Chapter 2

Evolution of Broadband Communication Networks: Architecture and Applications

Sonia Gul and Jairo Gutierrez

Additional information is available at the end of the chapter

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Abstract

With the rapid increase in users' demand for flexibility and scalability of communication services, broadband communication networks are facing an ongoing challenge of providing various broadband services using a single communication architecture. This leads to the evolution of a challenging field of multiservice broadband network architectures. This chapter discusses the basic concepts associated with broadband communication network architectures with emphasis on provision of multiservice, and it also focuses on the evolution of broadband communication networks from the traditional architecture to the incorporation of virtualization services, that is, cloud computing. Another important aspect, which relates to the multiservice broadband network, is the "applications" which, as this chapter highlights, are a key-driving factor for the evolution of broadband communication networks. Moreover, this chapter also includes a discussion on New Zealand's government initiatives to provide improved network coverage within the country.

Keywords: broadband, communication network, evolution, applications, architecture

1. Introduction

Broadband communication networks have become increasingly popular. These are the networks, which give telecommunications a new perspective by supporting traffic of multiple types, that is voice, video and data (also known as multimedia), but also communicating these to the end user using a single packet. Some of the networks which started with the provision of multimedia capabilities include asynchronous transfer mode (ATM) and Frame Relay [1].

Broadband communication networks are regarded as aggregated networks (providing voice, video and data) over the wired network including Ethernet and fibre. The multiservice support of these networks not only opened a new era in telecommunications but rather also has challenged the network operator's abilities and capacities.

In this chapter, a tutorial background on broadband communication networks is provided. The challenges faced and the techniques adopted by the service providers are described with the insight into the evolution of broadband communication networks starting from ATM to the virtualization of broadband services.

2. Broadband communication networks

During the 1980s, the telecommunication industry started to work towards the concept of providing any type of information to anyone, anywhere. This concept pushed the evolution of wireless networks including both cellular networks and wireless local area networks (WLANs). The WLANs have then evolved supporting faster data rates, higher throughput and better roaming capabilities, hence a more efficient communication network for offices, home and other purposes. Similar to WLANs, cellular networks have also gone into the transition from 2G to the current 5G efforts mainly targeting the communication needs of mobile users. All these advancements brought up a range of technologies including ATM, International Mobile Telecommunication (ITM)-2000 systems [2], wireless IP networks, WLANs, and 4G and 5G networks (ITM-2020).

2.1. History: standardization point of view

The evolution of broadband communication networks can be seen as a competition between two technological domains, namely WLAN and cellular. The international standardization organizations have been working hard to progress each of these technological domains that are taking over the broadband communication era [3]. A number of standards under both domains are being set, published and provided to the market to be used commercially. In **Tables 1** and **2**, we summarize the standards to date for both technological domains.

2.2. Technological view point

The terminology "band" has been used for a long time by engineers, and it started with the definition referring to a set of channels and/or frequencies. Later, this term has been used with other adjectives to make it sound more understandable, for example, baseband, passband, etc. In the 1980s, the term wideband started to be used very frequently when referring to a number of channels [4].

In telecommunications, broadband communications are achieved using a wideband of channels. This allows channels to have more capacity, and hence they can support communications from

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Year	WLAN standards	Year	WLAN standards
1997	IEEE 802.11-1997	2009	IEEE 802.11 n, w
1999	IEEE 802.11b	2010	IEEE 802.11z
2001	IEEE 802.11 a, c, d	2011	IEEE 802.11 s, u, v
2003	IEEE 802.11F, g	2012	IEEE 802.11 aa, ad, ae, 802.11-2012
2004	IEEE 802.11h, i, j	2013	IEEE 802.11 ac
2005	IEEE 802.11e	2014	IEEE 802.11af
2007	IEEE 802.11-2007	2016	IEEE 802.11 ai, ah, 802.11-2016
2008	IEEE 802.11k, r, y	2017 (in progress)	IEEE 802.11 aj, aq, ak, ax, ay, az, ba

Table 1. IEEE WLAN standard summary [5].

the applications that require high data rates. As per the standard (802.16-2004) broadband refers to "having instantaneous bandwidths greater than 1 MHz and supporting data rates greater than about 1.5 Mbit/s" [6]. Lately, the Federal Communications Commission (FCC) has increased the download and upload speeds to at least 25 and 3 Mbits/s, respectively [7].

