Hybrid Satellite-Optical Ring Network for Regional Blackspots in Australia's National Broadband Network

Sithamparanathan Kandeepan[1], Chava Vijaya Saradhi[1], Sam Reisenfeld[2], Eryk Dutkiewicz[2], Nicolas Chuberre[3], and Pierre Fraise[3]

[1] CREATE-NET Research Centre, Trento, Italy
kandeepan@ieee.org, saradhi.chava@create-net.org
http://www.create-net.org
[2] Macquarie University, Sydney, Australia
{samr,eryk}@science.mq.edu.au
http://www.mq.edu.au/
[3] Thales Alenia Space, Toulouse Cedex, France
{nicolas.chuberre,pierre.fraise}@thalesaleniaspace.com
http://www.thalesgroup.com/

Abstract. Satellite communications is the most prominent solution for covering remote areas for broadband Internet access where long and expensive cables are not feasible to be deployed. The Australia's National Broadband Network (NBN) initiation 'delivering superfast broadband to Australian homes and workplaces' currently face the problem of deploying long fibres to cover regional blackspots considering the geographic structure of the continent. Considering this we present some preliminary ideas to have hybrid satellite-optical broadband networks specifically covering the regional blackspots in Australia based on ring network topologies. We present topologies for the hybrid network and also architecture for the electronic (RF)-optical interface which enables to connect the fibre optical network to the satellites. Furthermore, topologies for the regional fibre optical networks in the blackspot regions are also presented in this paper.

Keywords: Hybrid satellite optical networks, Australian National broadband network, coverage of regional blackspots, ring topology.

1 Introduction

The Internet in the current era has influenced significantly on the global economic and social aspects. It has been predicted that the Future Internet will play a vital role in every business by connecting millions and millions of people around the globe simultaneously [2]. The Internet traffic is substantially growing at a predicted rate of $50\% - 70\%$ a year and by the year 2012 the IP traffic is expected to be 50 terabits per second. One of the possible solution to address

K. Sithamparanathan et al. (Eds.): PSATS 2010, LNICST 43, pp. 203–217, 2010.

the Future Internet requirements is the enhancement of the existing fibre optic telecommunications backbone and infrastructure. Fibre optic communications provide very high speed communications at the expense of cost per cable length and maintenance, and is also unfeasible to be deployed depending on the terrain structure such as mountains etc. This restricts the high speed network coverage for the Future Internet using the fibre optical infrastructure for the extended geographic region.

The telecommunications infrastructure convergence is therefore necessary to cater the demand of Future Internet, and to provide seamless connectivity and services to the users. Extending the geographic coverage is one of the key aspects of Future Internet, and it is a well known that satellite communications provide such extended coverage. With the rapid development of the ground based wired telecommunications infrastructure for global connectivity, mainly the optical fibre communication backbone that has an extensively increasing cost factor associated with the coverage region, it is essential to consider hybrid systems such as satellite-optical hybrid system to deliver extended coverage. The fixed-cost versus benefit (profit) trade-off for deploying long haul fibre optical links to cover regional areas to provide broadband services does not attract any investors and service providers, or in other words it does not seem sensible to have a house built and maintained with a hundred rooms to accommodate five people. Therefore, hybrid satellite-optical systems are considered to provide extended broadband coverage which we consider in this paper.

Here we consider a particular case study for the deployment of the hybrid satellite-optical network, namely in Australia. The Australian government's initiative for a National Broadband Network (NBN) [1] to provide broadband Internet services to every home and business in Australia by 2014 has the potential need to address all the issues discussed above. In particularly, the Australian government has identified the regional blackspots for the broadband network coverage where lengthy expensive cables are not feasible to be deployed to cover the regions. Several stake holders have been invited to present their ideas and proposals for network coverage to the regional blackspots and some of them are listed in [5]-[8].

In the literature the term optical satellite systems mainly refer to free space optics and inter satellite optical links. However, the research literature associated with this topic 'hybrid satellite-optical systems' is not at all rich, and on the other hand closely related patents exist in this field, which are given in [3], [4].

