Flexwave

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Document Control

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Updates

Vodafone reserves the right to revise this document from time to time. The need for updates may result from implementation of advances in networking technologies; requirements for conformance with new or updated International standards; or to reflect changes in equipment design, techniques or procedures.

Modification Register

Version	**Modification**	**Section**	**Date**	**Who**
0.5	Initial Draft for comments	All	15 March 2014	Drew Barr
1.0	Updated with feed-back	5 & 6	1 July 2014	Drew Barr

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2 Introduction

Purpose

The purpose of this document is to provide Vodafone Wholesale customers with:

A clear description of the network architecture and technical characteristics of the FlexWave services, in sufficient detail to enable a customer to confidently select service options suitable for their application needs.

Details on Service Fulfilment and Assurance practices including ordering, provisioning, service level agreement (SLA) targets, reporting and fault management.

Explanation of pricing constructs and billing

Intended Audience

This document is aimed at product managers, technical personnel and solutions consultants of service providers, carriers, system integrators and other qualifying Wholesale customers needing to understand how FlexWave connectivity services can be used for high capacity networking.

Relationship with other documents

FlexWave is one of the data products within the Wholesale product portfolio. Other products in the suite are covered in separate documents.

Commercial terms and conditions are recorded in the Vodafone Wholesale Services Agreement (WSA).

The Customer Operations Manual contains general service level information applicable to Vodafone's products and services along with policies, processes and procedures for ordering, provisioning, maintenance and billing.

3 Product Overview

FlexWave is a high capacity digital data transport service.

FlexWave circuits enable point to point linking of site equipment within and between New Zealand cities. FlexWave is based on Wave Division Multiplexing (WDM) technologies that enable multiple client signals to be securely transported over a single fibre path.

The service delivers fully managed, full duplex, exclusive use transmission capacity at speeds up to 100Gbit/s with a flexible choice of standards based interface protocols including:

- Gigabit Ethernet
- Synchronous Digital Hierarchy (SDH)
- Optical Transport Network (OTN)
- Fibre Channel/FICON

Customers are able to choose between single access unprotected or dual access protected service topologies to match their network resilience requirements.

Some typical applications for FlexWave circuits include:

- Inter-nodal trunking between existing network operator platforms or trunking to new platform locations to extend operators backbone network reach.

- Fixed backhaul linking from Ultra Fast Broadband (UFB) network Points of Interconnect, Mobile Network sites or International Submarine Cable Stations.
- Converged networking applications providing simultaneous transport of voice, video and data, Data Centre interconnection.

- Storage Area Network (SAN) links supporting data backup, disaster recovery and mirroring applications.

- FlexWave services come with Service Level Agreements (SLA's) that include targets for service performance and availability.

- New service orders and changes to existing FlexWave services are managed by a dedicated project manager.

- Fault support of services is provided through the customer help premium support helpdesk. The helpdesk provides a 24x7 fault logging facility and investigates and manages FlexWave faults through to resolution.

The FlexWave charging construct is flat rate based on service bandwidth and charge zone. Billing is carried out on a monthly basis. Recurring charges apply for each service and non-recurring charges apply for new installations and moves, adds and changes to existing services.

4 Features and Benefits Summary

Summary of Features

Key features of FlexWave services are summarised as below

Feature	Details
Client Interface Options	**Ethernet** 1GE 10GE 40GE 100GE **SDH** STM-16 / OC-48 (2.5G) STM-64 / OC-192 (10G) STM-256 /OC768 (40G) **OTN** OTU1 (2.666G) OTU2 (10.709G) OTU1e (11.049G) OTU2e (11.095G) OTU3 (43.018G) OTU3e1 (44.571G) OTU3e2 (44.583G) OTU4 (111.810G) **Fibre Channel / FICON** 1GFC (1.0625G) 2GFC (2.125G) 4GFC (4.250G) 8GFC (8.500G) 10GFC (10.519G)
Service Topology	Point to Point
Duplex Modes	Full Duplex Only
Network Access Media	Single Mode Fibre
Resiliency Options	Single Access Unprotected Dual Access Protected
Geographical Coverage	At time of writing Vodafone FlexWave is currently available for linking between 25 of the largest New Zealand cities and within the CBD and Metro areas of selected cities (including Auckland, Wellington and Christchurch)

Key Benefits

The key benefits of FlexWave services from Vodafone are as follows:

By entrusting your mission critical network linking to us you can have peace of mind knowing you are dealing with one of the largest Tier 1 Telecommunications providers in New Zealand and a stable and proven supplier of data networking products for over 20 years.

With our scale and extensive New Zealand coverage we can provide cost effective short and long distance backhaul services. FlexWave circuits allow you to quickly expand your network footprint and potential market without the major capital expenditure needed to develop your own solution and potentially saving you the costs of developing and maintaining the skillsets to manage in-house.

Next generation Carrier Grade transmission equipment coupled with multiple diverse paths on our wholly owned core fibre network means you benefit from a managed service with high performance, high availability, and lowest latency.

FlexWave provides dedicated capacity with highly deterministic performance characteristics, giving you the flexibility to determine how to most efficiently utilise the purchased bandwidth.
Multi-protocol support with a choice of standards based client interface protocol types increases the number of applications the service can be used for and ensures maximum interoperability with vendor CPE and other service provider's network services.

Vodafones experienced team of solutions specialists have a high level of technical expertise and will work with you to identify an optimal FlexWave solution for your business needs. Our 24 x 7 Network Operations Centre carries out monitoring of optical transport platforms allowing rapid detection of service degradation or interruptions to ensure maximum service availability and provide a superior customer experience.

5 Technical Description

Flexwave is a digital data transport service. Available with a choice of standards based interface options it provides high capacity point to point connectivity for linking site equipment within and between New Zealand cities.

Flexwave circuits for all customers are transported securely across common Vodafone optical networks.

Architecture

Vodafone's optical transport networks provide the foundation for delivery of FlexWave services.

The optical transport networks are composed of sets of optical network elements connected by fibre links. The networks provide transport, multiplexing, routing, management, supervision and protection (survivability) of optical channels that carry client signals.

Optical Transmission Systems

The network architecture is based on multi-channel optical transmission systems. Figure 1 shows an example of a simple unprotected system connecting two sites over a single unamplified fibre span.

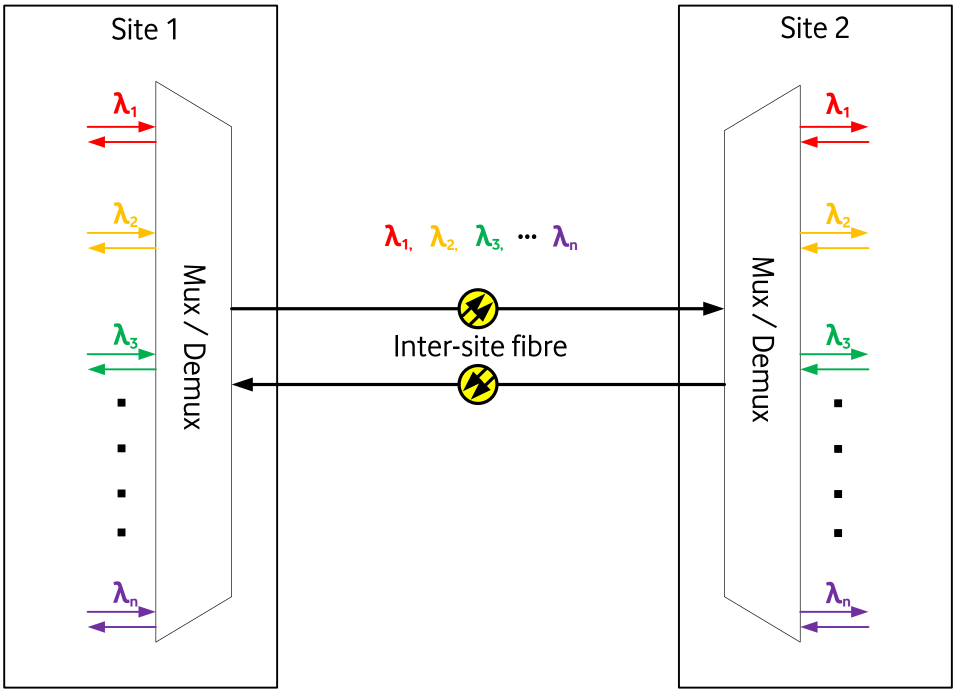

Figure 1 – Simple single span unprotected OTS

The Mux / Demux terminals at each site perform the Wave Division Multiplexing (WDM) function. Each terminal has an optical filter that combines and separates multiple optical signals to and from a pair of inter-site fibres (one fibre for each direction of transmission).

Each input to a system is a separate optical channel that has a specific operating wavelength band (slot) and nominal centre wavelength (λ). The individual signals travel on the fibre line in their assigned wavelength slots without interference. The number of multiplexed channels on the fibre line ranges from 4 to 88 depending on the filter equipment deployed.

Optical Network Topology

Vodafones optical networks are configured in a variety of connection topologies including point to point, ring and mesh

Figure 2 illustrates how sites may be linked in different topologies.

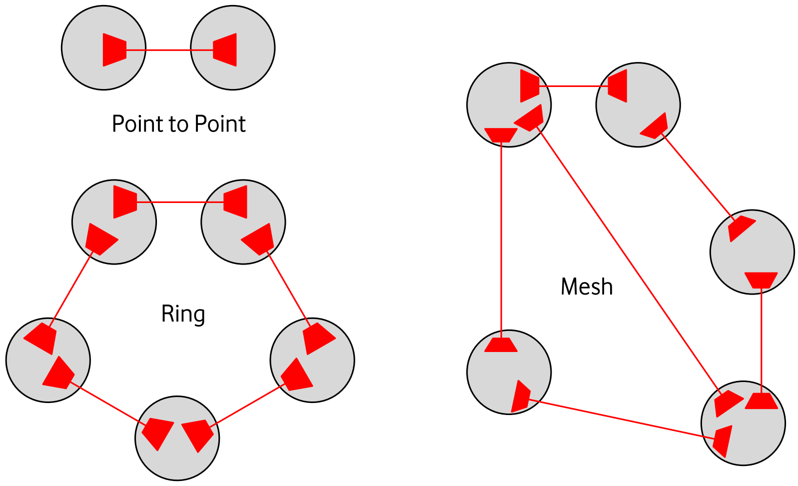

Figure 2 – Optical point to point, ring and mesh topologies

The simplest arrangement is a point to point topology where a single system links two sites. This topology supports unprotected services.

