function as a TV, a built-in tuner, and an IR (infrared) sensor for remote control. The PC is equipped with a standard TV input and an Ethernet WAN connection. Samsung's media center PCs will also have wireless interfaces for peripherals. The IR remote control requires the PC to be in the same room as the remote control. Comfort is another reason to put a media center PC in the living room. It must be easy for consumers to physically change a DVD without walking to another room. Such media center PCs are heralds of type F RGs, but will initially serve a niche market.

Broadband Modems

Traditionally, broadband modems (cable and DSL modems) only performed L1–2 conversion to enable the connection of a single PC to the access network via its USB or Ethernet interface. Those modems are typical type B RGs. IP connections were directly set up from the PC, and the modem was fully transparent on the network layer.

Broadband modems that support voice over Broadband (VoB) form a special subset of type B broadband modem RGs. VoB technologies offer a way to generate revenue from new value-added IP-based services. VoB is fairly new and not completely standardized yet. Standardization consortia (CableLabs, DSL Forum) are strongly access-technology-oriented, and a large number of companies are still releasing proprietary hardware. The OpenVoB consortium promotes the use of existing standards and is working closely with the current standardization bodies to ensure alignment of the evolving standards.

Voice over DSL (VoDSL)-supporting RGs are often called integrated access devices (IADs), while media terminal adapters (MTAs) are related to cable technology. IAD and MTA hardware mainly differ in termination of the access network. To the home network, the IAD and MTA both offer standard telephone connectors, an Ethernet port, and switching function. A splitter before the modem allows the connection of one traditional public switched telephone network (PSTN) interface in case of an IAD, or the connection of traditional analog TV in case of an MTA. The data is then processed and switched to the appropriate interfaces and different peripherals (PC, TV/STB, IPphone, etc.). In the public network, voice and data are separated at some voice gateway, and forwarded to the public telephony network or an ISP, respectively.

In recent years, broadband modems extended with L3 functionality became the de facto standard. Routing and a DHCP server are minimum requirements, and support of IP QoS [8], remote configuration capabilities, extended decoding functions (e.g., MPEG-4, H.323, voice), and simultaneous access to multiple service providers have entered the specifications of modern broadband modem architectures, such as CableHome [9] and full service-very high speed DSL (FS-VDSL) [10]. These modems are actually type C RGs, offering L1–3 functions to a broad palette of services and devices (*Reqs. 6 and 7*). Some also support additional functions, such as firewalls. They are relatively cheap (*Req. 5*) and because they are rather basic they do not require an update every three years (*Req. 4*). A downside of much of the current broadband modem hardware is the limited support of configuration management by the consumer (*Req. 3*).

We do not foresee that these modems will grow into full-fledged type F RGs as fast as STBs, because of business models and cost considerations. To sell them to consumers via subsidized business models is probably more difficult than to sell STBs (*Req. 5*), because audio and/or video (A/V) distribution markets generally still happen to be more vertically organized than telecommunication markets.

Another reason for the relatively low popularity of PC-based PVRs might be the fact that in most (European) households the desktop PC is placed in any room but the living room.

Multiple Access Network Connections

Whether or not RGs are going to support concurrent multiple access network connections in the medium to long term is of great interest to service providers who want to be able to deliver services based on the characteristics of different networks. There are some indications that this is actually going to happen. Far-reaching architectures, such as OSGi and HomeGate [11], enable different (access and in-home) network technologies to be combined. Many satellite STBs already have DSL or PSTN interfaces to support upstream data traffic.

There are, however, a number of strong arguments against such an evolution in the coming five to ten years:

- Most RG defining consortia focus on just one access technology per device.
- Most households are expected to subscribe to not more than one broadband connection simultaneously in the near future.
- In the medium to long term, many RGs will be sold to consumers by access network providers or strongly related service providers within a subsidized business model. The provider will therefore not be interested in stimulating RGs with other access technologies that enable the consumer to

For many vendors and their parent companies, the winner in this broadband access technology race is irrelevant anyway, because they are flexible enough to produce devices with any of the competing access technologies.

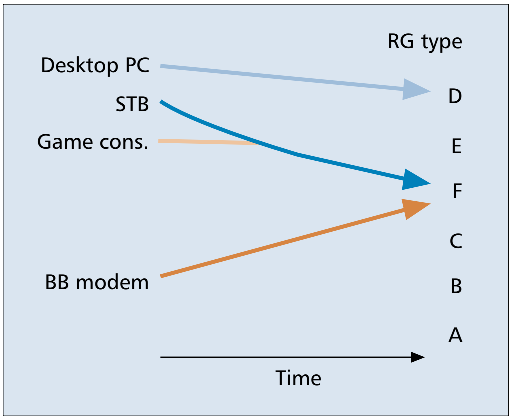

Figure 2. *RG evolutionary paths in the medium to long term.*

connect to third parties. In the long term this may change, when value chains unbundle and business models become more horizontal.