In this paper though we present some preliminary ideas considering the hybrid satellite-optical networks for satisfying the requirements for the Australian NBN to cover the regional blackspots. In particularly, we identify the existing satellite services and their related coverage areas and footprints across Australia which could potentially be used for regional broadband access, and associate them with the existing fibre optic backbone infrastructure in Australia. We present two hybrid satellite-optical ring network topologies for the NBN. We also present the optical to electronic (RF) and the electronic (RF) to optical conversions for the on ground optical-satellite uplink station and the satellite-optical downlink station transceiver architectures. It should be noted here that, because of the limited capacity of the satellite transmissions, we are not making proposals in this paper to directly compete with the optical and/or wireless systems which could provide services (if feasible) to the blackspots regions potentially with greater capacity. We mainly consider such satellite-optical systems where satellite is chosen to be the best option. There is also a major role for satellite communications in rural areas outside the major cities in Australia. In these regions, the dwellings are reasonably far apart, but there are still considerable regional population densities. Examples of these regions are the North Coastal and the South Coastal regions which are adjacent to Sydney. In these regions, fibre optical communications is not a commercially desirable option and terrestrial radio communications is not viable because of blockage from hills and because a large numbers of users are located in valleys. The total traffic from these regions is likely to exceed the traffic for the large land, but very small population density, areas in Australia. An additional major role for satellite communications is emergency and disaster communications services in which connectivity could be provided for the major cities in the event of a catastrophic outage of the fibre optical backbone. This is an extremely desirable feature in a national broadband network.

The rest of the paper is organized as follows. In Section 2 we briefly present the Australian NBN and the regional blackspots, in Section 3 we present the existing commercial satellites for coverage in Australia. The hybrid satellite-terrestrial networks based on the ring architecture are presented in Section 4, and the regional optical network with satellite access is presented in Section 5. In Section 6 we present the satellite-optical interface architecture, and finally in we provide some concluding remarks in Section Section 7.

2 Australia's National Broadband Network Initiative and Responses

The Australian government's initiative on the construction of a National Broadband Network (NBN) worth of 42 billion$ Australian over the next eight years has attracted many stakeholders in and around the region [1]. In particularly, the NBN had called for proposals to provide telecommunications backbone extension to the regional blackspots such as Darwin, Broken Hill, Emerald, Geraldton, Long Reach and many more areas as depicted in Figure-1. These blackspot regions are geographically situated further from the nearest metropolitan telecommunication hubs which then require cost effective extensions of the backbone to provide broadband communications. The all possible solutions to extend the backbone to the blackspot regions, which are 1) Extending the fibre-optic network, 2) Providing long range high speed wireless communications, and 3) Providing access with satellite coverage, have their own advantages and disadvantages associated with them. In this section we briefly describe the blackspots and also highlight some of the proposals made by leading stakeholders addressing solutions to the regional blackspots program.

Fig. 1. Australia's Regional Blackspots for the National Broadband Network

2.1 The Regional Blackspots

The identified regional blackspots in Australia for the NBN project are not only situated further from the metropolitan areas but also have very low population densities compared to the other cities. These two facts make a challenging task for the telecommunications service providers to provide a cost effective (lossless) services to the regions. Though the cities such as Darwin, Geraldton, Broken Hill etc. are considered as the regional blackspots for the NBN development there exist a fibre optic ring network covering some of the areas such as Darwin and Alice Springs. In some places (east coast and south-west) there are also additional inland fibre connections between major cities such as Brisbane, Sydney, Melbourne, Adelaide, Perth. There are also several satellite stations connected to the fibre network well outside of major cities rather than in major cities. The Greatest "need" for satellite coverage in Australia is mainly on the east coast in the valleys along the Gold Coast, Central Coast areas. These areas are reasonably densely populated but are not economical for fibre or even wireless coverage and are also prone to a reasonable amount of rain. The above considerations are useful in determining the configurations for the hybrid backbone network considered in our paper.

2.2 The Stakeholders' Proposals

In this section we sumarrize some of the proposals made to the regional blackspot program published by the Australian Department of Broadband, Communications and Digital Economy [1].

Alcatel-Lucent-Australia: The Alcatel Lucent Australia proposes to provide broadband network solutions to the blackspots by identifying two types of backhaul systems "aggregation backhaul fibre" and "access seeker backhaul fibre" [5].

They also seek wireless solutions for the less densely populated regions, hence proposing combination of fibre and wireless solutions.

Telstra: The Australian telecommunications giant Telstra proposes to extend its fibre backbone infrastructure further to provide broadband to the regional blackspots and points out some fundamental economic issues related to pricing [6]. Telstra also proposes low data rate wireless access for low population areas.

