PPC-1 Sydney-Guam PIPE Pacific Cable: New Internet Gateway for PNG via Madang

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Abstract

PPC-1 Sydney Guam PIPE Pacific Cable (PPC1) provides a third Internet gateway for Australia. A branching unit to Madang will be an initial connection for PNG to connect to the Internet via this pathway. The PPC-1 undersea submarine cable which runs from Guam to Sydney provides a third high speed international gateway to Australia. A branching unit to Madang will be an initial connection for PNG providing a total bandwidth capacity of 10Gbps enabling high speed telecommunication traffic within PNG and also between PNG and the world. This paper presents the technical characteristics of the PPC-1 including the earlier submarine cable facilities.

Key words: submarine cable**,** fiber optic, attenuation, signal amplification, dense wave division multiplexing (DWDM), optical add/drop multiplexing (OADM), branching unit.

Introduction

The evolving digital revolution is making a seemingly insatiable demand on bandwidth[1]. Simultaneous paradigm shifts in telecommunications technology leading to enormous growth of transmission and switching capacity make more digital services available which further fuels the demand for bandwidth.

Well known digital online services which drive demands on bandwidth include instant messaging (email) and Web access with file downloads, online shopping or electronic commerce (e.g. purchasing from Amazon.com), Internet banking and video conferencing[2]. Emerging bandwidth demanding services include movie and video downloads, real time audio and video streaming, video on demand, free long distance telephone calls (VOIP[3]), digital TV, and social networking sites such as Face Book, Twitter and Youtube which provides low definition TV. The increasing availability of online data services[4] via ubiquitous mobile cellular phones necessitates further demand for bandwidth.

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[1] Here we refer to data bandwidth which is a measure of data throughput in bits per second (bps) commonly experienced as speed of access to online services.

[2] Other drivers of bandwidth of a less satisfactory nature when considering national development include online gambling, interactive games and pornography.

[3] Voice over Internet Protocol (VOIP) carries digitised voice traffic over the Internet mesh network as IP packets at only the cost of access to an ISP.

[4] Media convergence whereby voice, video and data are accessed via a single medium

New transmission technologies both enable these services and also promote emerging and more bandwidth demanding services. These voice, video and data services have a global reach blurring national boundaries and requiring intercontinental connectivity via terrestrial (microwave over unguided media), satellite, and submarine cables (infra-red, IR, over single mode optical fibers)[5].

This global growth in demand for voice, video and data necessarily requires higher bandwidths which conventional Radio based transmission systems can only support to a limited extent. Higher bandwidths also mean higher speeds. Both radio and satellite based transmission schemes are characterized by bandwidth limitations, free space and distance attenuation[6] which results in delays and latency issues rendering them unsuitable for high speed traffic. To overcome the disadvantages of radio and satellite based transmission systems, the global trend to accommodate for high speed video and data traffic is the use of optical fiber systems. Optical fiber systems work by transforming the signal to light rather than to electric wave as in radio and satellite schemes. The advantage gained is higher bandwidth supporting faster speeds, less attenuation and longer distances travelled by the signal.

This paper outlines significant elements of the construction of a new submarine fiber-optic cable: PIPE Pacific Cable-1 (PPC-1) which is expected to provide high bandwidth capacity between Sydney and Guam, but with a cable Branching Unit (BU) providing bandwidth to PNG via a Cable Landing Station (CLS) in Madang. The Madang connection has the capacity (10 Gbps) to provide PNG with greatly increased access to services such as those listed above with a view to fostering national development particularly in areas of commerce and mining which are generally perceived to be areas of enormous potential for PNG. PPC-1 increases capacity from that provided by earlier and continuing intercontinental cables available to PNG via Australia.

Previous and existing submarine cables

PNG and Australia are both geographically isolated island nations dependent on undersea cables[7] for quality and reliable international telecommunications. An outline history of PNG-Australia telecommunications (Table 1) shows the reliance PNG has had on its connection to Australian telecommunications services for its connection to the rest of the world for most of the 20th century.

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[5] Traditional Radio Frequency (RF) carriers (AM, FM Radio, shortwave, TV) occupy a ~300 MHz frequency bandwidth, microwave communication a ~ 1000 GHz bandwidth, and Infra red a ~200 THz. Increasing frequency bandwidth means increasing data bandwidth here seen to be progressively increasing on each level by several orders of magnitude.

[6] Attenuation or signal loss can result from absorption by atmospheric gas molecules particularly H_2O in unguided media and trace levels of OH- and metal impurities. Transmission bands are identified as frequency bands with low absorption.

[7] Whilst communication satellites are available, inherent time delays (latency) and atmospheric attenuation are features which are not optimal for voice communication.

Australia already has reliable global connectivity via two submarine cables, the Australia Japan Cable (AJC) and the Southern Cross Cable (SX) which provide voice, video and data bandwidth to telecommunication carriers and Internet Service Providers (ISP). A third cable, PIPE[8] Pacific Cable (PPC-1), the subject of this paper, has recently been completed to provide further bandwidth and competition between infrastructure providers which is expected to force down bandwidth costing for Australian consumers.

Of special interest to PNG, and Madang in particular, is a branching unit in PPC-1 which will provide bandwidth (10 Gbps to each of Sydney and Guam) to PNG via a Branching Unit (BU).

Cable System	SEACOM	APNG-1[9]	APNG-2	PPC-1[10]
Type	Analogue submarine cable telephone circuits	Analogue coaxial cable	Fiber optic cable -reused PacRim West cable originally linking Australia, Guam and Japan.	DWDM or fiber optic cable linking Sydney / Guam with branching unit to Madang
Capacity	Sydney-Guam 160 two way telephone circuits, and 80 between Guam & Singapore.	480 channels at 5 MHz with data rate = 16 Mb/s	2x565 Mb/s PDH system = 1120 Mb/s = 1.12 Gb/s	1.92Tb/s or 2 fiber pairs, Madang receives 2x10 Gb/s via branching unit which carries 1 Lambda.
Route	Australia and Singapore via Cairns, Madang (1964) & Lae (1968). Madang /Cairns (48 repeaters) Madang / Guam (83 Repeaters)	Cairns / Ela Beach, POM 897km	Ela Beach, POM / Australia 3200km	Sydney / Madang, Madang / Guam, 6900km
Telikom Gateway Traffic		16Mb/s	45 Mb/s	2 * 10 Gbps
Lease Capacity		10Mb/s	1120-1145) Mb/s	

Table 1 Submarine cable systems have been available to PNG Communication networks since 1964 initially with SEACOM and culminating with PPC-1 state of the art Dense Wave Division Multiplexed

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[8] Public Internet Peer Exchange

[9] Information on APNG-1 and APNG-2 was provided by T. Hacker, 2011, PNG Telikom, pers. Com.