Ring topologies where a number of point to point systems are interconnected to form a ring allow diverse optical paths between sites to be established and support unprotected and protected services.

Vodafone has deployed Reconfigurable Optical Add Drop Multiplexer (ROADM) equipment equipped with Wavelength Selective Switch (WSS) elements at selected sites in the network. WSS elements enable per wavelength photonic cross connections between optical transmission systems.

The ROADM's are a key enabler for flexible inter-connection of multiple systems. They provide a multi-way branching capability and allow sites to be linked into mesh topologies and mesh networks to be joined to point to point and ring networks.

Services are delivered using transparent light paths established between network endpoints by connecting an optical channel (i.e. wavelength) across one or more system segments in tandem. The ROADM equipment used allows fast turn up and flexible routing of optical channels at intermediate sites and permits channels to be remotely added, dropped or passed through between any of the systems appearing at a site automatically.

For protected applications two diverse light paths are established between sites.

Figure 3 shows an example of protected links using a ring topology and ROADM equipment. In the example Site A and Site C are connected with two diverse wavelengths (red λ). One wavelength is routed direct from A to C with the other routed via intermediate site B. The WSS elements in the ROADM sites perform optical cross connection to add, drop and pass through the red channel.

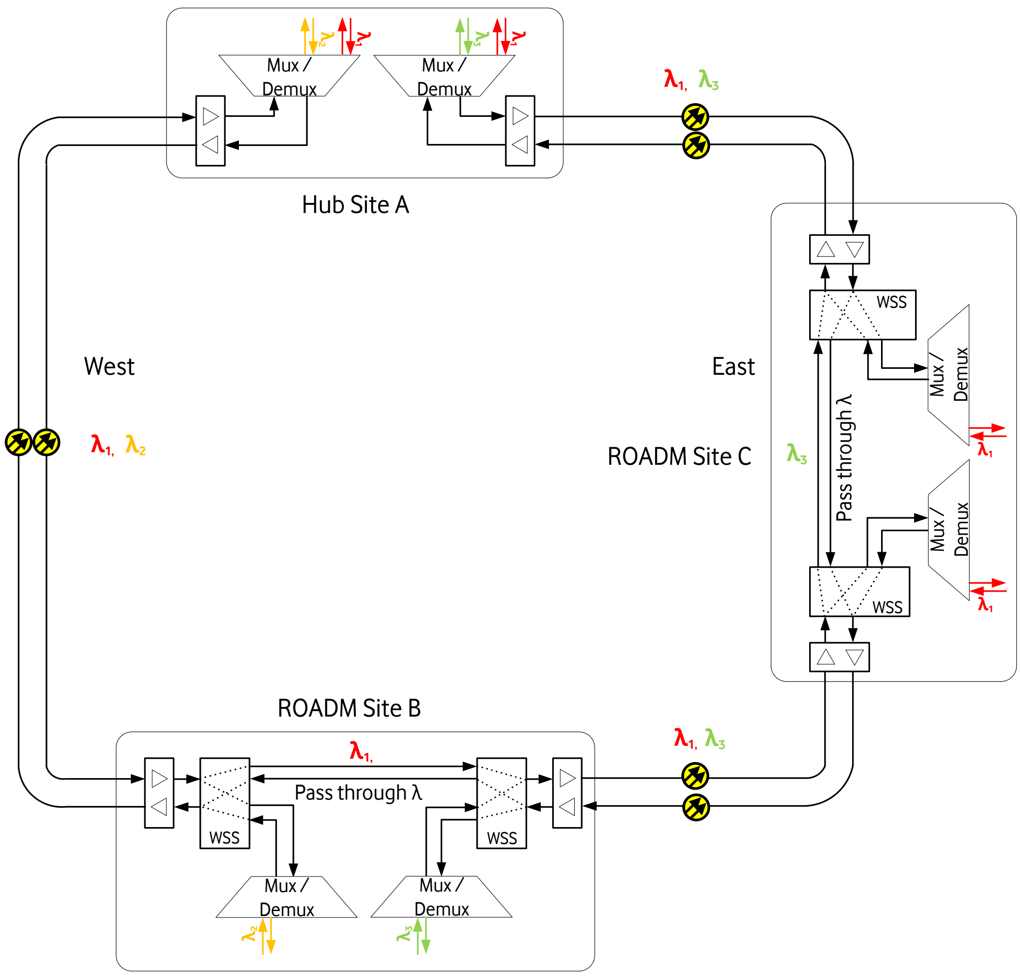

Figure 3 – Protected application diverse light paths

ITU OTN Standards

The data signals produced by customer equipment and presented for transport on FlexWave circuits (aka client signals) are first conditioned into ITU-T Optical Transport Network (OTN) standard forms by Vodafone Transponder / Muxponder terminal equipment before they are transmitted onto optical lines.

The generic architecture aspects and the optical interfaces of the OTN are described in ITU recommendations G.872 and G.709 respectively. The OTN standards were designed to allow interoperability and generic transport of any protocol across one or more operators' optical networks.

With OTN both asynchronous packet based data e.g. Ethernet and synchronous constant bitrate data streams e.g. SDH can be mixed and transported with bit-stream and timing transparency together on a single wavelength.

OTN combines the benefits of SDH transport technologies with the bandwidth scaling capabilities of wave division multiplexing. The comprehensive Operations, Administration and Maintenance (OAM) functions that were part of SDH standards that enabled defects and performance degradation of signals to be detected and localised and path monitoring and protection switching to be carried out have been enhanced with OTN.

The OAM functions of OTN can be used with protocols such as Ethernet that don't natively have transport OAM capabilities and include the ability to supervise individual network segments where signals pass across multiple operator networks i.e. Tandem Connection Monitoring (TCM).

The OAM functionality of OTN is provided by adding overhead information implemented as a "digital wrapper" around the signal to be transported creating an OTN frame similar in structure and format to an SDH frame.

Figure 4 shows how the supervision and management capabilities are achieved by adding overhead at various positions during transport of a client signal.

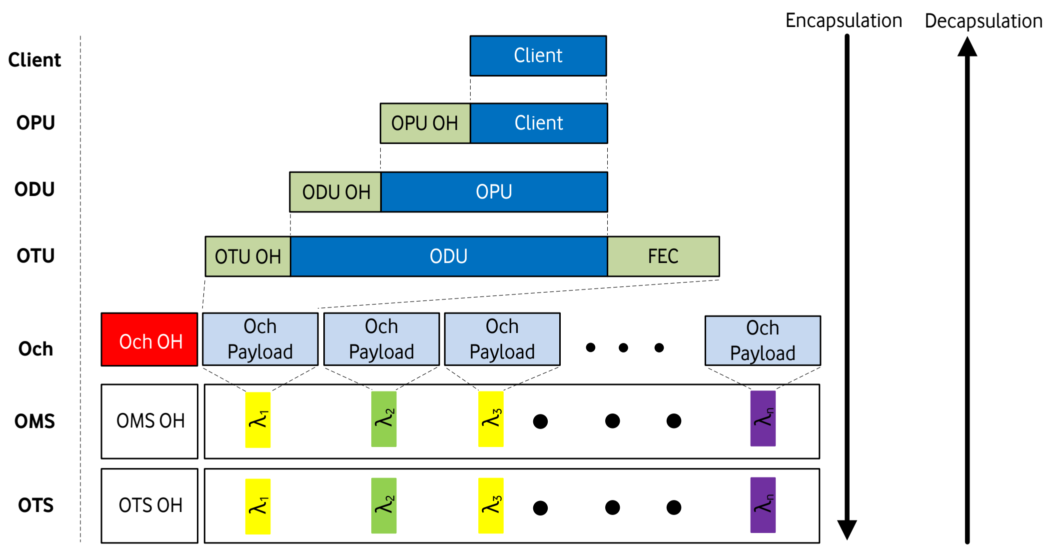

Figure 4 – OTN Transport Structure

As depicted the conditioning of a client signal to OTN format occurs as follows:

Overhead is added to the client forming the Optical Channel Payload Unit (OPU) Overhead added to OPU forms an Optical Channel Data unit (ODU) Additional overhead plus Forward Error Correction (FEC) forms the Optical Transport Unit (OTU)

The OPU, ODU and OTU signals are processed in the digital domain (i.e. electrical) and are referred to as digital layers in the ITU architecture.

The OPU overhead contains information relating to the adaption of the client signal to the OPU payload. This includes payload type information (that indicates the client signal type (e.g. CBR) and the mapping method used (e.g. asynchronous or bit synchronous)) and justification control bytes (used to compensate for clock rate differences between the client signal and OPU clock with asynchronous mappings).

The ODU overhead provides supervision of the end to end circuit path (i.e. detecting and reporting continuity, connectivity and signal quality defects) and supports maintenance signals (used to advertise upstream maintenance conditions affecting traffic), tandem connection monitoring, Automatic Protection Switching (APS) and embedded communications channels functionality.

The OTU overhead provides supervision of individual sections of the circuit path. Similar to ODU supervision, loss of continuity is reported using the Backward Defect Indication (BDI) bit. Connectivity mismatches are detected using the Trail Trace Identifier (TTI) byte. Signal quality is monitored using the Bit Interleaved Parity (BIP) byte for detecting errors and the four bit Backward Error Indication (BEI) field for reporting block error counts. The three bit Status field is used to indicate the presence of maintenance signals e.g. Alarm Indication Signal (AIS).