Vodaphone: Vodafone emphasizes on the fair pricing for the blackspot regions and the metropolitan regions, and favors the dark fibre backhaul access to be made available to an aggregation point (regional centres) [7] as a solution to the Australian NBN for the blackspot regions.

Huawei: HUAWEI proposes a Single Ethernet, Multi-Play service architecture for the regional blackspots, which is a single IP/MPLS Metro Ethernet Network powered by a single platform providing Fixed Mobile Convergence multi-play services under a single Network Management System [8] for the NBN.

3 Satellite Coverage for Australia

The Australian region is extensively covered by several commercial satellites delivering communications and broadcasting services. The state of the art satellite high speed communications are based on the Ka-band and the Ku-band frequency ranges providing larger bandwidths to accommodate higher data rates. The power limitation (received power) however is the major factor limiting the capacity of such links due to the enormous path loss encountered by the transmitted signals because of the larger distances between the satellites and the ground stations. The rain fading conditions will also add to the path loss degrading the performance of the satellite links further. Though the number Ku-band satellites for commercial services covering the globe is quite large, the Ka-band on the other hand which could potentially provide greater capacity is only at its preliminary stages of deployment. One of such Ka-band commercial satellites to be launched in 2010 is the Eutelsat's Ka-Sat to be delivered by EADS/Astrium [9]. On the other hand, a few test satellites and defense satellites have already been launched having the Ka-band communications payload. The Australian built and owned micro-satellite Federation Satellite-1 (FedSat) operating in the near polar low earth orbit (LEO) is an example of such a test satellite having the Ka-band payload launched in 2003 [10], another example is the Japanese WINDS satellite that reaches greater speeds in communications using the Ka-band frequencies [11].

Some of the commercial satellites operating in the Ku-band covering the Australian region capable of providing broadband links are listed in Figure-2. The Optus C1, B3, D1, D2 and D3 satellites have $24, 15, 24, 24$ and 32 Ku-band transponders respectively operating in the non-regenerative bent pipe mode. The NSS-12 satellite on the other hand has 48 Ku-band transponders. The effective isotropically radiated power (EIRP) coverage map and the corresponding G/T requirements at the ground stations for the Optus-D1 satellite are depicted

Satellite	Band	Position	Number of Transponders
Optus C1 (Australia)	Ku	156°E	24
Optus B3 (Australia)	Ku	164°E	15
Optus D1 (Australia)	Ku	160°E	24
OptusD2 (Australia)	Ku	152°E	24
Optus D3 (Australia)	Ku	156°E	32
AsiaSat 3S (Hong Kong)	C Ku	105.5°E	28 (C band) 16 (Ku band)
AsiaSat 4 (Hong Kong)	C Ku	122°E	28 (C band) 20 (Ku band)
AsiaSat 5 (Hong Kong)	C Ku	100.5° E	26 (C band) 14 Ku band
Thaicom 4 (IPStar) (Thailand)	C Ku	78.5°E	47 (C band) 20 (Ku band)
NSS-12 (France)	C Ku	57°E	40 (C band) 48 (Ku band) (C/Ku cross-strapping)

Fig. 2. Satellite coverage in the Australian region

in Figure-3 and Figure-4 respectively. Depending on the EIRP and the G/T values the satellite could provide (with the current standards) up to a few hundreds of Mbps of capacity. Furthermore, apart from the satellites mentioned in the table in Figure-2, there is also an experimental satellite WINDS (Japan) operating in the Ka band at a position of 143°E with link capacities of Uplink: $1.56, 24, 51, 155$ Mbps and Downlink: 155 Mbps in the regenerative mode, and $155, 622, 1244$ Mbps in the Non-regenerative Mode, giving very high throughput compared to the currently existing satellite links.

Apart from the main issue of the limitation in the throughput of the current geostationary satellites compared to the NBN needs another issue is the latency due to the distance of geostationary satellites (500 ms or more round trip delay). Considering this a possible solution would be a MEO constellation. The O3b network solution based on the MEO constellation has a higher throughput than regular Geostationary satellites and a lower latency (around 140 ms round trip delay) due to the difference in the altitude [12].