Broadband communication networks are still considered as one of the vital factors which may help businesses throughout the world to achieve their goals for sustainable development, by 2030 [8]. A number of broadband technologies are required to work together to meet this goal. These technologies include, but are not limited to, mobile and fixed broadband, backhaul satellite networks, Wi-Fi (unlicensed) technologies and cellular (licensed) networks.

With the advancements in technology, wireless networks are able to support almost the same data rates as those of some wired networks (including cable modems and asymmetric digital subscriber line (ADSL). Therefore, both fixed and wireless broadband networks have grown tremendously in previous years [9]. In **Table 3**, the broadband technologies to date are summarized for easy reference.

Year	Cellular network standards	Year	Cellular network standards
1985	AMPS (TIA, EIA), N-AMPS, TACS, ETACS	2003	UMTS, W-CDMA
1992	GSM, CSD, HSCSD, CDMA, D-AMPS	2005	HSPA, HSPA+, LTE, WiMAX, Flash-OFDM
2000	GPRS, EDGE, CDMA2000	2011–2013	LTE Advanced/Pro, WiMAX (IEEE 802.16m), WiMAX 2.1

Table 2. Popular cellular network standard summary [10].

Year	Broadband technologies	Data rate (max)
Fixed line		
1990	Hybrid fibre coaxial (HFC)	400 Mbits/s
1990s	Broadband over power lines (BPL)	3 Mbits/s [11]
1998	ADSL	12.0–1.8 Mbits/s
2003	ADSL2+	24.0–3.3 Mbits/s
2008	FTTH-FTTX	2.5 Gbits/s–622 Mbits/s [12]
Wireless		
1947	Microwave	800 Mbits/s
1998	LMDS	64 kbits/s–155 Mbits/s [13]
1998	MMDS	27–38 Mbits/s
2000	W-CDMA, CDMA2000	153 kbits/s
2008	FSO	10 Gbits/s
2008	LTE (standard)	144 Mbits/s
2011	WiMAX	30 Mbits/s–1 Gbits/s
2011	LTE Advanced	200–300 Mbits/s
2015	LTE Advanced Pro	1 Gbits/s

*Satellites are also being used for broadband communications.

Table 3. Popular broadband technology summary.

3. Multiservice-broadband network architecture evolution

The evolution of multiservice broadband network architectures extends from the digital subscriber line (DSL) architecture [14, 15]. The network architecture has evolved to fulfill the increasing demands of service, not only for residential users but also for wholesale markets and businesses. Based on these the focus is not only of the provision of quality of service (QoS) but also on availability and reliability. This leads to a whole list of new motivations about the services which were expected from the multiservice broadband network architecture including a simpler network design architecture, unified connectivity, enhancements and improvements in operations, independent provision of services, improved availability, improved scalability and efficient support for multi-edge services [15, 16].

Multiservice broadband architectures evolve to address the needs of triple play and converged broadband networks. This evolution provides a pathway for service providers to face the upcoming broadband network challenges in an effective and efficient manner. Some of these challenges are listed below [17]:

- Easy and quick provision of services for both business and residential users
- Support of IP-based applications

- High level of quality of service (QoS), security, reliability, scalability and availability
- Effective management of services
- Support for virtualization services

3.1. Triple play services: aggregated services using multicast

In the early 2000s, there was an increasing demand for voice, data and video (triple play) services especially for residential purposes. Based on the demand, the network architecture started to evolve towards providing these triple play services using Ethernet technology [18–21]. One major requirement which turns up for the provision of the said service aggregation is multicast forwarding which is designed to minimize the number of network links used for media streams.

On one side, the use of multicast enhances the performance and reduces the network load, while, on the other hand, using it with the traditional Point-to-Point Protocol over Ethernet (PPPoE) sessions makes the big picture more complex [22, 23]. To address this issue, the use of a more dynamic protocol, that is, DHCP is introduced instead of PPP for IP [24]. In broadband networks the sessions using DHCP started to prove their worth by proving simple and always-on connections for residential users.

This aggregated multicast networks proved so successful for residential clients that soon service providers started to offer these for businesses. This led to the next step of its evolution where the same network architecture is used to transport both mobile and fixed traffic. This was enabled with the introduction of backhauling for mobile traffic of 2G/3G networks, a capability that was later moved to work with 4G/LTE networks [25, 26].