The OTU includes Forward Error Correction for each frame. The FEC improves the Optical Signal-to-Noise Ratio (OSNR), allowing for longer optical spans and fewer regeneration requirements.

The OTU signal is used to modulate an optical carrier which is applied to the Optical Channel (OCh). For the OCh and underlying layers signals are processed entirely in the optical domain (i.e. photonic).

Individual OCh signals are carried in a wavelength (“colour”) and groups of optical channels are combined to form Optical Multiplex Section (OMS) and Optical Transmission Section (OTS) structures. The OCh, OMS and OTS layers each have their own overhead for management and supervision of the optical elements in the circuit path e.g. optical amplifiers. The overhead of these optical layers is transported in a wavelength slot outside the traffic band in an out-of-band channel called the optical supervisory channel (OSC).

Figure 5 shows the hierarchy of OTN layers and the points in the network where the different signals are terminated and processed.

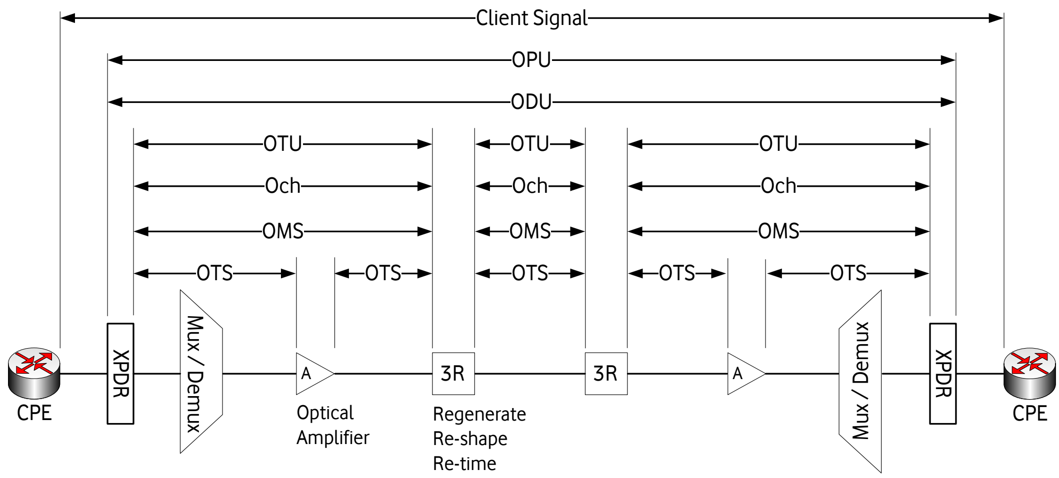

Figure 5– OTN Layer hierarchy and termination points

The OTN has a standard multiplexing hierarchy that defines how lower rate signals map into higher rate payloads. The standardised speeds of the OTN and some typical client mapping examples are shown in Table 2. The OTU represents a physical optical interface or port. The OTU line rates shown are approximately 7% higher than the client signal rates.

G.709 Interface	Line Rate (Gbit/s)	Mapped Client Signal	Client Line rate (Gbit/s)
OTU1	2.666	STM-16	2.488
OTU2	10.709	STM-64	9.953
OTU3	43.018	STM-256	39.813
OTU4	111.810	100GE	103.125

Table 2– OTN Line Rates

Fibre Infrastructure

Vodafone operates a wholly owned terrestrial fibre network which stretches from Whangarei in the north to Invercargill in the south.

Multi strand single mode fibre cables with varying fibre counts link Vodafone POP's within and between major cities. To support resilient transmission multiple fibre routes are available (e.g. between Auckland and Wellington there are three cable routes - one eastern via Tauranga and Napier, one western via Hamilton and Palmerston North and one terrestrial/submarine via Hamilton and New Plymouth). Figure 6 shows the national fibre routes.

Figure 6 – Vodafone National fibre paths

Principles of Operation

FlexWave circuits are provisioned with a Vodafone supplied fibre demarcation tray at the two circuit endpoints. An optical port on customer equipment will be connected with an optical patch cord to a bulkhead connector on the demarcation tray. The demarcation connector is cabled by Vodafone back to a client side port on a transponder (or alternatively muxponder) terminal. The line side ports of the two transponder terminals are connected together using an optical channel derived across the Vodafone optical networks.

Digital data from customer equipment is sent out as a short reach single channel optical signal (i.e. grey or black and white) towards the client side of the transponder terminal. The transponder converts the received optical signal into an electrical signal that is used to produce a laser modulated "coloured" optical signal that is tuned and fits within an assigned WDM wavelength slot.

The modulated OTN formatted signal is applied to the line side of the transponder and propagates along the light path through the optical transport network to the far end transponder where the signal is reconverted back to electrical form reshaped, retimed and retransmitted out to the customer equipment as a single channel optical signal.

Performing a conversion function similar to the transponder, a muxponder can accept multiple single channel optical signals and time division multiplex them together for transmission as a higher rate coloured aggregate signal. The muxponder allows multiple independent services to be carried on the same wavelength.

Transponder/Muxponders can support a range of client side interface options including Ethernet, SDH, OTN and Fibre Channel protocols.

Attenuation and dispersion present in the fibre light path limits the maximum distance span between transponders. Intra–City (Metropolitan) FlexWave services generally do not need additional line amplification. The transponders used with Intra – City services typically span distances up to 120km and support service speeds to 10Gbit/s.

FlexWave Services with speeds above 10Gbit/s and longer distance (Inter-City) services may require optical amplification of the light path and dispersion compensation or signal regeneration at intermediate sites. Different transponder units and in some instances additional regenerators are used for delivering these services. These transponder models may include built in electronic dispersion compensation and use alternative modulation methods.

Figure 7 shows an example of two FlexWave circuits provisioned using both transponders and muxponders.

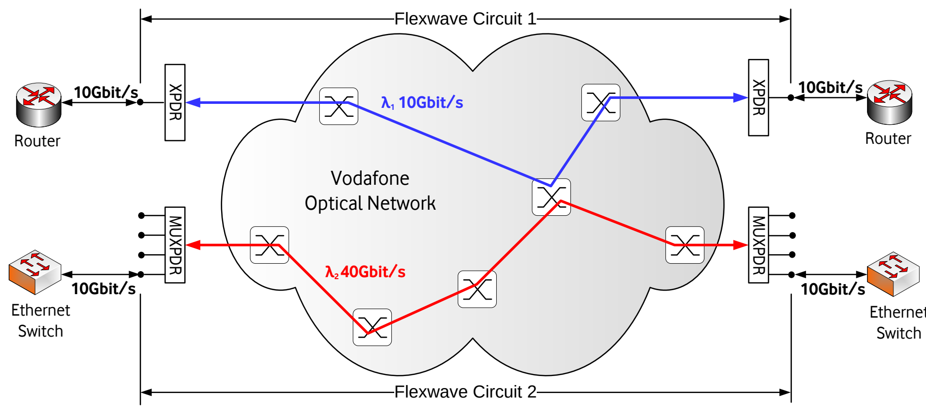

Figure 7 – FlexWave transponder and muxponder based circuits

Geographical Service Coverage

FlexWave is currently available where Vodafone have deployed suitable WDM infrastructure. Currently this is in twenty five cities across New Zealand as listed in Table 3 on the next page and shown on the map in Figure 8.

Table 3 – ROADM Node locations

Coverage Locations	
Whangarei	Masterton
Warkworth	Levin
Wellsford	Wellington
Auckland	Blenheim
Tauranga	Nelson
Hamilton	Kaikoura
Rotorua	Christchurch
Taupo	Ashburton
New Plymouth	Timaru
Whakatane	Queenstown
Napier	Dunedin
Wanganui	Invercargill
Palmerston North	

The coverage of the service within a city may vary depending on the geographic and technical capability of Vodafone's Network at the time at which a request for the Service is made or the Service is to be delivered.

Figure 8 – FlexWave Coverage Map

Data Product Inter-relationships

Although providing point to point connectivity similar to other products in the Vodafone data product portfolio FlexWave is differentiated by its bandwidth range and granularity. As shown in figure 9 FlexWave has less bandwidth steps (granularity) than Transmission and Carrier Ethernet products and supports higher speeds.

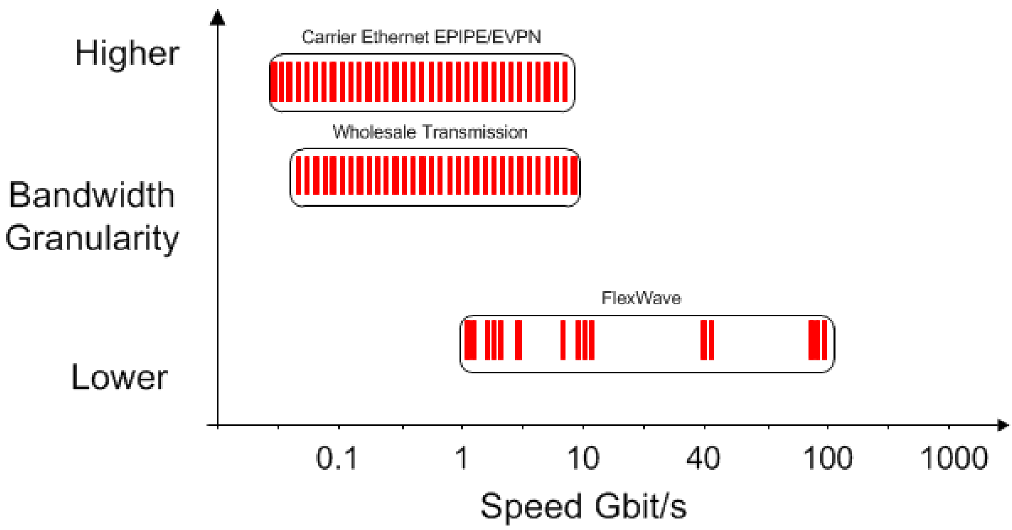

Figure 9 – Data product bandwidth granularity comparison

Common FlexWave deployment arrangements

Flexwave circuits can be deployed in a variety of different arrangements as illustrated in Figure 10. The chosen configuration will depend on specific customer connectivity requirements.