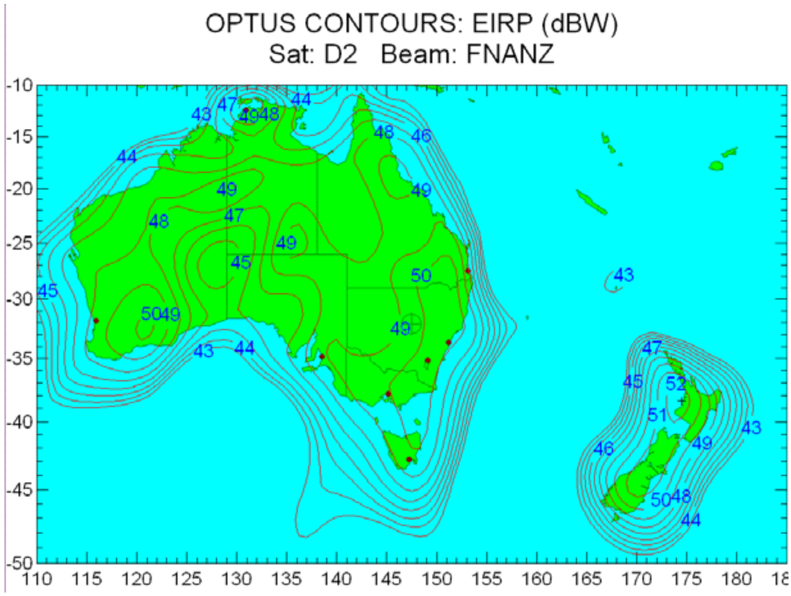

Fig. 3. The Optus D1 satellite coverage across Australia, transmitted EIRP dBw, reference

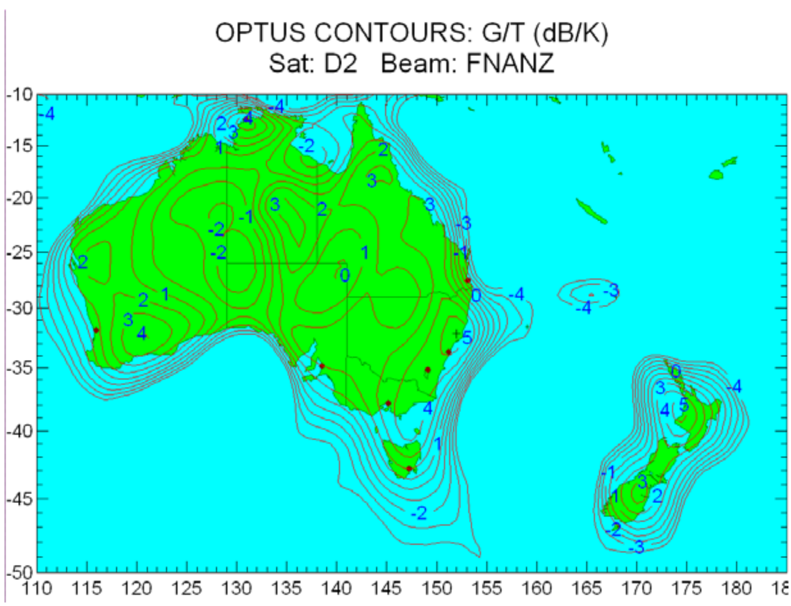

Fig. 4. The Optus D1 satellite coverage across Australia, G/T in dB/K

Based on the capacities of the satellites and the regional requirements (number of users in the region etc.), one or several satellites can be connected to the Australian NBN backbone in order to provide broadband access to the blackspot regions. The satellite connects to the NBN backbone and extends the coverage further by providing services to the blackspot regions. In the following sections we provide some networking topologies for the satellites to connect to the fibre optic backbone giving a hybrid satellite-optical network.

4 Hybrid Backbone Network

The proposed hybrid satellite-optical network architecture based on ring topologies are presented in this section. We provide two types of topologies based on 1) single satellite, and 2) two satellites, as we explain subsequently. The general idea behind the hybrid backbone network is presented in Figure-5, in the figure we provide an example for covering Darwin one of the regional blackspots in Australia and the eastern coastal areas. The proposed technology based on satellites, as mentioned in Section 1, is however considered well suited where its counterparts such as fibre and wireless technologies are not feasible to be deployed based on the terrain structure (hills and mountains) and the distance from the metropolitan cities.