3.2. IP to MPLS-based routing

Internet Protocol/Multiprotocol Label Switching (IP/MPLS) is a well-adopted technology [27, 28]. However, based on its flexible nature, it was initially used for backbone and core networks. Later on, this technology also started to spread in the aggregated service network domain and started to support the service access layer which connects IP-based service nodes and customer premises equipment (CPEs).

The success of IP/MPLS in the access layer of multiservice broadband networks opened new horizons for building a unified network architecture using commonly used technologies. This allowed service providers to use the same technology throughout their network including at the access, aggregation and core levels, which results in [29, 30]:

- Better scalability of the network
- Flexibility in the placement of service nodes
- Simple provision of aggregated services

Based on the need and functionality of access node (AN), two implementation models for IP/MPLS have been mainly used [17]:

3.2.1. Seamless MPLS model

Seamless MPLS model extended only limited functionality to the AN. This model used the simplest form of IP routing, that is, static routes between aggregation nodes and the access nodes. To get better scalability, the label distribution feature of MPLS is used.

3.2.2. Full MPLS model

On the other hand, full MPLS model extended the complete functionality of Layer 3, that is, dynamic routing to AN. This makes access nodes and aggregation nodes functionally equivalent.

The choice of model depends on the specific requirements and the current network structure.

3.3. Architecture-supported functions

Based on the challenges mentioned in the previous section, the functions of the multiservice broadband architecture are defined. These functions are defined keeping in mind the main objective, that is, provision of all these services using a common network infrastructure [31]:

- Layering functions include forwarding (relaying layer information) and termination/adaptation functions (mapping user information to a specific layer).
- Control functions include session control and resource control.
- Filtering and scheduling involve filtering of data (e.g. using ACL-access control lists) and scheduling considering priorities, policies, etc.
- Synchronization functions deal with frequency, phase and time synchronization.

3.4. Service layers

The unique multiservice nature allows the provision of services at various layers. This yield to the design of various service layers as follows:

- IP-service layer: These include the IP-layer services which can be seen directly by the end user. Such services include VPNs, Internet access for business and residential purposes, etc.
- Ethernet-service layer: These are the services which provide transport capabilities based on the service, for example, service aware, such as Ethernet access services (some are defined by Metro Ethernet Forum (MEF)), etc. [32, 33]. This is mainly achieved by using the concept of Infrastructure Virtual Circuit (IVC).
- Support-aggregation layer: These services support to map Ethernet services on top of other technologies, for example, IP/MLPS, etc.

Cloud computing and virtualization services do not get across to all the above-mentioned layers. **Figure 1** depicts the view of the discussion above.

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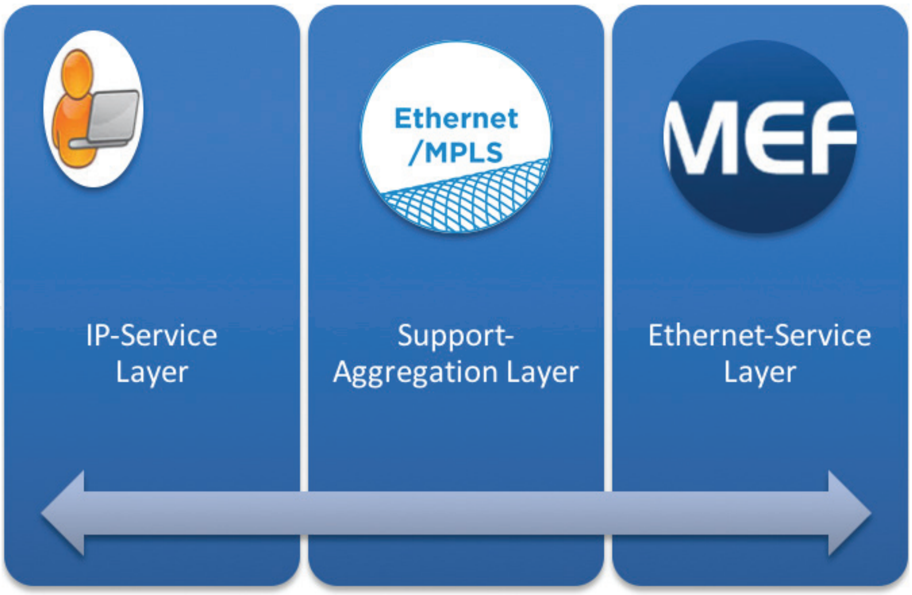

Figure 1. Multiservice broadband network's service layers.