The simplest configuration is unprotected point to point. Protected point to point configurations are available subject to feasibility. More complex arrangements may include drop and continue at multiple sites.

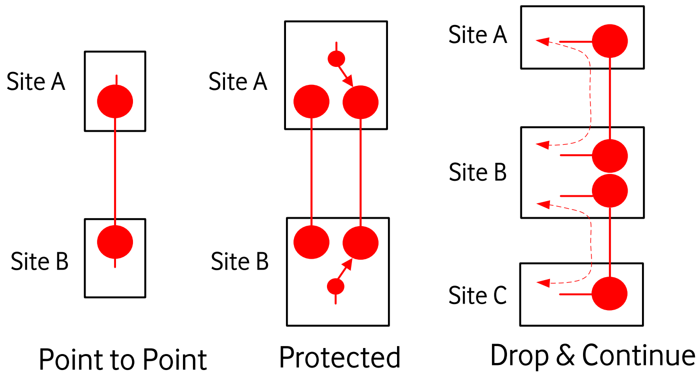

Figure 10 – Common FlexWave deployment scenarios

Bespoke Ethernet connectivity solutions

FlexWave circuits may be used as components in bespoke customer solutions delivering switched Ethernet connectivity at sub rate speeds between sites. In these custom built packet optical solutions, Ethernet Muxponders or other dedicated Ethernet switching equipment may be deployed at circuit endpoints that provide a native Ethernet switching capability as illustrated in Figure 11.

Depending on specific customer requirements this may also include service performance reporting capability accessible through a web portal. Reporting capability is enabled using Ethernet Service OAM technologies available in SNMP managed intelligent Network Interface Devices (NID's) that are deployed at customer sites.

Designs may support MEF compliant E-LINE and E-Access service types providing Ethernet Private Line (EPL); Ethernet Virtual Private Line (EVPL); Access Ethernet Private Line (Access EPL) and Access Ethernet Virtual Private Line (Access EVPL) connectivity.

Bespoke solutions are price on application (POA) and provided on an individual case basis. Customers who require bespoke configurations should contact their Vodafone Solutions Specialist to validate designs and confirm feasibility.

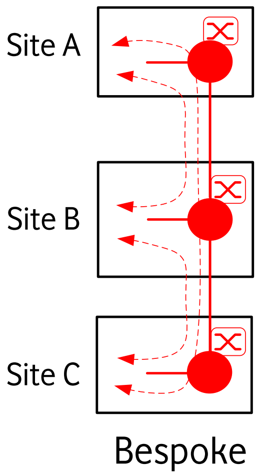

Figure 11 – Bespoke Ethernet connectivity solutions

Protocol and Interface support

FlexWave services being based on WDM technology are able to carry signals of different speeds and types simultaneously and transparently over fibre with protocol and bit rate independence.

The physical interface for FlexWave services is an optical connector on the Vodafone supplied demarcation device installed at the each of the circuit endpoint locations.

Supported Protocols

The protocol and speeds that are currently supported by the FlexWave service are shown in Table 4:

Protocol	Speeds				
Ethernet	1G	10G	40G	100G	
SDH	2.488G (STM-16/OC-48)	9.953G (STM-64/OC-192)	39.813G (STM-256/OC-768)		
OTN	2.666G (OTU1)	10.709G (OTU2) 11.049G (OTU1e) 11.095 (OTU2e)	43.018G (OTU3) 44.571G (OTU3e1) 44.583G (OTU3e2)	111.810G (OTU4)	
Fibre Channel / FICON	1.0625G (1GFC/ FC100)	2.125G (2GFC/ FC200)	4.250G 4GFC/ FC400)	8.500G (8GFC/ FC800)	10.519G (10GFC/ FC1200)

Table 4 – Supported FlexWave Protocols

Client Interface Technical Specifications

Vodafone Transponder and Muxponder terminal equipment use pluggable optics with a variety of different form factors that are dependent on the required protocols and speeds needed for the client facing interface.

The interface technical specifications for each of the different protocols and speeds are listed below in Tables 5 – 8. These interface specifications are the defaults which require single mode fibre cable, LC connectors (compliant with IEC 61754-20 standard) and use O band operating wavelengths. Other fibre types and wavelengths may be available on an individual case basis.

Customers are responsible for supplying and installing the necessary fibre connectivity between the optical ports on their equipment and the assigned connector on the FlexWave demarcation. The fibre cable used if external should comply with ITU-T specification G.652.D or G..657 Category A. For internal building cabling fibres must meet appropriate fire regulations i.e. Flame-Retardant, Non Corrosive, Low Smoke, Zero Halogen.

Table 5 – SDH Client Interfaces

Interface Speed (Mbit/s)	2488	9953	39813
Classification	IR1/S16.1	I-64.1	39.8G-44.6G multirate (4x10G CWDM Lanes)
Connector type	LC	LC	LC
Fibre Type	Single Mode	Single Mode	Single Mode
Transmitter			
Nominal wavelength	1310 nm	1290 nm to 1330 nm	1271 nm, 1291 nm, 1311 nm, and 1331 nm
Transmit output power	0 dBm to -5 dBm	-1 dBm to -6 dBm	+2.3 dBm to -2.3 dBm
Receiver			
Receiver type	PIN photodiode	PIN photodiode	PIN photodiode
Wavelength range	1260 nm to 1360 nm	1290 nm to 1600 nm	1264.5 nm to 1337.5 nm
Receiver Power Range / Sensitivity	-18 dBm	1 dBm to -11 dBm	2.3 dBm to -10.8 dBm
Optical Path			
Attenuation range / Minimum channel insertion loss	0 dB to 12 dB	0 dB to 4 dB	6.7 dB
Nominal reach	15 km	2 km	10 km

Table 6 – Ethernet Client Interfaces

Interface Speed (Gbit/s)	1	10	40	100
Classification	1000Base- LX	10GBase- LR	40GBASE-LR4	100GBASE-LR4
Connector type	LC	LC	LC	LC
Fibre Type	Single Mode	Single Mode	Single Mode	Single Mode
Transmitter				
Nominal wavelength	1310 nm	1290 nm to 1330 nm	1271 nm, 1291 nm, 1311 nm, and 1331 nm	1295 nm, 1300 nm, 1305 nm, and 1310 nm
Transmit output power	-3 dBm to -9.5 dBm	-1 dBm to -6 dBm	+2.3 dBm to -7.0 dBm	+4.5 dBm to -4.3 dBm
Receiver				
Receiver type	PIN photodiode	PIN photodiode	PIN photodiode	PIN photodiode
Wavelength range	1270 nm to 1355 nm	1260 nm to 1355 nm	1264.5 nm to 1337.5 nm	1294.53 nm to 1310.19 nm
Receiver Power Range / Sensitivity	-20 dBm	0.5 dBm to -14.4 dBm	2.3 dBm to -13.7 dBm	4.5 dBm to -10.6 dBm
Optical Path				
Attenuation range / Minimum channel insertion loss		0 dB	6.7 dB	6.3 dB
Nominal reach	10 km	10 km	10 km	10 km

For Ethernet the Maximum Transmission Unit (MTU) is configurable 9600 Bytes (default) or 1600 Bytes.

FlexWave Ethernet circuits will transparently pass Unicast, Multicast, Broadcast and Layer 2 Control Protocol Frames including:

- VLAN 802.1Q
- QoS 802.1P
- Spanning Tree
- LACP
- LAMP
- Ethernet OAM
- PAUSE

Table 7 – OTN Interfaces

Interface Speed (Gbit/s)	2.666	10.709 - 11.095	43.018 – 44.583	111.810
Classification	Fixed wave-lengths (15xx.yy nm)	VSR-2000-2R1	39.8G-44.6G multirate (4x10G CWDM Lanes)	OTU-4
Connector type	LC	LC	LC	LC
Fibre Type	Single Mode	Single Mode	Single Mode	Single Mode
Transmitter				
Nominal wavelength	1310 nm (1260 nm to 1360 nm)	1290 nm to 1330 nm	1271 nm, 1291 nm, 1311 nm, and 1331 nm	1295 nm, 1300 nm, 1305 nm, and 1310 nm
Transmit output power	0 dBm to -5 dBm	-1 dBm to -6 dBm	+2.3 dBm to -2.3 dBm	-2.5 dBm to +4.5 dBm
Receiver				
Receiver type	PIN photodiode	PIN photodiode	PIN photodiode	PIN photodiode
Wavelength range	1260 nm to 1360 nm	1290 nm to 1600 nm	1264.5 nm to 1337.5 nm	1294.53 nm to 1310.19 nm
Receiver Power Range / Sensitivity	-17 dBm	-1.0 dBm to -11.0 dBm	2.3 dBm to -10.8 dBm	+4.5 dBm overload +5.5 dBm damage
Optical Path				
Attenuation range / Minimum channel insertion loss		0 dB to 4 dB	6.7 dB	6.3 dB
Nominal reach	15 km	2 km	10 km	10 km

Table 8 – Fibre Channel Interfaces

Interface Speed (Gbit/s)	1.0625 2.125 4.250	8.500G	10.519
Classification	FC100 SM-L/ FC200 SM-L/ FC400 SM-M	800-SM-LL-L	1200-SM-LL-L
Connector type	LC	LC	LC
Fibre Type	Single Mode	Single Mode	Single Mode
Transmitter			
Nominal wavelength	1310 nm	1290 nm to 1330 nm	1290 nm to 1330 nm
Transmit output power	-3.0 dBm to -11.2 dBm	-1.0 dBm to -14.4 dBm	-0.5 dBm to -14.4 dBm
Receiver			
Receiver type	PIN photodiode	PIN photodiode	PIN photodiode
Wavelength range	1280 nm to 1345 nm	1260 nm to 1580 nm	1290 nm to 1600 nm
Receiver Power Range / Sensitivity	-17.2 dBm at ER of 9 dB	-1 dBm to -14 dBm	-1 dBm to -11 dBm
Optical Path			
Attenuation range / Minimum channel insertion loss		0 dB	0 dB
Nominal reach	10 km	10 km	10 km

Link Loss Forwarding and AIS

To assist customers in managing their own end to end service restoration FlexWave circuits are configured to support fault propagation and notification techniques including link loss forwarding and alarm indication signal.