As shown in the Figure-5, the satellites connect to the metropolitan fibre hub by means of one/multiple satellite link(s) which has an optical-electronic hybrid interface in the ground station to provide high speed communications. The optical-electronic interface, which is further explained in Section 6, provides the conversion from the optical signals to the electronic signals suitable for uplink satellite transmissions and vice versa in the downlink. In our proposal we also provide an optical-electronic interface for possible optical inter satellite links considering future developments.

4.1 The Ring Topology - 1

The first ring topology is formed with a single satellite connected to the broadband backbone network on ground as depicted in Figure-6 covering the regional blackspot. We provide an example of using the Optus-D1 satellite connected to the fibre backbone hub in the metropolitan cities Perth and Brisbane forming a ring network. The backbone hub connecting the satellites as shown in the figure can be connected to any cities that has the capabilities to do so, it would be desirable to have the satellite connected to a hub outside the metropolitan area which would have less traffic passing through the hub. The regional blackspot areas in the east coastal valleys will access the high speed backbone national broadband network via the satellite Optus-D1.

We choose a ring architecture here because the ring topology in general will have higher reliability and the possibility for better load distribution. It is important to have intelligent traffic routing or splitting to avoid bottle necks especially on the satellite links.

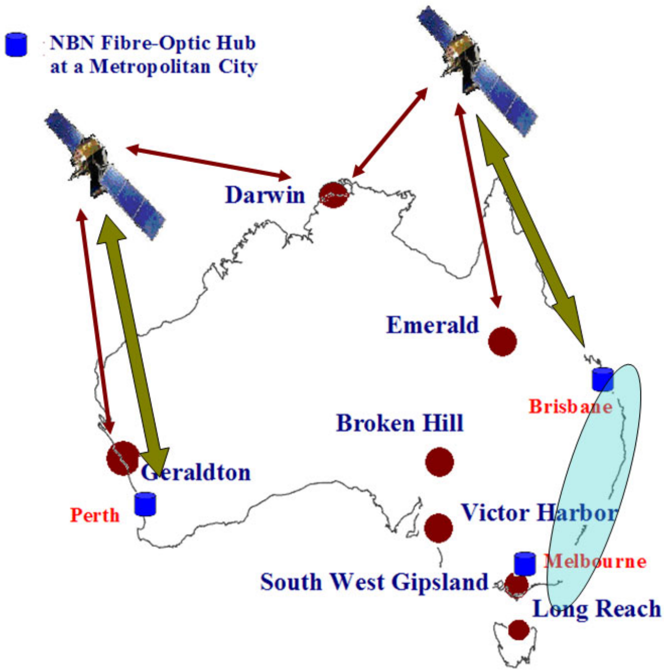

Fig. 5. Part of the Hybrid Satellite-Optical Network for providing broadband access to Australia's Regional Blackspots through the National Broadband Network

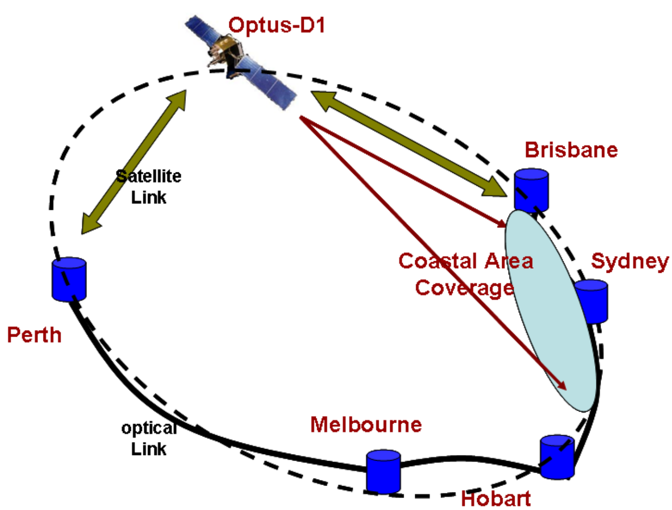

Fig. 6. An example of Ring topology-1 for the Australian NBN, considering AsiaSat4 and covering the blackspot region Darwin

4.2 The Ring Topology - 2

The second topology is formed with two satellites connected to the NBN backbone as depicted in Figure-7. This architecture forms several rings with the fibre optic backbone hubs in the metropolitan cities. We provide an example considering two satellites connecting to the fibre backbone hubs in the metropolitan or outer cities. In our proposal we also provide an inter satellite link which is considered for future systems. For the system without the inter satellite links two satellites are able to form multiple ring topologies as depicted in Figure-8. Furthermore, another ring topology is also possible in addition to the