[10] PIPE Pacific Cable 1. This was a project of PIPE Networks of Australia. PNG Telikom negotiated the Branching Unit to Madang on Commercial Terms.

> (DWDM) 2 pair fiber cable providing a Branching Unit to Madang. Prior to the submarine cable systems a HF (High Frequency, short wave) radio and telegraph services existed between Port Moresby and Sydney, and Rabaul and Sydney, the PNG-Australia radio telephone service (Sinclair, 1994, p 197). Prior to that again, in 1913 a wireless telegraphy service was established between Port Moresby and Brisbane via Cairns as a matter of urgency pending the outbreak of war with Germany and the presence of a German Protectorate on the north coast of PNG.

The Australian Government's implementation of a National Broadband Network (NBN) by providing broadband via optical fiber to the home (FTTH) will significantly increase demand for international bandwidth, thereby helping to ensure the financial viability of PPC-1. The NBN[11] will deliver 'Super fast broadband for all Australians, at affordable prices with an objective of providing broadband via fibre to 90 percent of premises, and via next-generation wireless and satellite technology for the remaining areas'.

Of particular technical interest to this series are the quantum leaps in technology and available bandwidth as the development proceeds from copper cables (SEACOM and APNG-1) to fiber-optic cable carrying single channels (APNG-2) and then to single fibers carrying multiple channels (PPC-1), with each stage providing significant increases in bandwidth.

Fiber optic long haul cables

A long haul trunk Optical Fiber Network begins and ends with digital electrical signals entering and leaving the fiber optic network (Figure 1).

Electrical data is first converted into optical pulses using Lasers[12] on a particular wavelength (lambda) before entering a multiplexer (MUX) where the separate wavelengths converge onto a single fiber using Dense Wave Division Multiplexing (DWDM). The MUX/DEMUX equipment is housed in the Submarine Line Terminating Equipment (SLTE).

To overcome signal attenuation, Erbium Doped Fiber Amplifiers (EDFA) are periodically inserted in the network at up to 100 km intervals to maintain the desired signal level along the fiber. Whilst these amplifiers require electrical power, via a power line running the full length of the cable there is no need for time consuming optical-electrical-optical conversions in the amplification process.

[11] NBN Implementation Study Complete Report www.dbcde..gov.au Available 21/3/11

[12] A LASER (Light Amplification by the Stimulated Emission of Radiation) from the field of quantum optics is a light source which produces an intense parallel beam of coherent light and is used to produce pulses for transmission over fiber optic cable at precisely defined wavelengths.

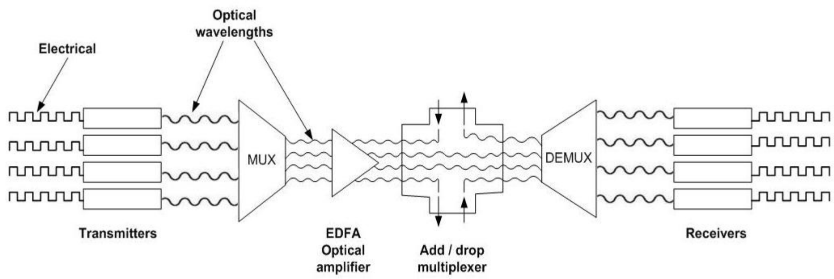

Figure 1[13] shows the main components of a long haul trunk Optical Fiber Network. At either end there will typically be digital electrical signals entering and leaving the fiber optic network. Electrical data is converted into optical pulses on a particular lambda before entering a MUX where the separate wavelengths are multiplexed onto a single fiber using DWDM. Optical amplifiers are periodically inserted in the network. Particular lambdas are added or removed from the main data traffic on the way to spur stations using OADM.

Particular lambdas can be added or removed from the main data traffic on the way to spur stations using Optical Add Drop Multiplexers (OADM).

Signal attenuation

Electrical or electromagnetic wave signals passing through any transmission medium experience decrease in magnitude known as attenuation. In the case of microwave radiation through atmospheric free space or infra-red radiation through optical fiber attenuation is caused by absorption of radiation by resonating atmospheric molecules in free space and electrically charged ions present as impurities[14] in fiber optic cable.

In high bandwidth data communication, high frequency microwaves or infra-red radiation is necessary. The wavelengths of these radiations are of similar orders of magnitude to the sizes of atoms, ions and molecules in guided (copper, fibre) and unguided (free space atmospheric) media. Their frequencies also coincide with the resonant frequencies of these particles. This means that the radiation involved in high speed data transmission will generate resonant vibrations in these particles present as trace impurities and thus suffer attenuation.

[13] Adapted from Sheldon 2001, p 936

[14] Infra-red radiation in fiber cable excites electron transitions in trace amounts of impurity ions such as Ni^{+2}, Cr^{+3}, Fe^{+3}, OH^- (Water peaks in Figure 4), Co^{+2}. Vibration of the Si-OH bond also absorbs signal strength.

The attenuation spectrum for optical fiber[15] (Figure 2) shows bands of low IR absorption for single-mode fiber. These fibers usually operate in the 1310 nm (O band) or 1550 nm (S, G and L bands) regions, where attenuation reaches a minimum.