Link Loss Forwarding also known as Laser Off Far End Fail (LOFEF) is a signal conditioning technique issued by Ethernet interfaces on Vodafone transponders to ensure that a loss of received signal from a customer's CPE at the ingress port at one end of a FlexWave service will cause the transmitted signal from the egress port at the other end of the FlexWave circuit to be dropped also, allowing correct operation of routing protocols which rely on loss of signal to detect link failure.

Alarm Indication Signals (AIS) are issued by SDH and OTN interfaces on Vodafone transponders to ensure that faults within the FlexWave service are indicated to the customers CPE at both ends of the service. When the fault condition is cleared, AIS signals are replaced with normal customer traffic between endpoints. Where AIS signals are received from CPE, they will be propagated through the FlexWave service.

Protected Service Delivery Options

The default delivery option for FlexWave services is unprotected consisting of a single end to end path. For customers that have high availability requirements, options are available (subject to feasibility) that can provide additional resilience in the core and access network. FlexWave services may be delivered into customer premises, third party Data Centres or Vodafone POP sites.

Non-Resilient Service – Unprotected Access/Core

The unprotected service when delivered to customer premises consists of a single access segment at each end which presents a single User Network Interface (UNI) at the delivery location. The default unprotected service is non-resilient in the core between Vodafone POPs and in any access segments as illustrated in Figure 12.

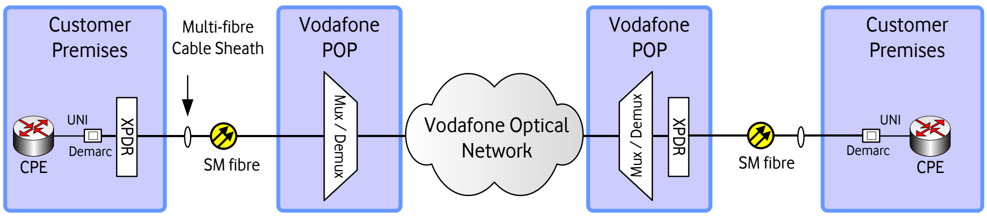

Figure 12 – Non-resilient FlexWave circuit

Connectivity between the Vodafone POP site and the Customer Premise UNI is via a fibre pair in a single mode fibre cable. The lead in cable sheath to the customer premise and Vodafone POP is via a single building entry. The transponders or muxponders used for the service may be located at the customer premises or at the Vodafone POP subject to Vodafone design.

The unprotected service does not provide any protection against failure of any of the fibre path segments (e.g. access fibre cut by external party) or failure of the network elements that are in the circuit path.

Protection Switching Mechanisms

For resilient services Optical Protection Switches (OPS) are used. OPS Layer 0 protection switching operates in a fashion that is based on the protection architecture defined in ITU G-873 (i.e. 1+1 Linear APS protection at OTN layer 1).

Figure 13 illustrates a typical optical protection switch configuration. In the transmit (TX) direction, the signal from the customer CPE is divided into two optical streams by a splitter and is sent to the RX in ports of both the working and the protection circuits. The splitter functions as a standard head-end bridge defined in a 1+1 protection scheme, where the normal traffic signal is permanently bridged to protection.

In the receive (RX) direction, the signal arriving at the customer CPE will be sourced via a switch from either the TX out of the working or the protection circuit. The selection of which signal is used is made by the optical switch and is based on optical power and provisioned Loss of Signal (LOS) thresholds. At the tail-end, the OPS operates as per any 1+1 unidirectional protection-switching architecture - a Rx selector makes a decision according to defects and commands received at the tail end.

Since the OPS is using a splitter to perform a permanent head-end bridge, switching only occurs for one direction of transmission (i.e. unidirectional).
The OPS does not support bidirectional switching.

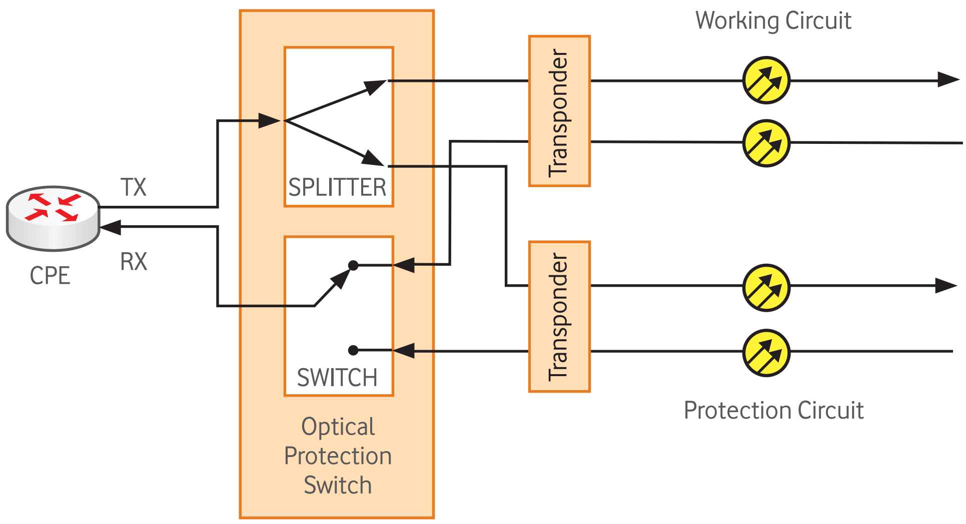

Figure 13 – Optical Protection Switch

Resilient Service – Protected 1+1 End to End

The protected service consists of dual access segments at each end with duplicated transponder equipment at the customer sites and where feasible physically diverse building entry. The service is presented on a single UNI at the delivery location via an optical protection switch. Within the Vodafone core network diverse equipment and two fibre paths are provided with geographic separation. Figure 14 below illustrates typical interconnection arrangements.

The dual access fully protected service provides automatic 1+1 protection using an optical protection switch at each end. One circuit path is designated as the working link that carries traffic under normal conditions (i.e. no-failure). The second path is designated as the protection link which does not carry traffic under normal conditions.

Should the working link experience failure traffic will automatically switch to the protection link and the protection link becomes the active link. The protection switching is Non Revertive i.e. Traffic switched to the protection path due to a fault condition (or manual switch) does not automatically switch back to the original path once a fault is repaired (unless there is a fault on the new path).

The protection switch occurs within 50mSec of detection.

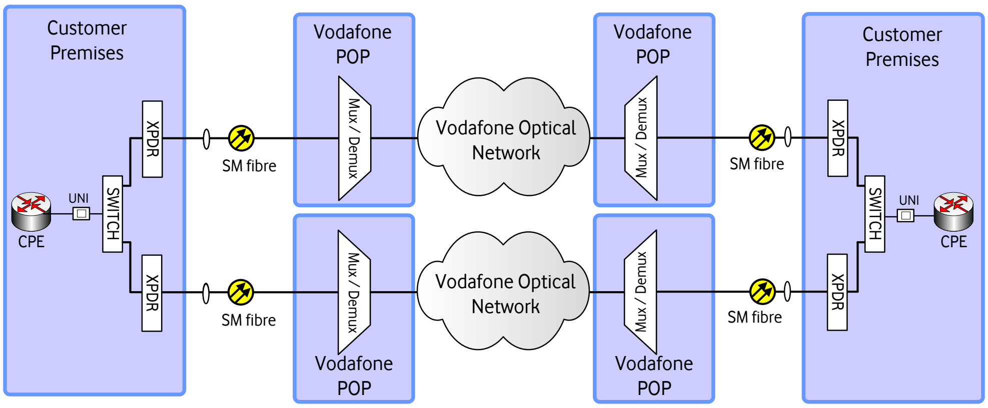

Figure 14 – End to end protected FlexWave service

The protected service being dual routed with separation between circuit paths can protect against fibre failure of one fibre path or cable failure or failure of one piece of equipment.

Customers wishing to perform their own protection switching can alternatively order two unprotected FlexWave circuits and manage the traffic failover between the two. Provision of geographic separation between circuit paths is subject to feasibility. NB - Vodafone cannot guarantee that geographic separation if provided can be indefinitely maintained between unprotected circuits.

Service Delivery Point Environment

Where FlexWave is delivered to a customer site using on site active electronics a suitable environment is required to be provided by the customer.

The equipment that is deployed will depend on Vodafone assessment of likely future capacity needs. The type and quantity of equipment will be determined during Wavelength service design.

The customer will be required to provide a rack or enclosure (or alternatively a footprint where Vodafone can deploy a rack) to accommodate Vodafone Multi Service Provisioning Platform (MSPP) terminal equipment. Following are the environmental requirements for the Vodafone equipment.

Power Supply Requirements

The customer must ensure that the rack or enclosure that houses any FlexWave service equipment is supplied with a suitable AC Mains or DC power supply.