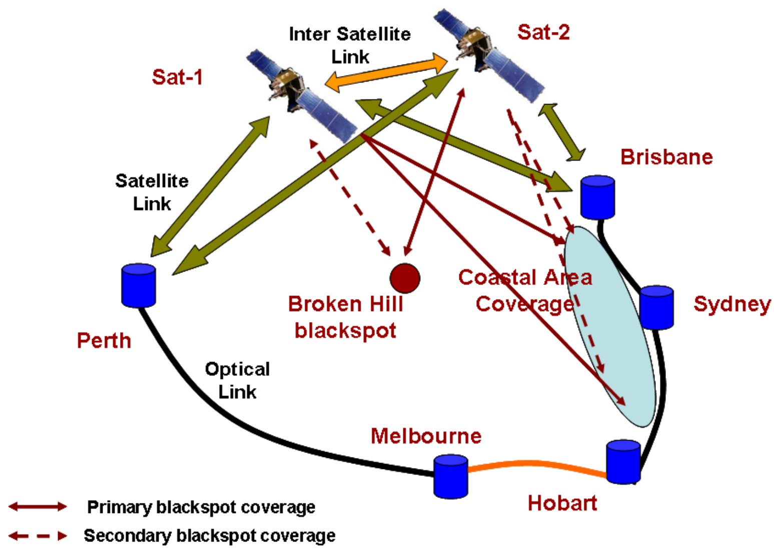

Fig. 7. Examples of Ring topologies for the Australian NBN, considering two satellites covering the blackspot regions Darwin and Broken Hill, where the inter satellite links are futuristic proposals

Ring Topologies with two satellites	Topology
Ring-1 (Futuristic)	Sydney – Brisbane – Sat1 – Sat2 – Perth – Melbourne – Hobart – Sydney
Ring-2	Sydney – Brisbane – Sat1 – Perth – Melbourne – Hobart – Sydney
Ring-3	Sydney – Brisbane – Sat2 – Perth – Melbourne – Hobart – Sydney

Fig. 8. Table showing different logical ring topologies with two satellites for the Australian NBN requirements to cover regional blackspots , of Figure-6

ones shown in Figure-8, which is given by: Brisbane-Sydney-Hobart-Melbourne-Perth-Sat1-East Coast-Sat2-Brisbane. In this topology (the latter one), the regional blackspot also becomes part of the ring connecting through the two satellites. The multiple-ring configurations, such as in Figure-7, provide more capacity and reliability at the cost of higher complexity on satellites (for inter-satellite traffic) and at ground station (for directing the traffic towards appropriate satellites according to load demands).

5 The Regional Optical Network

Based on the blackspot geographical size and population density, the regional network architecture could be a single metro ring connecting the satellite earth station and several other metro access nodes. This in turn could feed a passive optical network or two level architecture with one inner metro ring and one outer metro ring to provide connectivity to the whole region. The fibre-based access network that we consider here however, connected to the satellite gateway, can be considered unnecessary due to the limited satellite capacity when compared to the fibre access network. But we consider the deployment of such regional optical network assuming future expansions of satellite link capacities and/or future deployment of high speed access networks replacing the satellite links to these regions. An alternate option is to have ADSL for the access network which is quite sufficient to match the capacity of the satellite link.

In this paper we present an example with single metro ring network connecting several access points. There are several possible alternatives of passive optical networks available. The selection of suitable architecture for each of the blackspots again depends on the population, population density, and demand for the bandwidth. In this paper we will present an example with generic passive optical network and call it as FTTx (e.g., FTTH, FTTB, FTTC, FTTP, etc.), however it can be changed to EPON, GPON, WDM PON, etc.