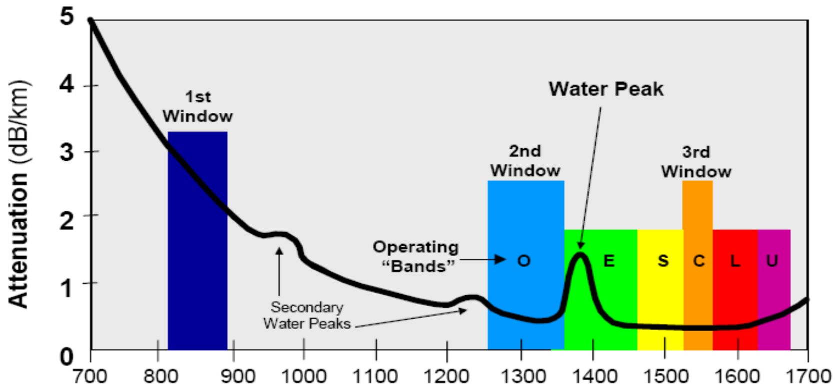

Figure 2 The attenuation spectrum for optical fiber[16] shows bands of low IR absorption for single-mode fiber. These fibers usually operate in the 1310 nm (O band) or 1550 nm (S, G and L bands) regions, where attenuation reaches various minima.

Low attenuation in these bands makes single mode fibers suitable for long distance submarine communications. If trace amounts of water could be removed in the manufacture of the fiber, a continuous low absorption band would include bands O to L with a total wavelength bandwidth of 300 nm.

These bands can be sub-divided into individual wavelength carriers called lambdas[17] separated by guard bands to prevent cross-talk between channels. Wave Division Multiplexing (WDM) places multiple signal carrying channels on a single fiber. High levels of multiplexing formed by reducing guard band width with high precision laser light sources can be achieved using Dense Wave Division Multiplexing (DWDM).

[15] This spectrum can be compared with the attenuation spectrum of atmospheric absorption in the microwave region and above (Anderson, 2009, Figure 4) which clearly shows the high attenuation of IR radiation making IR a prohibitive option for long distance communication in unguided media. Hence the need for a low absorption guided medium such as is provided by optical fibre to facilitate levels of data bandwidth now required. Note also that because of the very high values of frequencies involved here, the spectrum is displayed here and referred to as wavelengths in the nanometer (10^{-9} nm) range.
[16] Understanding –Attenuation, www.ofsoptics.com/resources, available 15/3/2011.
[17] The word lambda is derived from the name of the Greek symbol, λ, which is the symbol used for wavelength in wave propagation theory. The channels referred to here are also known as lambda circuits. Each is tuned to a slightly different frequency or wavelength. And multiple lambdas can be projected onto a single fibre strand to carry multiple streams of data.

DWDM: Multiplexing on PPC-1

On a single fiber pair[18] each of 96 separate wavelengths (lambdas) or channels, with wavelengths distributed between 1537 and 1563 nm, are tuned to a slightly different frequency in PPC-1 with each one capable of carrying 10 Gbps of data (Figure 3).

Thus each fiber pair therefore provides a 960 Gbps data bandwidth, with two pairs providing 1.92 Tbps. The individual graphs show the sharp decrease in signal intensity on either side of the expected frequency which is required to reduce the possibility of cross talk between channels.

Summary data for PPC-1 (Table 2) shows the use of s band (see Figure 2) range of lambdas. Of particular significance are the very high frequency bandwidth and its associated potential for carrying data as spectral efficiency[19] develops.

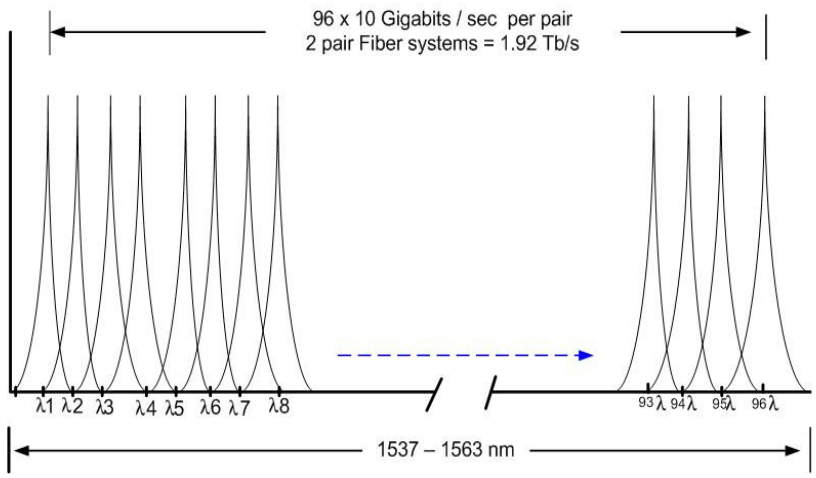

Figure 3 illustrates lambda signal intensity distribution with DWDM as used by PPC-1[20]. On a single fiber pair 96 separate wavelengths (lambdas) or channels are tuned to slightly different frequencies in PPC-1 with each one capable of carrying 10 Gbps of data. The rapid drop off of signal intensity on either side of the carrier wavelength is designed to prevent cross talk between adjacent lambdas.

[18] Fiber pairs are used to allow two-way (full duplex) high capacity communication, one fiber for each direction.
19 Spectral efficiency refers to the number of channels available per fiber. It is the ability to select individual lambda channels out of the available spectral band. As the precision of lasers, the providers of lambdas, increases more lambdas per channel and so greater data throughput will be come possible. There are a theoretical infinite number of lambdas on a single fiber and this is where the future development will lie.
[20] Adapted from Sheldon 2001, Fig W1.

	Initial values	**Central values**	**End values**	**Bandwidth**
Wavelength λ (lambda) nm	1537 nm	1550 nm	1563 nm	26 nm
Frequency f Hz or cps	195.05 THz	193.4 THz	191.81 THz	3.24 THz

Table 2 Available wavelength and frequency bandwidth for PPC-1. The 3.24 THz may be compared with 1GHz available for the entire RF spectrum and 300 GHz for the entire microwave spectrum. This indicates the data carrying potential of IR over fiber strands using DWDM.

The 3.24 THz of available bandwidth may be compared with the orders of magnitude smaller values of 1GHz available for the entire RF spectrum and 300 GHz for the entire microwave spectrum. As previously noted data carrying capacity increases with available frequency bandwidth. This indicates the relatively enormous future data carrying potential of IR over fiber strands using DWDM as Laser precision develops further.

Calculations for PPC-1 (Table 3) relate to spectral efficiency of the DWDM technology presently in use. Channel spacing is 0.27 nm or 34 GHz per channel.