AC Supply	240V Single Phase
DC Supply	-48V DC Nominal

Equipment Power Consumption

Typical power consumption will vary depending on the number of Transponders / Muxponders and common equipment cards deployed at the customer site, but is expected to lie within the following approximate range:

Installation Type	Typical Power Consumption
Standard (e.g. where no. of FlexWave services < 5)	250 Watts
Medium to Large (e.g. where no. of FlexWave services > 5)	750 Watts

AC Mains Supply

Where an AC mains supply is provided, the customer must ensure the following conditions are met for the AC power supply:

- 2 x 10A general purpose switched outlet sockets are available for Vodafone use
- The AC power feed supplying the Vodafone rack must be separately protected and hard wired from the building power distribution board.
- Power and earthing of the Vodafone rack must conform to AS/NZS 3000:2007 and be performed by a qualified electrician.
- AC power sockets and power board circuit breakers must be legibly and indelibly labelled by the electrician.
- Earthing must comply with AS/NZS 3000:2007 and AS/NZS 3015:2004

DC Mains Supply

Where a DC power supply is provided, the customer must ensure the following conditions are met for the DC power supply:

- DC power system to comply with AS/NZS 3000:2007 and AS/NZS 3015:2004
- Nominal output voltage must be -48V DC with the positive conductor connected to a suitable telecommunications earthing system.
- Minimum battery reserve time must be 8 hours at actual power system load. Reserve time may be less than 8 hours (minimum of 3 hours) where the AC mains primary power input to the customers power system is backed up with a standby automatic start generator set.
- Distribution must be low ohmic with dual (A/B) DC feeds sourced from separate overload protection devices available if required by Vodafone. Feeds to be dedicated to Vodafone equipment and not shared with others.

Operating Temperature and Humidity

To ensure correct operation of DWDM equipment, the following environmental conditions need to be maintained at customer premises that house FlexWave service equipment.

Operating Temperature Range	5 degrees Celsius to 40 degrees Celsius
Relative Humidity Limits	5% to 85%

Optical Lead In

Vodafone will provide single mode fibre lead in cable to a site which will terminate on a fibre termination unit. The termination unit is usually wall or rack mounted in the building communication room, communications cabinet or main distribution frame. Wall space may be required which the customer will need to provide where a new wall unit is required. An existing optical fibre termination panel may be used subject to Vodafone assessment and approval.

6 Service Fulfilment and Assurance

Ordering Eligibility

To be eligible to purchase Vodafone FlexWave services a new Wholesale customer must have signed a Wholesale Services Agreement (WSA) and have an account opened with Vodafone Wholesale. The criteria used to determine customer eligibility are as follows:

- Must be a Telecommunications Network Operator; and/or
- Must on-sell services received from Vodafone Wholesale to its own customers under its own brand; and/or
- Must be selling services in direct competition to the Vodafone Retail Business Units; and
- Must perform all its own sales, marketing, customer service and billing functions

FlexWave services are offered under the terms of the WSA and the associated FlexWave Service Description

Pre Sales Support

Vodafone Client Liaison and Solutions Specialists are available to provide pre-sales support for customers.

Client liaison staff can assist customers with feasibility checks to determine if sites where customers would like services delivered are reachable on the Vodafone network via intact facilities or whether network augmentation or extension is required to access a site. Formal feasibility studies and quotations are available on request. All quotations include a unique reference number that can be used in any subsequent orders.

Submitting Orders

FlexWave services are ordered using a Vodafone order form.
Orders types fall into three categories:

- New Connections
- Moves, Adds and Changes
- Cancellations (Relinquishment)

The provisioning lead time for an order may vary depending on the nature of the work involved (i.e. whether intact network facilities are in place at all sites or if new facilities are needed to be constructed at some locations). Typical SLA timeframes are given in section 6.3.4.

An acknowledgement confirming receipt of an order, and an estimated completion date and Order reference number are provided for all orders. The order number should be used when requesting any order progress updates.

7 Provisioning

Install Co-ordination

Once an order has been placed and accepted, a Project Manager will be assigned who will confirm delivery dates and oversee install and provisioning activities of internal teams through to handover.
An install typically has four stages

- Audit - In this stage delivery methods, capacity checks and approvals are carried out
- Design - In this stage design and building of any required physical infrastructure is carried out and records systems are updated
- Activation – In this stage an order is prepared for cutover which includes bearer stand-up, port configuration and logical connections in network elements
- Cutover – In this stage services are turned up providing end to end connectivity

The Project Manager will notify customers on order completion and provide fulfilment information such as circuit identifiers for the service(s).

Access Fibre Installation

Where a new access fibre is required to deliver a service a Vodafone Installation Manager or Field Service contractor will contact the customers nominated site contact to arrange on site access to the end customer site and to clarify technical details regarding the service delivery.

Vodafone will deliver and extend the access fibre to the nominated delivery location. The fibre will be terminated on a Vodafone supplied demarcation.

8 Operations and Maintenance

Faults

The Vodafone Customer Help Premium Support helpdesk is the primary point of contact for fault reporting. Through the helpdesk, Vodafone provides a 24x7 fault logging facility. The helpdesk will investigate and manage faults through to resolution, update customers on progress with fault resolution and escalate any unresolved faults to an appropriate manager.

Customers experiencing faults on FlexWave services should investigate and perform initial diagnosis to ensure the trouble is not within their own network or equipment before logging a fault with Vodafone.

The following information should be to hand when reporting faults:

- Vodafone Account Number
- Contact details for advice of progress/resolution
- Full description of fault and impact to user
- Arrangements for site access if required
- Vodafone circuit ID (if available)

Faults are prioritised by the helpdesk and are actioned according to their priority. Table 9 describes the criteria for classification for each level.

Fault Prioritisation Level	Description
Critical Impact (P1)	A service affecting incident for which there is no alternative solution e.g. complete failure of a circuit that has caused a customer site isolation or severe degraded performance.
Major Impact (P2)	A service affecting incident caused by degraded performance of the leased line e.g. errors or intermittent short outages. Or A failure of a circuit where the customer has some form of resilience, which enables normal business operations to continue while the Supplier restores service to the failed lease line.
Minor Impact (P3)	Incidents that have no noticeable impact on the customers' business e.g. errors on the leased line well within normal performance parameters. Typically raised as an attempt to prevent a critical or major Incident.

Table 9 – Fault Prioritisation Criteria

A trouble ticket reference will be provided by Customer Help which can be used in any further interactions and for obtaining trouble ticket status updates. Charges may apply for unnecessary site visits by service personnel to attend a fault when there is no fault found in the Vodafone network.

Planned Outages

Where Vodafone needs to carry out any planned maintenance on its network which may affect an FlexWave service Vodafone will endeavour to give the customer a minimum of 10 business day's notice prior to any service impacting planned outage or a minimum of 3 business day's notice prior to any Non-service impacting planned maintenance.

Un-planned Outages

In the event of a major unplanned service interruption to FlexWave services Vodafone will endeavour to provide customers with a written report upon request (Reason For Information (RFI)) within 10 Business days of the event, outlining:

- Fault timeline
- Incident summary
- Resolution
- Preventive/Corrective action
- Root Cause

Service Delivery Timeframes

Attribute	Service Level Target Lead Time (ONNET)
New Installation (Intact Cabling) Assumes existing site with existing intact fibre cabling (customer premise to Vodafone POP) and network equipment available to provide service (i.e. Standard Installation).	30 Business Days
Network Extension For sites requiring network extension to reach the customer premise. This may involve network equipment installation, road trenching, duct laying, cable hauling, jointing and internal cabling. (i.e. Non Standard Installation).	Minimum 45 Business Days – reliant on building owner and council consents.
Moves/Adds/Changes Remote configuration - No site visit required (Simple MAC)	3 – 5 Business Days
Moves/Adds/Changes Work requiring a site visit (Standard MAC)	15 Business Days
Moves/Adds/Changes Complex work requiring a site visit (Complex MAC)	As agreed.
Cancellation[1] (Relinquishment) Removal of any associated site equipment , jumpers and deactivation of circuit path	10 Business Days
External Relocation Relocation of UNI from one site to another site	As per new installation
Internal Relocation Relocation of UNI within a site	Timeline to be discussed and advised at the time of the order
[1] This is the service level for the physical cancellation. Contracted terms are not affected by this	

Table 10 – Service Delivery Timeframes from Order acceptance

9 Fault Management

Fault logging, response, status notifications and Incident Reporting Timeframes

Attribute	Service Target
Fault Reporting Telephone contact with Customer Help Premium Support	Faults can be reported 365 days per year and 24 hours per day
Trouble ticket status updates Telephone contact with Customer Help Premium Support	Status updates can be requested 365 days per year and 24 hours per day
Helpdesk Response Advice Initial notification to advise the issue's progress and the latest expectation of a resolution timeframe	Target within 0.5 hours of the issue being logged, unless Vodafone Wholesale has agreed otherwise with the Customer
Helpdesk Follow Up Advice An updated notification of the latest progress of the issue and expected resolution timeframe	P1 Faults - Every 1 hours P2 Faults – Every 2 hours P3 Faults – Every 8 hours, or - as otherwise agreed with the Customer, or in the event of changed circumstances
Helpdesk Resolution Advice Advise the issue has been resolved	As soon as practical and with consideration to the customer' requirements
Post Incident Reporting After the incident, Vodafone Wholesale can provide a report with details of a particular fault on the service	Reason for Outage (RFO) reports provided on request
Vodafone Wholesale reserves the right to charge customers for costs in the event that we are called to a Customer's site for a fault call that is subsequently proven to be in the Customer's equipment or third party equipment used by the Customer. This also applies to faults caused by negligent use or misuse by the Customer, its employees, agents, suppliers, customers or other third parties.	

Table 11 – Fault Management Communication Timeframes

Fault Restoration Site Visits - Site Location Categories

Site Classification	Definition
Metro Sites	Sites that are within 65km of the central business districts of Auckland, Hamilton, Wellington, Christchurch and Dunedin.
Regional Sites	Sites that are within 30km of the central business district of Whangarei, Rotorua, New Plymouth, Napier/Hastings, Palmerston North, Nelson, Greymouth and Invercargill.
Other NZ Sites	Sites outside of Metro and Regional Sites.