3.5. Trend of fixed mobile convergence

The need for ubiquitous service delivery between fixed and mobile networks has emerged with the advancement in technology, specifically the availability of IP-based mobile handsets/devices. The number of mobile devices' users continues to grow, and the demand for service availability regardless of the type (i.e. fixed or wireless) of the access network has increased. This laid the basis for a new trend in technology, that is, fixed mobile network convergence [34].

Several aspects have been considered for the internetworking of fixed and mobile network architectures, but mainly the standardization bodies have focused on the following:

- Convergence of business needs and services
- Convergence of network technologies and infrastructure
- Convergence of end user devices and management

The broadband forum has produced a technical report considering all the challenges and aspects of the internetworking of fixed and mobile networks [35]. The main aim is to provide a converged network architecture that will support the provision of any service, anywhere to anyone regardless of type of the access network.

For the convergence of network technologies and infrastructure, one of the emerging solutions is the use of fibre wireless (FiWi) networks. Wired networks based on fibre optics are considered as having potential to deliver huge bandwidth to the end users; however, the technology has limitations in terms of supporting end user roaming requirements. While the networks using wireless-access technologies are supporting easy roaming and mobility, they are not supporting high-bandwidth and long-distance solutions. Fibre wireless (FiWi) has introduced to the best features of both wired-fibre networks and wireless-access networks [36]. FiWi technology allows to use wireless technologies for access, while the rest of the network is mainly fibre.

A conceptual view of the fixed mobile convergence is illustrated in **Figure 2**.

The above-illustrated conceptual view incorporates various technologies which support high-bandwidth requirements with mobility. Such technologies include access networks using mm-wave and radio-over-fibre (RoF), micro−/millimetre wave-based relay and RoF and digital baseband-based core/backhaul networks. Another important aspect included in the above conceptual view is the support of cloud computing. More details on cloud computing and virtualization support are provided in the following section.

3.6. Cloud computing and virtualization support

To keep pace with the increasing demands of the applications over the network, service providers have started to embrace cloud computing. Cloud computing has given freedom to the service providers which enabled them to serve the user requests with the use of virtualization services in a cost-effective and time-saving manner. Virtualization enabled them to achieve ubiquitous and on-demand access to network services.

Cloud computing is one of the vital parts of the multiservice broadband architecture. Virtualization services have been added in the said architecture in many ways; however, one of the popular techniques is to incorporate virtual services as one of the network functions [17]. Virtualization services should be providing the following features:

- The resources are accessible immediately as per the request, and the allocation can be terminated when the job is done.
- The resources should be available whenever requested, that is, resource scarcity should not occur.