5.1 Fibre to the Premises

Figure-9 shows the interface between the satellite earth station and regional optical network. The earth station antenna's are used for either for transmitting user data from the regional network such as metro ring network or FTTx to satellite or to receive the signals from satellite and send it to FTTx user. In the Figure-9 the earth station antennas are directly connected to optical ine terminal (OLT) which feeds the regional FTTx network. However, in actual deployment OLT can be placed at one of the nodes in the regional metro ring network and the earth station can be connected to the metro ring network through appropriate interfaces at some other node on the ring network. The splitter is a passive optical element which splits the optical signals and is connected to a number of optical network units (ONUs). Depending on the configuration of FTTX, ONUs can be placed at home or business or appartment to serve the end users. The architecture shown also supports existing xDSL and cable modem operators,

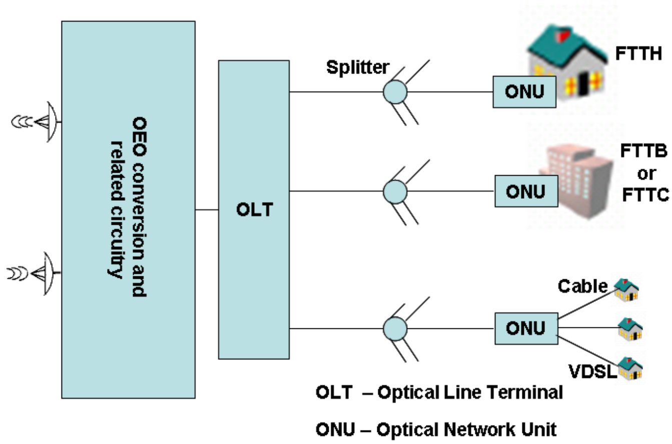

Fig. 9. Example of fiber to the premises regional network

which are fed by ONUs. The OEO conversion and related circuitry is required to convert RF signals that are received from earth station receiver and to route them appropriate end user(s).

6 The Optical Satellite Interface Architecture

The optical satellite and the satellite optical interfaces are used where ever the a conversion of signals from optical to electronic or electronic to optical respectively are required. The interfaces will lie in the optical hub on the ground for uplink and down link satellite communications. The optical to electronic conversion and the electronic to optical conversion are performed at the base band of the RF communications chain. We also propose a similar optical to electronic interface for an optical inter satellite link connecting two satellites considering future commercial systems. It is important to point out that such optical inter satellite links require on board satellite processing which is not available in many commercial satellites that are currently available.

6.1 Optical Part

The optical hardware that interfaces with the electronic part of the hybrid satellite-optical network is shown in Figure-10. The in/out fiber cables are connected to some optical nodes in the fiber network. The signal from the out/in fiber cables are received, amplified and demultiplexed at the fibre hub node. Then the optical signals (wavelengths) that are meant for local use are dropped using the drop module and the rest are converted to the electronic domain and routed to the satellite using the electronic circuitry and lookup tables. The look up tables can be implemented in the network layer, and the treatment of such

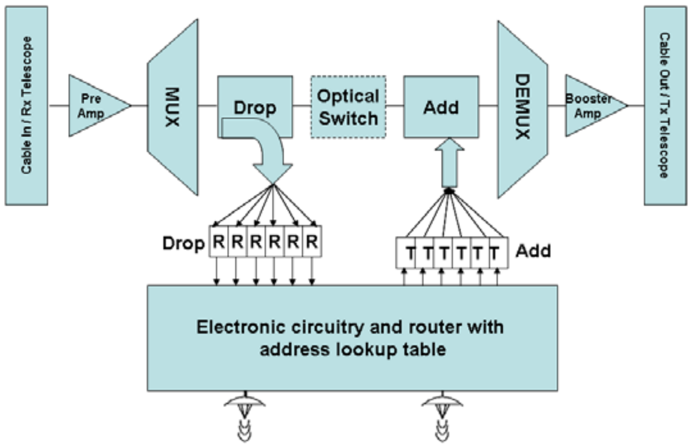

Fig. 10. An example of the optical-satellite hardware interface, for the optical to electronic and electronic to optical signal conversions

are beyond the scope of this paper. For the optical inter satellite link part the in/out cable interfaces are replaced with optical telescopes on board the satellite as shown in the figure. The optical signals received from the telescopes that are meant for relay to other satellite will be switched in optical domain and combined with local signals that are added in the add module. The local signals that are received from earth station are converted into electronic domain and routed to appropriate optical interfaces using lookup tables and then will be added in the add module with the pass through optical signals that are meant for relay. All combined optical signals are multiplexed and then amplified before transmitting through inter-satellite link to other satellite. The electronic circuitry contains the lookup tables and the modules that are necessary to convert the electronic signals into RF signals as described in the subsequent section.