Table 12 – Site Location Classification

Fault Restoration Timeframes

Fault Priority	ONNET Equipment fault	
	Category	Elapsed Time
P1 Critical	No Site Visit	4 Hours
P1 Critical	Site Visit- Metro	6 Hours
P1 Critical	Site Visit -Regional	6 hours
P1 Critical	Site Visit- Other NZ	8 hours
P2 Major	No Site Visit	8 hours
P2 Major	Site Visit- Metro	10 hours
P2 Major	Site Visit -Regional	10 hours
P2 Major	Site Visit- Other NZ	12 hours
P3 Minor	Minor Fault	5 days

Table 13 – Fault Restoration Timeframes

NB – SLA targets in the above table are for service interruptions due to equipment failure. Individual resolution times will be increased where the resolution is delayed due to external factors including:

- Periods of time during which the end user is not able to assist Vodafone in providing data or technical specifications, or building access (provided such information and/or access requests are reasonable and requested in a timely manner);
- Malfunction due to hardware or services not provided by Vodafone (directly or indirectly via Subcontractors or otherwise);
- Incidents caused by the end user, which directly and solely caused delay;
- General power cuts at the end users Site;
- Planned network maintenance agreed by the parties, which is carried out entirely within the window agreed by the parties; or
- A) Force Majeure Event;

Where a Service interruption is the result of a fibre optic cable cut by a third party the cable repair time target is 9 hours.

Service Performance

Performance Objective Parameter Definitions

Parameter	Definition
Availability	A measure of the percentage of time that a service is useable.
Latency	The delay between initiating (sending) data into one UNI and the reception of that data out of the far end UNI. Latency is a one way delay measurement (source to destination).

Service performance target metrics for latency and availability are set out in Table 14 below.

Parameter	Target
Availability* - Unprotected Single Access	99.70%.
Availability* - Protected Dual Access	99.95%
Latency	<5mSec Intra – City <15mSec Inter - City

Table14 – Service Performance Target Metrics

The target availability for the FlexWave service is based on a rolling 12 month period.

* - Vodafone makes no guarantee or representation about the actual availability of the FlexWave service. Although we aim to meet the service metric shown in the table, breaches of this target do not trigger rebates on FlexWave services.

10 Pricing and Billing

Pricing

The rate elements associated with FlexWave services are as follows:

- Installation Charges
- Circuit Charges
- Moves, Adds and Changes Charges
- Miscellaneous Charges
- Early Termination Charges
- Additional Works Charges

A minimum one year term applies to FlexWave services. All charges are in New Zealand Dollars and exclude GST. Non-recurring and recurring charges may be eligible for fixed term discounts.

Monthly Recurring Charges (MRC)

Each circuit incurs an MRC charge. These charges are payable for each whole month, or as a pro-rata charge for each part of a month thereof that each circuit is supplied (commencing on the start Date). Charges are invoiced in advance.

Circuit pricing takes into account speeds, charge zone and resiliency options.

The applicable zone that applies to a circuit is based on the city that the circuit endpoints reside in and can be determined by consulting the charge zone matrix shown in Table 15.

Non Recurring Charges

Installation Charge – Each circuit installed incurs an NRC charge. This charge is invoiced in arrears.

Network Extension Charge – An additional charge may apply where the Installation of a circuit requires the extension of network infrastructure or work (including but not limited to trenching, additional cabling or boring) to connect the Vodafone Network with the UNI at the Customer Site.

MAC Charge – MAC charges are incurred following completion and invoiced in arrears for:

- Speed upgrades/downgrades
- Interface presentation change
- UNI Internal Relocation
- UNI External Relocation

	Whangarei	Warkworth	Wellsford	Auckland	Tauranga	Hamilton	Rotorua	Taupo	New Plymouth	Whakatane	Napier	Wanganui	Palmerston North	Masterton	Levin	Wellington	Blenheim	Nelson	Kaikoura	Christchurch	Ashburton	Timaru	Queenstown	Dunedin	Invercargill
Whangarei	A	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D	E	E	E
Warkworth	B	A	A	B	C	B	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	E	D	E
Wellsford	B	A	A	A	C	B	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	E	D	E
Auckland	B	B	A	A	B	B	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D	D	E
Tauranga	C	C	C	B	A	B	A	B	C	B	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D
Hamilton	C	B	B	B	B	A	B	B	C	B	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D
Rotorua	C	C	C	C	A	B	A	B	C	B	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D
Taupo	C	C	C	C	B	B	B	A	C	B	B	C	C	C	C	C	C	C	C	C	D	D	D	D	D
New Plymouth	C	C	C	C	C	C	C	C	A	C	C	B	C	C	C	C	C	C	C	C	D	D	D	D	D
Whakatane	C	C	C	C	B	B	B	B	C	A	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D
Napier	C	C	C	C	C	C	C	B	C	C	A	C	B	C	C	C	C	C	C	C	C	D	D	D	D
Wanganui	C	C	C	C	C	C	C	C	B	C	C	A	A	B	B	B	C	C	C	C	C	C	D	D	D
Palmerston North	C	C	C	C	C	C	C	C	C	C	B	A	A	B	A	B	C	C	C	C	C	C	D	D	D
Masterton	C	C	C	C	C	C	C	C	C	C	C	B	B	A	B	B	C	C	C	C	C	C	D	D	D
Levin	C	C	C	C	C	C	C	C	C	C	C	B	A	B	A	B	C	C	C	C	C	C	D	D	D
Wellington	C	C	C	C	C	C	C	C	C	C	C	B	B	B	B	A	B	B	C	C	C	C	D	C	D
Blenheim	D	C	C	C	C	C	C	C	C	C	C	C	C	C	C	B	A	B	B	C	C	C	C	C	D
Nelson	D	D	D	D	C	C	C	C	C	C	C	C	C	C	C	B	B	A	C	C	C	C	C	C	D
Kaikoura	D	D	D	D	C	C	C	C	C	C	C	C	C	C	C	C	B	C	A	B	C	C	C	C	C
Christchurch	D	D	D	D	D	D	D	C	C	D	C	C	C	C	C	C	C	C	B	A	B	B	C	C	C
Ashburton	D	D	D	D	D	D	D	D	D	D	C	C	C	C	C	C	C	C	C	B	A	B	C	C	C
Timaru	D	D	D	D	D	D	D	D	D	D	D	C	C	C	C	C	C	C	C	B	B	A	C	B	C
Queenstown	E	E	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	C	C	C	C	C	A	C	B
Dunedin	E	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	C	C	C	C	C	B	C	A	B
Invercargill	E	E	E	E	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	C	C	C	B	B	A

Table 15 - Charge Zone Matrix

Miscellaneous Charges – These charges may be incurred for:

- Incorrect Callouts
- Feasibility Study
- Relocation of Telecommunications Infrastructure

Early Termination Charges – A charge may apply when FlexWave services are terminated before the minimum term for the service has expired.

Additional Works Charges – These charges may be incurred for:

- Work performed outside Vodafone's Standard Hours of Business including installation
- Miscellaneous works associated with service activation
- Work performed at customer request to resolve a customer problem

Billing

FlexWave services are billed on a monthly basis. Installation charges and recurring charges are itemised on the invoice.

Vodafone runs five bill cycles T01, T10, T16, T21 and T26 spread across each month. The bill cycle that a customer account is assigned to will determine the day of the month their bill preparation occurs on.

Vodafone will provide customers with a paper invoice (or pdf copy) for each account they operate showing charges for FlexWave services. Electronic billing (E-bill) files supporting the monthly paper bills can be provided on request. E-bill files are available for download from the Vodafone website. Customers requiring E-bill files should contact their Account Support Representative to arrange a website login.

FlexWave services are identified on the invoice by a circuit identifier. Each circuit is given a unique circuit identifier. Each circuit identifier appears as a line item on the invoice. Additional line items associated with the circuit identifier (i.e. billing service instance) provide the following information:

- Charge component description
- From and To dates applicable to the charge
- Charge amount

The circuit recurring charge component descriptions will identify the speed and the charge zone.

Billing enquiries should be directed to customers Account Support Representative in the first instance.

Acronyms

Acronym	Expansion
CBD	Central Business District
CBR	Constant Bit Rate
CPE	Customer Premise Equipment
CWDM	Coarse Wave Division Multiplexing
DEMUX	Demultiplexer
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium-Doped Fibre Amplifier
E-MOTR	Ethernet Multiplexing Optical Transponder
EPL	Ethernet Private Line
EVPL	Ethernet Virtual Private Line
FEC	Forward Error Correction
FICON	Fibre Connection
IEEE	Institute of Electrical and Electronics Engineers
INCITS	International Committee for Information Technology Standards
ITU	International Telecommunication Union
LASER	Light Amplification by Stimulated Emission of Radiation
MEF	Metro Ethernet Forum
MMF	Multi-Mode Fibre
MSPP	Multi Service Provisioning Platform
MUX	Multiplexer
OAM	Operations Administration and Maintenance
OCh	Optical Channel
ODU	Optical Channel Data Unit
OMS	Optical Multiplex Section
OPU	Optical Channel Payload Unit
OSC	Optical Supervisory Channel
OSNR	Optical Signal to Noise Ratio
OTN	Optical Transport Network
OTS	Optical Transmission Section
POA	Price on Application
ROADM	Reconfigurable Optical Add Drop Multiplexer
SAN	Storage Area Networking
SDH	Synchronous Digital Hierarchy
SLA	Service Level Agreement
SMF	Single Mode Fibre
TCM	Tandem Connection Monitoring
UNI	User Network Interface
POP	Point of Presence
WDM	Wave Division Multiplexing
WSA	Wholesale Services Agreement
WSS	Wavelength Selective Switch