Number of lambdas = 96 each carrying 10Gbps per fiber pair	
Channel width per fiber	= 26/96 = 0.27 nm
Channel spacing	= 3.24/96 = 34 GHz
Channel throughput for the central value frequency	= 193.4 THz/ 10 Gbps = 19.34 K cycles / bit = ~ 20 K cycles / bit
To carry one bit of data requires a signal element of 20 000 cycles.	
Total through put for PPC-1 10 Gbps per channel.	= 2 fiber pairs * 96 channels / fiber pair * = 1.92 T bps

Table 3 Spectral efficiency calculations for PPC-1 for the DWDM technology in use. Channel spacing is 0.27 nm or 34 GHz per channel. The total throughput on all channels is then verified as 1.92 T bps.

Given the data throughput on each channel, this means that each bit requires a signal element of 20 K cycles or wavelengths on the lambda. Future development should see much greater efficiency here with fewer cycles required per signal element. The total throughput on all channels is then verified as 1.92 T bps.

Further calculations (Table 4) show all available lambdas and their associated frequencies and wavelengths on a single fiber pair on PPC-1. Each of the 96 lambdas are distinguished by slightly different wavelengths and frequencies (calculated for this paper and rounded correct to 2 decimal places) to which Lasers providing signals on individual DWDM channels on a single fiber pair are tuned**.**

PPC-1: Multiple Lambdas on a single fiber strand		
Lambda #	**Wavelength (nm)**	**Frequency (THz)**
λ_1	1537.14	195.03
λ_2	1537.41	195.00
λ_3	1537.68	194.96
λ_4	1537.95	194.93
λ_5	1538.22	194.90
λ_6	1538.49	194.86
….	….	….
λ_{91}	1561.51	191.99
λ_{92}	1561.78	191.96
λ_{93}	1562.06	191.92
λ_{94}	1562.33	191.86
λ_{95}	1562.60	191.82
λ_{96}	1562.87	191.81

Table 4 Shows each of the 96 slightly different wavelengths and frequencies (calculated for this paper and rounded correct to 2 decimal places) to which LASERS providing signals on individual DWDM channels on a single fiber pair are tuned**.** Lambdas 3 and 4 are used for connectivity to the Madang CLS via Branching Unit 4.

Adjacent lambdas (λ_3 and λ_4) are used for connectivity to the Madang CLS via Branching Unit 4. These lambdas (Table 5) are made available to the Madang Cable Landing Station (CLS) from the Optical Add Drop Multiplexer (OADM) at BU4 and are added or dropped from the main 2 FP cable linking Sydney to Guam.

	Lambda #	**Frequency**	**Wavelength**	**Data Bandwidth**
Madang-Sydney	λ_3	194.96 THz	1537.68 nm	10 Gb/s
Madang-Guam	λ_4	194.93 THz	1537.95 nm	10 Gb/s

Table 5 Wavelengths and frequencies of the adjacent lambdas (λ_3 and λ_4) 10G bps connections to and from Madang**.** These lambdas are made available for the Madang CLS from the OADM at BU4. This signal is added to or dropped from the main 2 fiber pair cable linking Sydney to Guam

Standards for digital hierarchies

It is of interest for purposes of comparison to locate the PPC-1 signalling rate (Table 6) on the various international and North American standards (OC, SONET, STM)[21] for digital optical hierarchies (Downing, p243, Dodd, p 280).

Optical Carrier (OC) level	**SONET STS level**	**SDH STM level**	**Signalling Rate** (Gbps)	**Equivalent telephone calls**
OC-192	STS-64	STM-64	9.953	129 024

Table 6 PPC-1 signalling rate is located on the various international standards for digital optical hierarchies. These are all referenced against the digital data rate of 64 Kbps required for a digitised telephone conversation[22]. Thus PPC-1 provides an STM-64 signal on the SDH Hierarchy which is a data rate equivalent of 129 024 telephone calls.

PPC-1 with nominal data rate of 10Gbps is shown with its exact data rate of 9.953 Gbps and its location on the various standards.

These are all referenced against the digital data rate of 64 Kbps required for a digitised telephone conversation. Thus PPC-1 provides an STM-64 (Synchronous Transport Module) data rate signal on the SDH Hierarchy which is the data equivalent of 129 024 telephone calls.

Optical amplifiers

Seventy eight all optical Erbium Doped Fiber Amplifier (EDFA) stations (Figure 4) are located at 100km intervals along the submarine fiber cable as there is still residual attenuation in the spectral windows (Figure 2). EDFAs take advantage of the ability of a section of the fiber cable which has been doped with the Rare Earth Element (REE) erbium to amplify simultaneously

[21] OC: Optical Carrier; SONET: Synchronous Optical Network; STS: Synchronous Transport Signal; SDH: Synchronous Digital Hierarchy; STM: Synchronous Transport Mode. These multiplexing standards replace the original digital standard for electrical only signals, PDH (Plesiosynchronous Digital Hierarchy). These new standards subsume the PDH standards and are developed to include higher data rates available with fiber optic cables. They arise from either ITU-T International standards or North American standards (SONET) which are all compatible.

[22] A single telephone conversation has to be sampled at a rate twice the highest available voice frequency available for telephone conversations (Nyquist Theorem). This is Pulse Code Modulation where 1 byte or 8 bit samples of the analog voice signal are taken at 2 by 4000 times per sec thus requiring 64 kbps of bandwidth for a single telephone conversation. Note also that these optical hierarchies subsume the older PDH hierarchy used for multiplexed electrical signals over copper cable.

across the full range of lambdas used in the s band (Figure 2) centred on 1500 nm sometimes known as the 'erbium window'. The special significance of an EDFA for high speed transmission is that it amplifies without the need for a series of optical-electrical-optical conversions making them ideal for long haul applications. Two signals are combined onto a single fiber via a coupler, one requiring to be amplified across a range of lambdas centred on 1500 nm, and the other being light from a pump laser that excites the erbium atoms to metastable energy levels.