- Most current and future services mentioned in the literature can be enabled perfectly well by a single broadband access network connection of any technology.

There is, therefore, no compelling reason for the RG industry to support concurrent multiple broadband access networks on a single RG in the near future. For many vendors and their parent companies, the winner in this broadband access technology race is irrelevant anyway, because they are flexible enough to produce devices with any of the competing access technologies [6].

Conclusions

In this article we devise a model for RG classification and postulate seven requirements RGs should fulfill to class as type F. We then analyze the successors of current RG solutions that are expected in the medium to long term, and determine which requirements they are likely to meet. The results are summarized in Table 1. There we have roughly scored the successors of various current solutions against the requirements with a +, 0, or –. The scores not explained in this article we think are fairly obvious. From the table it can be concluded that especially current set-top boxes and broadband modems have strong potential to evolve into popular type F RGs in the medium to long term.

In Fig. 2 we have sketched the likely evolutionary paths of the four current RG solutions, following the line of reasoning in the earlier sections of this article. From this figure it can be seen that game consoles and STBs are expected to converge to type F RGs that are almost technologically indistinguishable. Broadband modems will, however, remain technologically different. Further convergence is only expected in the long term with the deployment of fiber access.

Only dedicated and reliable embedded PCs will evolve to type F RGs. The standard desktop PC will remain a type D device that, together with a type C broadband modem, will form a type F RG. The separation of modem/router functions and processing on the application level in two different L2/3 interconnected devices or by means of a modular RG architecture has a number of advantages [7]. The main advantage is that the different modules can be provided, managed, and possibly subsidized by different providers in a horizontally organized market, such as network connectivity providers and service providers. A well defined open interface between the modules then becomes a necessity.

We also gave some arguments against multiple access network connectivity of RGs in the near future. From this it can be concluded that there are no compelling reasons for the RG industry to support concurrent multiple broadband access networks on a single RG soon.

The final conclusion to be drawn from this work is that the OSI-based model for RG classification as presented in this article serves its purpose rather well. It has some clear advantages over other models previously given in literature. First, it takes modular and distributed solutions into account. Furthermore, it does not presume any evolution toward multiple access network connectivity. Finally, it respects the residential gateway nomenclature grown in industry during the past years.

	Requirement						
RG	1	2	3	4	5	6	7
STBs	+	+	0	+	+	+	+
Game Cons.	–	+	–	–	+	–	+
Desktop PCs	–	0	–	0	0	0	+
BB modems	+	+	0	+	0	+	+

Table 1. *Scores of likely medium–long–term successors of current RG solutions to the requirements (given in the main text) for type F RGs.*

Acknowledgments

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Biographies

FRANK DEN HARTOG [M] (F.T.H.denHartog@telecom.tno.nl) received an M.Sc. degree in applied physics from the Technische Universiteit Eindhoven in 1992. He obtained a Ph.D. in physics and mathematics at Leiden University in 1998, after which he joined KPN Research (In 2003, KPN Research became part of TNO Telecom). He specialized in home networking technologies and established an expert group dedicated to the subject. Currently he is leading the Dutch industrial ICT research project Residential Gateway Environment, a two-year collaboration between TNO Telecom, KPN, Philips Research and the universities of Delft and Eindhoven. He is a guest lecturer at several universities and (co-)authored about 50 papers and contributions.

MIKE BALM (M.Balm@telecom.tno.nl) holds an M.Sc. degree in applied physics from the University of Twente, The Netherlands. He joined KPN Research in 1998. His initial assignment was on DWDM and MPLS development and rollout support. Since 2001 he has been working on new first mile technologies such as FTTH, VDSL, VoIP, and the residential gateway. In 2003 KPN Research became part of TNO Telecom.

CÉCILE DE JONG (C.M.deJong@telecom.tno.nl) received her M.Sc. in the physics of laser communications from the University of Essex, England, in 1994. In 1999 she obtained a Ph.D. in applied physics from Delft University of Technology, The Netherlands. In 1999 she joined the First Mile Solutions group of KPN Research. Access and home networks have been her main area of research. She participated in a number of strategic projects for KPN, the Dutch incumbent operator, providing advice on the migration and termination of its access network. She leads a number of activities within national and European projects. In 2003 KPN Research became part of TNO Telecom.

JACCO KWAAITAAL (J.J.B.Kwaaitaal@tue.nl) received an M.Sc. degree in electrical engineering from the Technische Universiteit Eindhoven (TU/e) in 1999. He then joined the Telecommunication Systems (ECO) group at TU/e and was also connected to the Eindhoven Embedded Systems Institute (EESI). He specialized in Home Networking technologies and Residential Gateways. In 2001 he became project manager in the ECO group, representing the group in several (inter)national projects and programs: Residential Gateway Environment, VisionAIR (IST; full service trials) and GPRS/WLAN/UMTS access pilots. Since 2003 he has held a part-time position as scientific secretary in the Cobra Research Institute on Communication Technology. He also works for the advising company Infocal, which integrates both technical and juridical expertise.

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