6.2 Electronic Part

The electronic and the radio fr5equency (RF) hardware part to interface with the fibre optic part of the hybrid system is presented in this section. Figure-11 depicts the block diagram of such an interface unit to the optical system. In the receiver chain of the satellite RF link, the received signal is down converted to the base band with an inter mediate frequency (IF) stage and the corresponding electronic signal is passed to the electronic-optical interface for optical conversion. In the transmitter chain of the satellite RF link the optical signals are converted to electronic signals and then up converted to the corresponding frequency band (such as Ka or Ku) before transmitting it using the antenna. The base band processing unit's operation in the electronic circuitry can be specified as to what level the signals (data) are recovered before changing it to the optical signals. It is also possible to deploy a complete processing at the baseband and recovering

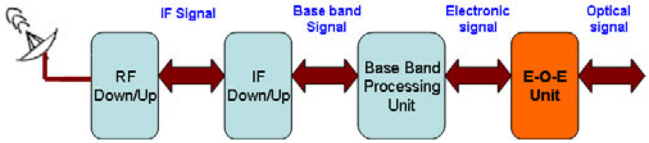

Fig. 11. The RF and electronic part of the hybrid satellite optical system interface, interface to teh optical system

the data before mapping it to the optical domain in which case the system acts as a repeater/regenerator and the O-E-O unit is simply the satellite and optical transceiver units on either sides. It is also possible to use buffers to store data to match the data rates between the optical link to satellite link.

7 Conclusion

In this paper we present the concept of hybrid satellite-optical networks for extending the coverage of the communications backbone. We present a case study on the Australian National Broadband Network requirements for providing broadband access to the regional blackspots. We present some network topologies based on the ring architecture for the hybrid satellite-optical system. We also present the interface architecture for the optical to electronic and electronic optical signal conversions that is required at the optical hubs. Furthermore, regional fibre based (FTTx) network architectures are also presented for regional network coverage on ground. It is also presented that hybrid satellite-optical network is the feasible solution for providing broadband to the regional areas in Australia such as in the valleys along the east coast.

References

1. The Australian National Broadband Network Inititation - Department of Broadband, Communications and Digital Economy, Australia, http://www.dbcde.gov.au/funding_and_programs/national_broadband_network
2. Proceedings of the Future of the Internet conference : European Commission, Solvenia (March 31, 2008)
3. United States Patent: US 6,912,075 B1, by Stanislav I, et. al, The DITECTV Group Inc, Ring Architecture for an Optical Satellite Communications Network With Passive Optical Routing (June 28, 2005)
4. United States Patent: US 7,373,085 B2, by john T. Austin, The DITECTV Group Inc., Hybrid Satellite Fibre Communications Systems May 13 (2008)
5. Response to the Call for Regional Backbone Blackspots Program Submissions for the National Broadband Network in Australia, 'Backhaul Blackspots Initiative Stakeholder Consultation Paper', Alcatel-Lucent-Australia, Published by Department of Broadband, Communications and Digital Economy, Australia (May 12, 2009)

6. Response to the Call for Regional Backbone Blackspots Program Submissions for the National Broadband Network in Australia, 'Telstra Response Backhaul Blackspots Initiative Stakeholder Consultation Paper', Telstra - Australia, Published by Department of Broadband, Communications and Digital Economy, Australia (May 2009)
7. Response to the Call for Regional Backbone Blackspots Program Submissions for the National Broadband Network in Australia, 'Backhaul Blackspots Initiative: Stakeholder Consultation Paper', Vodafone - Australia, 15 May-2009, Published by Department of Broadband, Communications and Digital Economy, Australia
8. Response to the Call for Regional Backbone Blackspots Program Submissions for the National Broadband Network in Australia, 'Backhaul Architecture Discussions for Australia NBN Network', Huwei, Published by Department of Broadband, Communications and Digital Economy, Australia (May 2009)
9. Eutelasat Communications, `http://www.eutelsat.com/satellites/upcoming-launches.html`
10. CRC for Satellite Systems, Federation Satellite-1, `http://www.crcss.csiro.au/`
11. Japanese Aerospace and Exploration Agency, WINDS Satellite, `http://www.jaxa.jp/pr/brochure/pdf/04/sat07.pdf`
12. O3b Netrworks, `http://www.o3bnetworks.com/advantage.html`