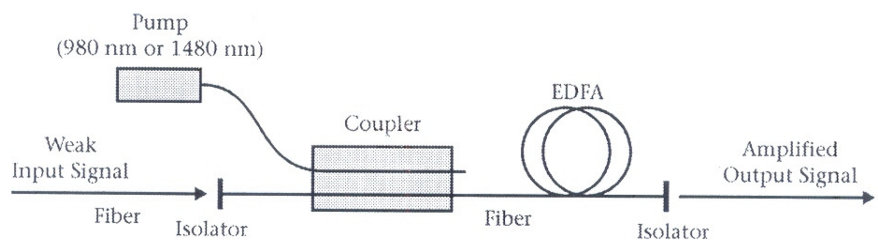

Figure 4 An EDFA repeater station (Downing, 2005, p207) takes advantage of the ability of an attached section of the fiber cable which has been doped with the Rare Earth Element (REE) erbium to amplify simultaneously across the full range of lambdas used in the s band (Figure 2) centred on 1500 nm. A coupler combines two signals onto a single fiber, one carries data and requires amplification across a range of lambdas centred on 1500 nm, and the other is light from the pump laser that excites the erbium atoms to metastable energy levels. The isolators retain this wavelength signal within the amplifier preventing reflections in either direction from the attached fiber.

In a process known as stimulated emission of radiation, electrons in the metastable energy levels will emit radiation of the same wavelength as the incoming signal which is thereby amplified on all lambdas as electrons return to stable energy levels. The process in the laser pump is similar as electrical energy is used to raise the energy of the electrons of the erbium atoms to metastable levels producing an intense beam of parallel light at a fixed wavelength shown here as 980 nm.[23] A special electrical power cable accompanies the fiber cable along its full length to provide the required electrical energy for the laser pump. The isolators retain the laser pump wavelength signal, which does not carry data, within the amplifier preventing reflections in either direction.

[23] A metastable Erbium atom releases energy as photons which are in the same frequency, phase and direction as the stimulating signal which is being amplified. Of particular significance here is that although the electronic transitions of isolated ions are sharply defined, broadening of the energy levels (individual energy levels are split into sublevels) occurs when the ions are dopants within the silica fiber. The result is a very broad spectrum (~ 30nm) over which amplification can occur. This amplification across a wide bandwidth using a single process makes it very useful in DWDM. All signals being carried by the fiber, which fall within the gain window are amplified.

Branching Units

Branching units (BU) are strategically located to enable some of the lambdas to service intermediate points along the 6900 km cable. Initially, Initially the Branching unit to Madang (BU4) will be activated.

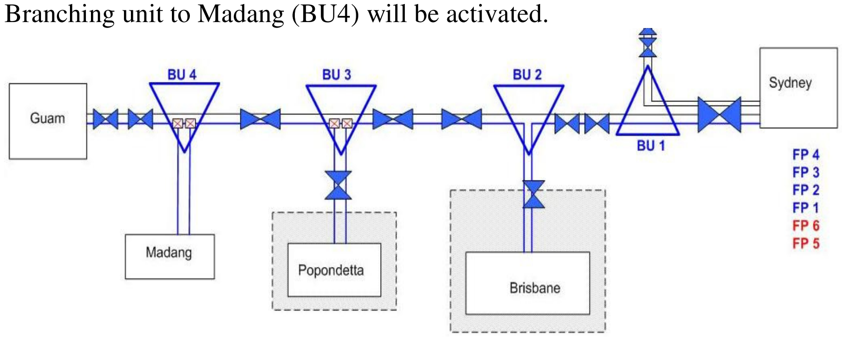

Figure 5 is a logical diagram[24] showing how the schematic diagram in Figure 1 is implemented for PPC-1. with the present Branching Unit to Madang (BU4) and possible future branches to NZ (BU1), Brisbane (BU2), Port Moresby or Popendetta (BU3). Two fiber pairs are for present implementation, with an additional 4 pairs available to install spurs to further strategic locations.

The branching unit (Figure 5) consists of an optical add/drop multiplexer (OADM) to extract and return particular lambdas from and to the main transmission line. An OADM consists of a Fiber-Bragg grating[25] which reflects only one lambda to which it is tuned and transmits the remaining lambdas.

On either side of the grating there are circulators which transmit signals in one direction only. A circulator cannot transmit a signal along the same path from which it entered the circulator. On the left the reflected signal cannot pass through the circulator and so must go to the local transceiver, the Submarine Line Terminal Equipment (SLTE) at the cable landing station. On the right side, the return signal will be reflected by the grating, return to the circulator and pass to the output onto the next section of the network.

24 Adapted from: www.pipenetworks.com /docs/media /ASX%2009_03_24%20PPC-1%20Presentation.pdf. Available 14/6/11

25 A Fiber-Bragg grating is an inline optical filter and reflector consisting of a short segment of optical fiber with periodic variations of refractive index. The variations are designed to cause reflection of a particular wavelength and transmission of others. All reflected wavelengths except the one desired cancel out in a process of destructive interference. Lambdas, therefore, which are not reflected will be transmitted.

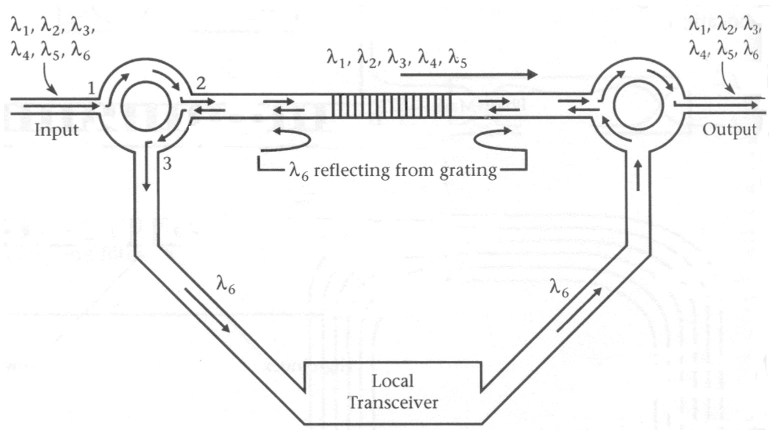

Figure 6 OADM (Downing, p220) positioned at a Branching Unit (BU) consists of a Fiber Bragg grating[26] which reflects only one lambda (λ_6) to which it is tuned and transmits the remaining lambdas (λ_1 to λ_5). On either side of the grating circulators transmit signals in one direction only. Circulators enforce the directions shown. On the left the reflected signal cannot pass through the circulator and so must go to the local transceiver, the SLTE at the cable landing station. On the right side, the return signal will be reflected by the grating, return to the circulator and pass to the output onto the next section of the network.