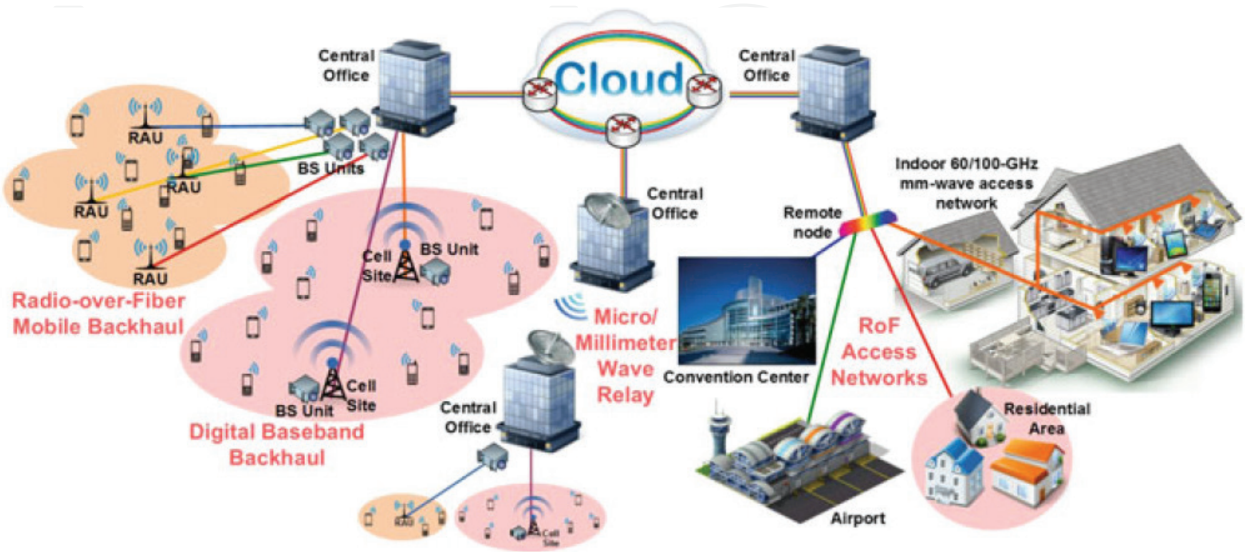

Figure 2. Conceptual view of fixed mobile convergence [36].

- Supports resource scalability according to the demand.
- Ubiquitous access of resources is provided.
- Resources are provided using a single infrastructure for multiple users.
- Accountability of resources usage is done, and customer is billed accordingly.

A number of frameworks have been proposed to fulfill the virtualization of service requirements. These cloud services have taken communication networks towards an entire new dimension. Currently, researchers have stated working towards a multi-access edge computing (MEC) platform. The MEC aims to converge services from IT and telecommunications and provide these at the edge of a radio network, that is, access layer. It also proposes to use cloud computing to provide an efficient access to requested services [37–39]. Another key tool used to achieve the said virtualization is network function virtualization (NFV) [40]. This is considered as an embedded part of the network, which ensures tight integration among various network nodes in order to provide a better communication service.

Cloudlets [41] are also introduced to address the challenge of quick response between the mobile devices and the associated cloud. Cloudlets are there to support the applications with high user interaction and require real-time responses. Cloudlets are small-scale cloud-based data centres which are located towards the edge of Internet to provide quick responses to mobile user requests. One of the other candidate technologies for supporting virtualization is fog computing [42]. It is considered as the combination of edge and cloud computing.

4. Application-driven network evolution

The evolution of multiservice broadband networks was not only led by the advancement in technology; another rather important factor was the “Applications”. Applications are what the end users’ experience, and network architectures have to enhance their offerings to provide end users with the flawless experience they are looking for. The following are some of the application trends, which contributed to network architecture advancements:

- IP television supporting through broadcasting
- Video on demand (VoD)
- Internet TV
- Video playing functions: play, pause, rewind, forward, etc.
- Distant learning
- Advertising: embedded inside the video
- Internet-based business-supported applications including HTTPS, Email, FTP and VPNs
- Gaming: multiplayer Internet-based gaming
- High-definition TV
- IP telephony, etc.

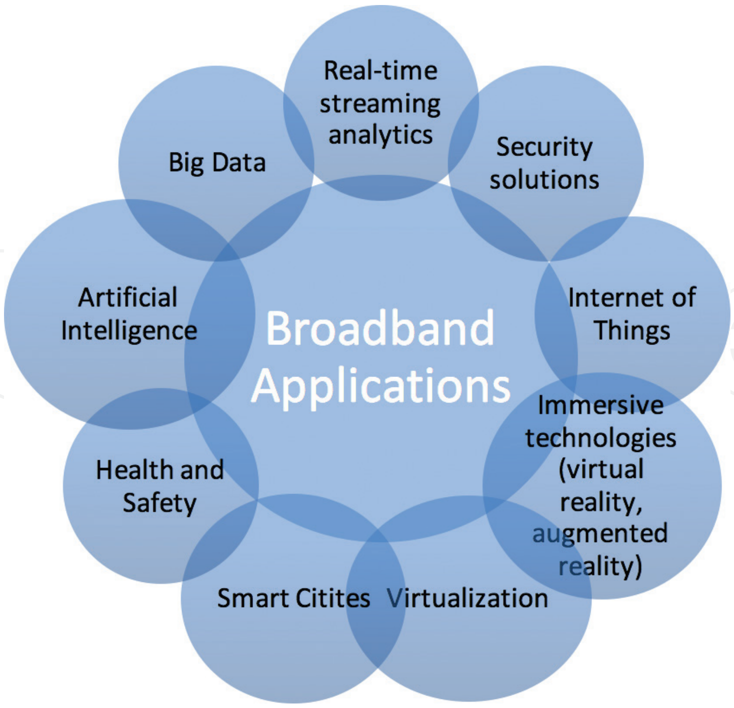

Figure 3. Future broadband application domains.