The SLTE functions as a multiplexer-demultiplexer and extracts lambdas using methods similar to the OADM. However, whereas the OADM extracts some lambdas the SLTE extracts all lambdas. The lambdas can be separated using multiple in-line reflection gratings, each one tuned to extract a different lambda, or a diffraction grating could be used. The diffraction grating will bring each lambda to a separate focus.

Path of PPC-1

The Northern portion of the 6900 km PPC-1 submarine cable[27] passes through Vitiaz Straight (Figure 7) parallel to the Finisterre Range, skirting Astrolabe Bay where the Madang BU4 is located, before veering north and traversing deep ocean trenches on its way to Guam.

[26] A Fiber-Bragg grating is an inline optical filter and reflector consisting of a short segment of optical fiber with periodic variations of refractive index. The variations are designed to cause reflection of a particular wavelength and transmission of others. All reflected wavelengths except the one desired cancel out in a process of destructive interference. Lambdas, therefore, which are not reflected will be transmitted.

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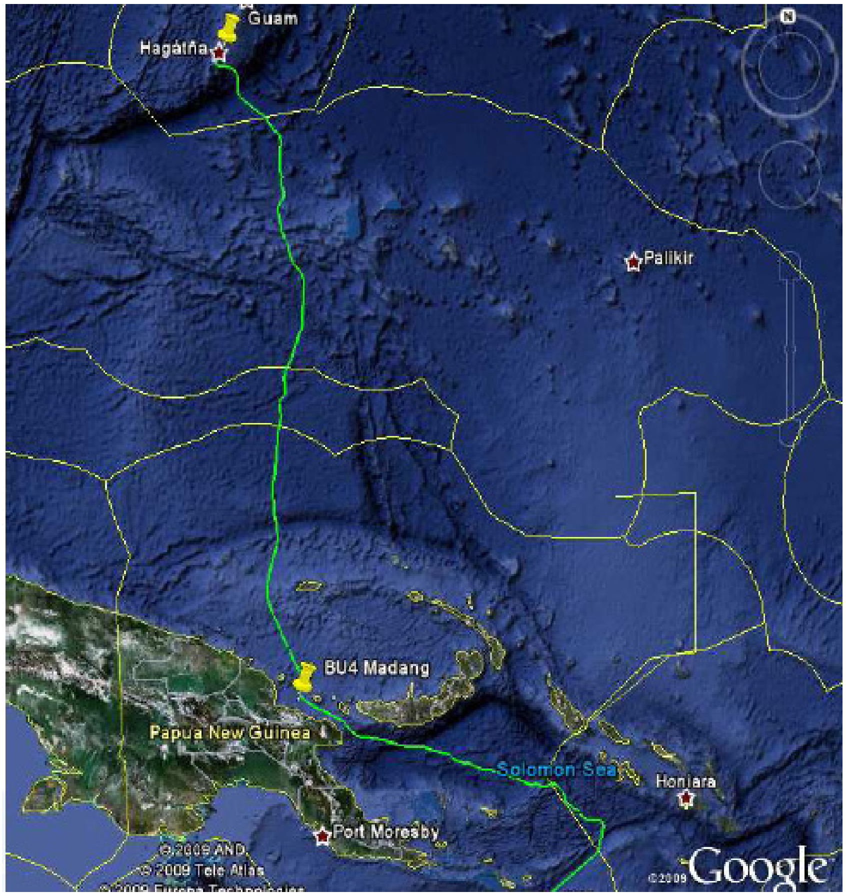

Figure 7 Northern portion of the 6900 km PPC-1 submarine cable[28] showing the Madang BU4 passing through Vitiaz Straight parallel to the Finisterre Range, skirting Astrolabe Bay before veering north and traversing deep ocean trenches on its way to Guam.

As previously noted, the 2 FP cable carries 96 lambdas each tuned to a slightly different frequency and each with a 10 Gbps data bandwidth.

Of the available important population centres, PPC-1 comes closest to Madang which has, therefore been chosen as the landing point. For similar reasons, Madang was the landing point for the previously mentioned Seacom cable and provided entry to the domestic trunk telephone microwave system. As a landing point, Lae would have had the advantages of convenient access to the National Capital, Port Moresby, and also a more direct link to the Highlands.

[28]www.pipenetworks.com/docs/media/ASX%2009_03_24%20PPC-1%20Presentation.pdf. Available 14/6/11

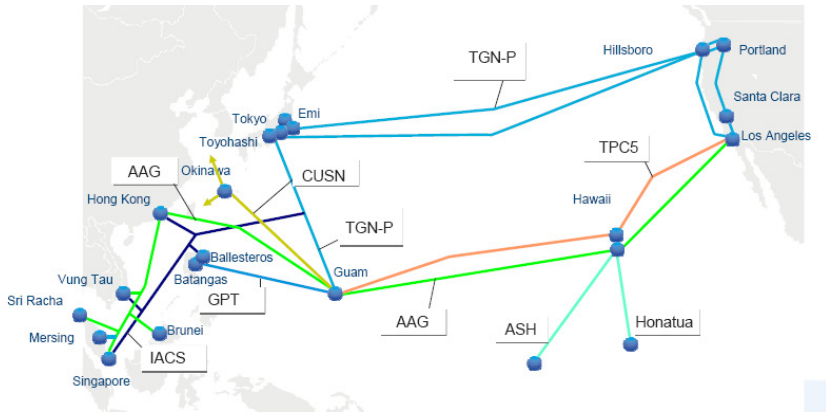

Figure 8 Guam is a strategically located landing point to provide high capacity submarine cable onward connectivity to America in the east and Asia in the west for PPC-1[29]. Particularly notable among the numerous existing cables is the 20 000 km Asia America Gateway (AAG) which is shown (green) with landing points from USA, to Hawaii, Guam, Philippines, Hong Kong, Malaysia, Singapore, Thailand, Brunei and Vietnam**.** Shown in blue is the Trans Pacific Cable which is part of the Tycho Global Network (TGN-P) also providing extensive connectivity and multiple landing points.

The PNG internal domestic telecommunications trunk network (Figure 8) was initially constructed to allow important centres to take advantage of the SEACOM cable to link PNG to Australia and the outside world via its Madang connection (Sinclair, 1994, p212). The network uses line-of-sight microwave (5-7 GHz) services involving chains of repeater stations located on mountain peaks every 50 km.

The PPC-1 connection, again with Madang as its landing point, will require a different backbone network as the transporting medium which will be fiber optic cable. It is proposed to support this cable above ground on the ground wire of Transmission lines used by PNG Power, Optical Ground Wire (OPGW).

As these power lines follow the road system, the new backbone will also follow the road system which passes from Bogia to Lae with a branch to the Highlands on the Madang-Lae road at the high point. separating the head waters of the Ramu and Markham river systems. As is no road linking Port Moresby to Lae a separate BU from PPC-1 will be required to allow Port Moresby and related coastal locations to take advantage of PPC-1.

[29]www.pipenetworks.com/docs/media/ASX%2009_03_24%20PPC-1%20Presentation.pdf. Available 14/6/11

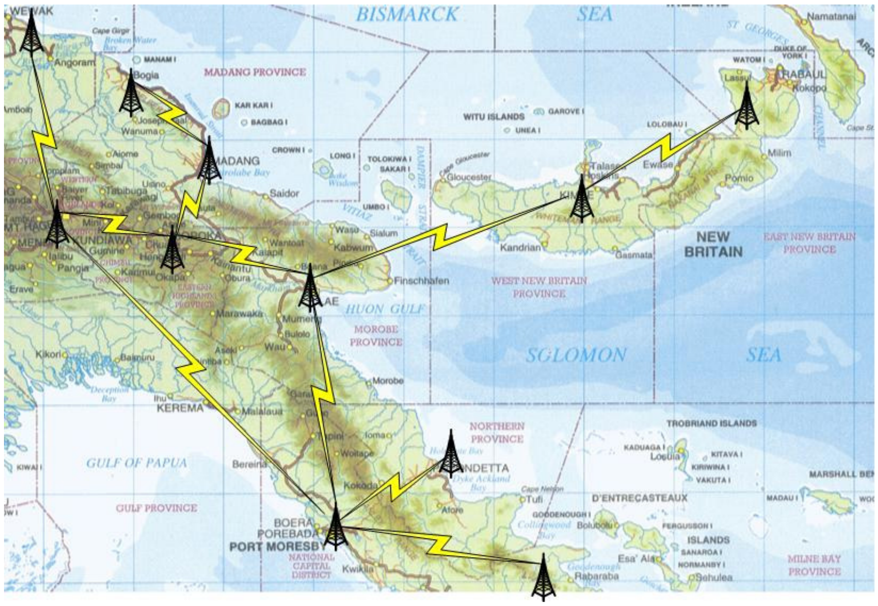

Figure 9 Important sectors of the PNG internal domestic telecommunications trunk network[30] initially constructed to allow important centres to take advantage of the SEACOM cable. The network uses line-of-sight microwave (5-7 GHz) services involving chains of repeater stations located on mountain peaks every 50 km. The proposed fiber optic backbone will use PNG Power transmission lines as bearers and will follow the road system. Shown are the main transmitter mast locations.

Of further interest is the fortuitous location of PPC-1 close to the island arc chains of New Britain and New Ireland (and even the Solomon Islands) where socio-economic development would be greatly enhanced if serviced by a BU from PPC-1 at some future date.

Madang Cable Landing Site

The fiber pair from BU4 of PPC-1 has a landing point on the coast line in the township of Madang adjacent to the iconic coast watchers lighthouse (Figure 10)**.** After passing through the Beach Manhole, the cable passes through a series of Hauling Manholes before reaching the Cable Landing Station (CLS) situated on the PNG Telikom Exchange Modilon premises.

[30] Network data was obtained from *Telecommunications Network of Papua New Guinea* (30/10/00) Issue 5 drawn by J Kila et al. of Telikom PNG.

Figure 10 Superimposed on satellite imagery is the PPC-1 landing point on the Madang coast beside the iconic Coast Watchers Lighthouse**.** After passing through the Beach Manhole, the cable passes through a series of Hauling Manholes before reaching the CLS situated on the PNG Telikom Exchange premises at Modilon.

PPC-1 Madang Cable Landing Station

The Madang Cable Landing Station (CLS) will service the many voice and data services which will benefit from the Madang PPC-1 connection (Figure 11). The options available from the ODF are the direct feed to end users in Madang be they an ISP or a corporate client, or other service provider and the requirement to feed the trunk needs for other Telikom routes within PNG. Starting from the top RHS a second Internet gateway for PNG (Tiare #2) will be provided through PPC-1 for PNGARNet clients, ISPs and WiMax services. Shown below this, PNG Telikom telecommunication services will have access to PPC-1.

The lower RHS shows a proposed fiber optic domestic backbone to complement the microwave line-of-sight backbone already in place. Here it is intended to carry the fiber cable on the ground wire of PNG Power transmission lines. The optical signal is converted to an electrical signal at the Submarine Line Terminal equipment (SLTE) located within the CLS. From there it will provide voice, video and data connectivity to other networks within PNG such as those owned by corporate bodies and other service providers.