4.1. Latest trends in broadband applications

In 2017, the growing demand for broadband communications still persists with the increasing need for mobility, machine-to-machine communications, big data, all-purpose sensors and the Internet of things (IoT) [43].

The need for hybrid networks (fiber and wireless) is growing to address the challenging goals of upcoming application domains. The latest application domains for broadband networks are highlighted in **Figure 3**. With the ongoing growth of broadband users for both business and residential [44] in conjunction with increasing demands for large volumes of data, the applications are getting more and more data hungry.

5. Broadband network: a New Zealand perspective

New Zealand has taken a number of steps to embrace the fibre broadband in previous years. Some major initiatives are the Ultra-Fast Broadband (UFB), Rural Broadband Initiative (RBI) and Mobile Black Spot Fund (MBSF) [45].

5.1. Ultra-fast broadband (UFB)

The UFB project aims to deploy optical fibre cables to provide fibre to the premises (FTTP) to as many New Zealanders as possible. Previously copper lines were laid in the whole country, and they served as the main communication medium. With the advancement in technologies

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and the need for more speed and data (more specifically broadband technologies), the copper has to be replaced by optical fibres. With the UFB New Zealanders will be able to access data and applications at the speed of 1000 Mbits/s approx.

In New Zealand, UFB is considered one of the biggest infrastructure-based projects. Around 85% of the population will have access to fibre to the premises (FTTP) towards the end of 2024 [46]. The NZ government, to make the UFB accessible by as many people as possible, is investing $1.8 billion. **Figure 4** shows the progress of the UFB deployment till June 2017.

5.2. Rural broadband initiative (RBI)

The Ultra-Fast broadband project mainly focuses on the provision of fast Internet services to urban areas. However, there are various rural and coastal areas in the country, which also need access to these fast network connections. To ensure every New Zealander can access and experience the improved Internet access, the NZ government has started another project named Rural Broadband Initiative (RBI). Funds worth 430 million NZD (approx.) has been allocated for this initiative.

The RBI project is divided in multiple phases. The first phase of the RBI project has already been completed by mid-2016. In this phase fast broadband connections are being provided to rural areas using the combination of upgrading existing fixed lines and installing new wireless fixed coverage solutions. **Figure 5** shows the highlights of the improved connectivity in rural areas after the completion of RBI phase 1.

The RBI (phase 2) project aims to provide fast broadband connection to more than 70,000 businesses and households in remote and rural areas. For the second phase, the NZ government is encouraging local network operators to propose some innovative ideas/solutions rather than specifying any particular technology use.

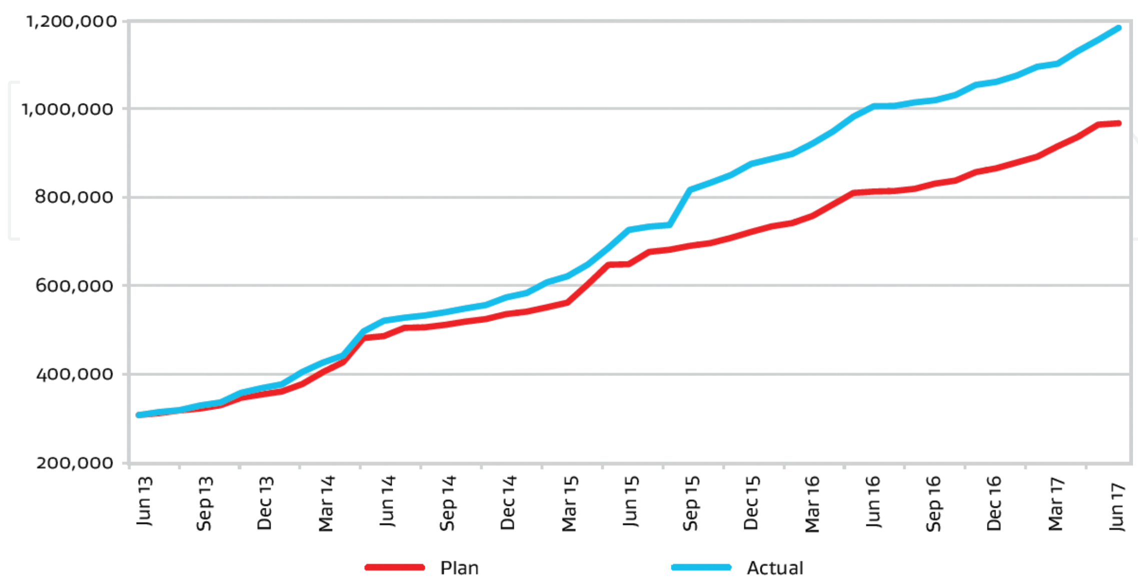

Figure 4. User (business and household) connections, UFB-1 [46].