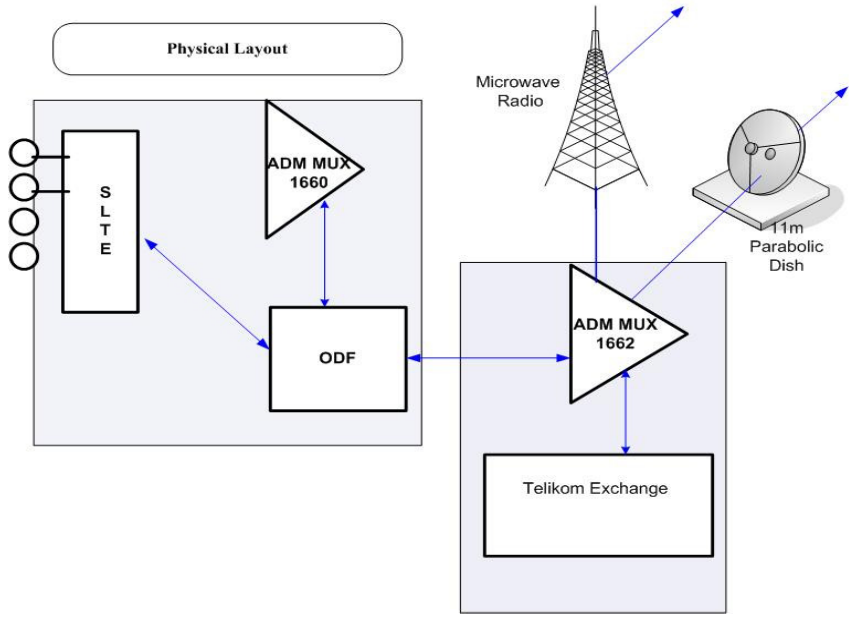

Figure 11 The physical layout of the Cable Landing Station (CLS) at the Telikom Exchange premises in Madang is shown on the left, with main components, the Submarine Line Terminating Equipment (SLTE) and the Optical Distribution Frame (ODF). On the left, underground conduits bringing the fiber pair from BU4 via enter the building. The schematic building on the right is the PNG Telikom telephone exchange with its connection to the PNG domestic microwave line-of-sight and satellite backbone.

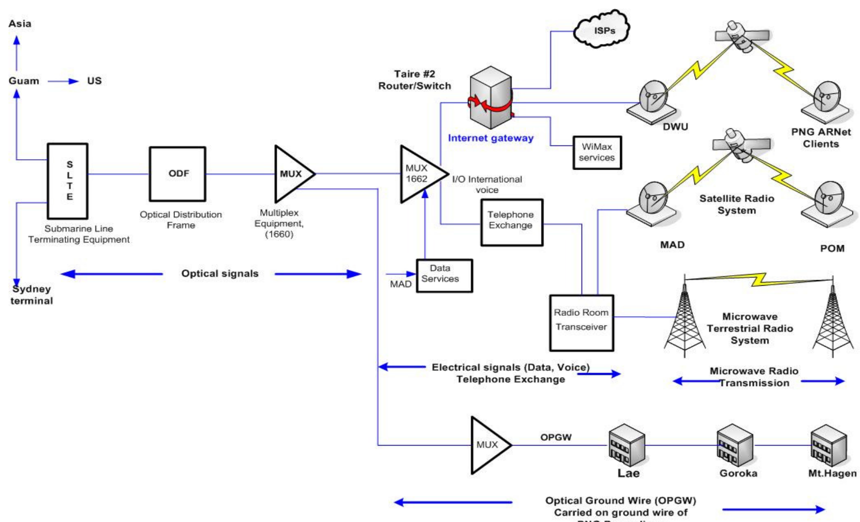

Figure 12 Shows the components of the Cable Landing Station (LHS: SLTE, ODF and MUX) and then the many voice and data services which will benefit from the Madang PPC-1 connection. The options available from

the ODF are the direct feed to end users in Madang be they an ISP or a corporate client, or other service provider and the requirement to feed the trunk needs for other Telikom routes within PNG. Starting from the top RHS a second Internet gateway for PNG (Tiare #2) will be provided through PPC-1 for PNGARNet clients, ISPs and WiMax services. Shown below this, PNG Telikom telecommunication services will have access to PPC-1. The lower RHS shows a proposed fiber optic domestic backbone to complement the microwave line-of-sight backbone already in place. Here it is intended to carry the fiber cable on the ground wire of PNG Power transmission lines.

Extensions from Cable Landing Station

A locality plan (Figure 13) for fiber optic extensions from PPC-1 into the Madang township shows how bandwidth provided by PPC-1 will be allocated to local instrumentalities via underground roadside conduits. The Divine Word University (DWU) fiber link will provide the access link for PNGARNet to access the Internet via PPC-1. The present satellite Internet connection for PNGARNet via Asia Sat 4 and Singapore will then become a backup service.

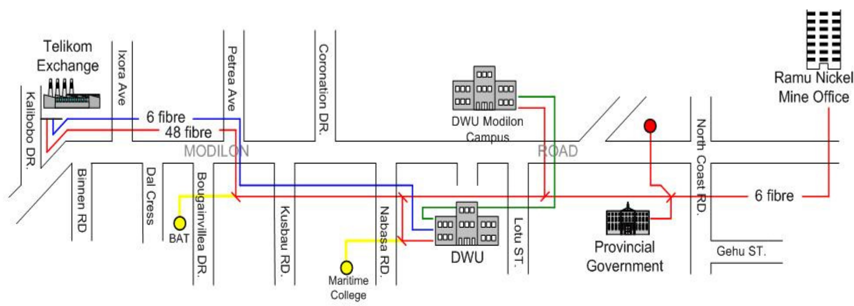

Figure 13 A locality plan[31] (not drawn to scale) for fiber optic extensions from PPC-1 into the Madang township showing how bandwidth provided by PPC-1 will be allocated to local instrumentalities via underground roadside conduits. The Divine Word University (DWU) fiber link will provide the access link for PNGARNet to access the Internet via PPC-1. The present satellite Internet connection for PNGARNet via Asia Sat 4 and Hong Kong will then become a backup service. At the time of writing the network shown was only partially complete.

Conclusion

This paper has attempted to provide the bandwidth offerings of the PPC-1 undersea submarine cable that runs from Guam to Sydney and branches off in Madang. The PPC-1 will provide high speed domestic and international connectivity insofar as Telecommunications in PNG is concerned. A brief description of preceding undersea cables and their capacities was given to

[31] Adapted and redrawn off locality plan drawn by PNG Telikom Network Planning Division, Cable Access Network. Available 13/3/09.

enable comparison with the greatly increased bandwidth offered by the PPC-1 providing unprecedented voice, video and data connectivity within PNG and to the outside world.

DWDM, the placing of multiple channels on a single optical fiber, is the very significant technological development incorporated into this cable network. This new technology will vastly increase the data carrying capacity of fiber optic cables already in use around the world.

The Madang connection has the capacity (10 Gbps) to provide PNG with greatly increased access to voice, video and data services that can ably support the socio-economic development initiatives in PNG. Whilst the PPC-1 has the potential to positively impact on the other sectors of the economy of PNG, much of its success will depend on the timeliness, costing and delivery of this asset to the end users at large.

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