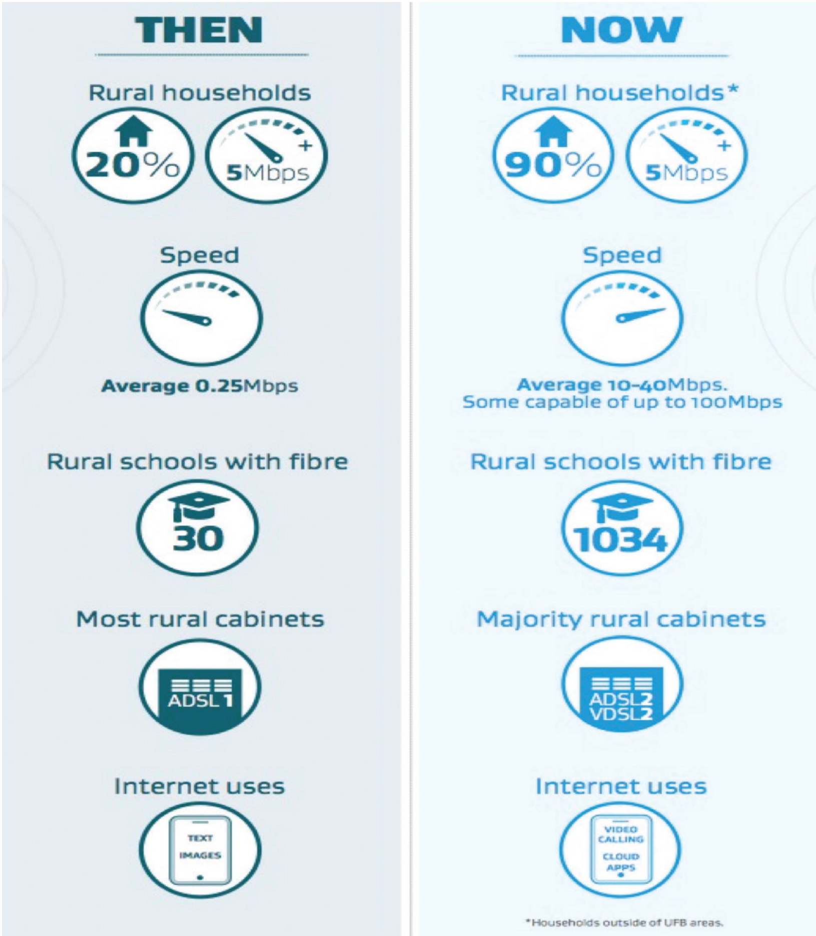

Figure 5. Summary of improved connectivity in rural areas after RBI phase 1 [47].

5.3. Mobile black spot fund (MBSF)

Another important step taken by the NZ government is the creation of MBSF. The purpose of MBSF is to provide improved network coverage to areas which are of tourists' interest and also to better cover the country's state highways. The government is looking forward to achieving improvements in the fields of public safety and in the tourism industry. The project will explicitly target two state highways (6 and 94) in Southland, covering in total of 11 tourism areas [48].

6. Conclusion

This chapter discusses the evolution of broadband communications with a focus on the development and adoption of multiservice broadband network architectures with the support of cloud and virtualization services. The need for this evolution is also discussed with focus on triple play services, IP/MPLS and mobile-fixed network convergence. Applications are also recognized to play a vital role in this evolution of broadband networks with the latest trends

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in broadband applications being discussed. Lastly, an overview of New Zealand's government initiatives to improve the network coverage is also provided including a brief discussion about Ultra-Fast Broadband, the Rural Broadband Initiative and the Mobile Black Spot Fund.

Author details

Sonia Gul* and Jairo Gutierrez

*Address all correspondence to: sonia.gul@aut.ac.nz

Auckland University of Technology, Auckland, New Zealand

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