Table 16: Acronyms

11 Glossary

Term	Description
Attenuation	In fibre optic communication attenuation is the decrease in intensity of electromagnetic radiation caused by absorption or scattering of photons.
Chromatic Dispersion	A phenomenon that occurs in fibre optic communications whereby different wavelengths (i.e. colours) propagating on the same cable arrive at their destination at slightly different times. Dispersion results in spreading of the on off pulses that convey digital information.
Constant Bit Rate (CBR)	A Constant Bit Rate signal is one that maintains a fixed bitrate over time. SDH and OTN are examples of transmission systems that generate CBR signals.
Erbium Doped Fibre Amplifier (EDFA)	A type of optical amplifier that uses a silica fibre core doped with trivalent erbium ions that is pumped using a laser at a wavelength of 980 nm or 1,480 nm, and exhibits gain in the 1,550 nm region.
Ethernet	A frame based computer networking technology that adheres to the IEEE 802.3 international standards and enables multipoint digital data communication.
Fibre Channel	A general purpose high speed data communications technology that adheres to INCITS standards and can be used to transport both server to storage peripheral Input / Output (I/O) communications and other multimedia and networking protocols over a single communication channel.
Frequency	The number of cycles that occur in a unit time of a periodic wave. Commonly designated by the Latin letter f, frequency is inversely related to wavelength (λ).
ITU Grid	A table of all the central frequencies (and corresponding wavelengths) of channels allowed in a DWDM communications system defined by the ITU in recommendation G.649.1
Laser	A device that emits coherent light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.
Multi- Mode Fibre (MMF)	A type of fibre optic cable that has a core diameter that is large enough compared to the wavelengths applied to support multiple light paths or modes.
Muxponder	A form of Transponder that can accept multiple single channel optical signals and time division multiplex them together for transmission as a higher rate coloured optical aggregate signal.
Nanometre (nm)	A unit of length in the metric system equal to one billionth of a metre. In scientific notation can be written as 1×10^{-9}
Optical Transport Network	A set of optical network elements connected by Fibre links, able to provide functionality of transport, multiplexing, switching, management, supervision and survivability of optical channels carrying client signals. An OTN enables transparent transport of data services over optical wavelengths in DWDM systems and has been standardized in ITU recommendation G.709.
Reconfigurable Optical Add Drop Multiplexer	A form of optical add-drop multiplexer that has the ability to remotely switch traffic from a wavelength-division multiplexing (WDM) system at the wavelength layer.
Single Mode Fibre (SMF)	A type of fibre optic cable that has a core diameter that is very narrow compared to the wavelengths applied and will only support a single light path or mode.
Synchronous Digital Hierarchy	A switching and transport technology that adheres to International Telecommunications Union (ITU) G.707, G.783, G.784 and G.803 international standards and enables multiplexing of multiple digital bit streams for transport over optical fibre
TeraHertz (THz)	A unit of electromagnetic wave frequency equal to one trillion hertz (1×10^{12} Hz). The terahertz is used as an indicator of the frequency of infrared (IR), visible, and ultraviolet (UV) radiation.
Transponder	A device that converts an optical signal at one wavelength to an optical signal at another wavelength (typically ITU standardized for DWDM communication). Transponders can be considered as two transceivers placed back-to-back.
Wavelength	The distance between identical points in adjacent cycles of a waveform signal propagated along a cable medium or in free space. Commonly designated by the Greek letter lambda (λ), wavelength is inversely related to frequency.

Term	Description
Wave Division Multiplexing (DWDM)	a fibre optic communications technology that enables multiplexing of multiple optical carrier signals onto a single optical fibre by using different optical frequencies (also referred to as wavelengths or colours).
Wavelength Selective Switch (WSS)	A components used in WDM optical communications networks to route (switch) signals between optical fibres on a per-wavelength basis.

Table 17: Glossary of Terms

Appendix A – Optical Transmission Fundamentals

Communications Spectrum

Digital data signals (i.e. digital bit streams) can be transmitted over optical fibres using light. Fibre strands act as waveguides for light.

Light is a form of electromagnetic radiation and can occur at many wavelengths (i.e. frequencies). The spectrum of light, as shown in Figure 15 below, runs from invisible infra-red through the visible colours (red, blue etc.) to invisible ultraviolet.

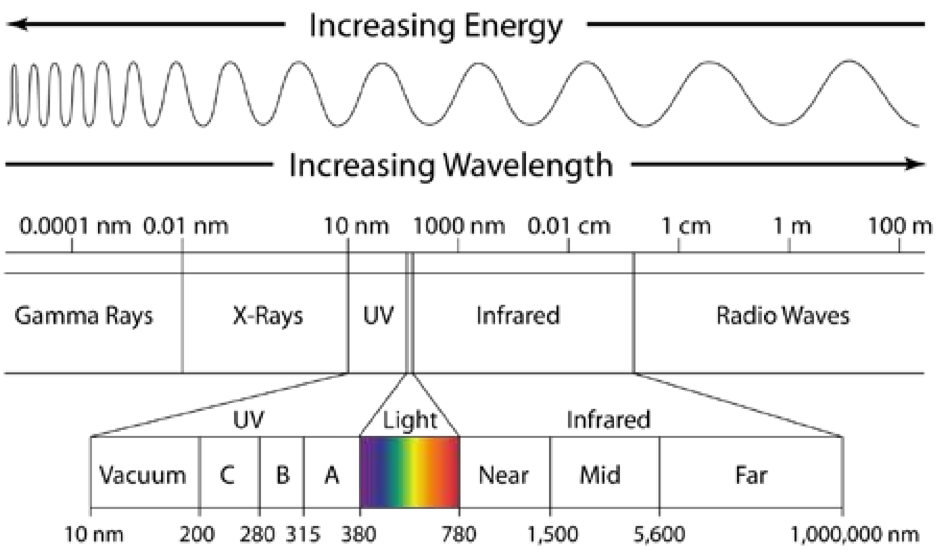

Figure 15 – Electromagnetic Spectrum

For telecommunication services over optical fibres light from the infra-red part of the spectrum is used mainly due to the lower attenuation experienced in fibres at these wavelengths.

Fibre construction and classification

Optical fibres are constructed from extruded glass (silica), are transparent and flexible and are typically bundled into multi-stranded cables. Fibre strands are composed of two optical layers known as the core and cladding as shown in Figure 16.

Figure 16 – Fibre Cable construction.

The cladding layer surrounds the core and has a lower index of refraction.
Light propagation in fibres

Light entering a fibre can take a finite number of paths known as modes. Fibre with a core diameter large enough to find multiple modes is called "multimode" fibre (MMF). Fibre with a core diameter that is very narrow compared to the wavelength in use will not support multiple modes and is called "single mode" fibre (SMF).

When light passes down a fibre it experiences impairments. These include:

Transmission Loss (i.e. Attenuation) - due to the effects of scattering and absorption in the glass. The weakening of light intensity with distance limits how far transmitted digital signals can travel and be successfully detected and recovered at the receiver without needing additional amplification.

Material (Chromatic) Dispersion – Light sources produce a range of wavelengths (light bands) rather than a single wavelength. Fibre has different refractive index characteristics at different wavelengths and therefore each wavelength will travel at a different speed in the fibre. This results in pulses of light spreading out during transmission becoming longer and ultimately joining with the pulse behind, making recovery of a reliable bit stream impossible. Dispersion increases as the square of the signal rate placing limits on the maximum data rate and transmission distance before signal regeneration is required.

Figure 17 illustrates the behaviour of a pulse of light introduced to multimode and single mode fibre. Single Mode fibre has lower attenuation and much lower dispersion that multimode making it the preferred choice for longer distance and higher bandwidth applications.

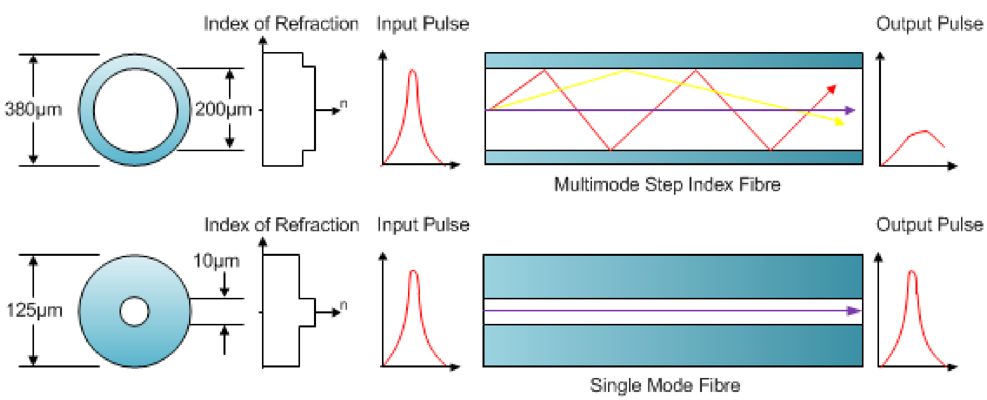

Figure 17 – Light propagation in different fibre types

Operating Wavelengths

To provide very high capacity for optical transmission systems, allowing as wide a range as possible for the system operating wavelengths is desirable. The choice of operating wavelength range depends on several factors, including fibre type, optical source characteristics, system attenuation range, and dispersion of the optical path.

For long distance communications having lowest attenuation and dispersion allows greater spacing between any required signal regenerators. Minimising regeneration points can significantly reduce total transmission system cost.
Historically three bands or windows in the fibre spectrum were identified where losses are lowest as described below.

Window Name	Wavelength range	Key Characteristics
First	Short Wavelength 800 – 900nm	First communications band (1970s). Highest attenuation. Lowest cost light sources and detectors. Short reach only rarely used today.
Second	Medium Wavelength 1260 – 1360nm	Lowest dispersion but higher attenuation (Zero at 1310nm on SMF). More expensive light sources and detectors. Used today for medium reach applications up to 10km
Third	Long Wavelength 1500 – 1600nm	Lowest attenuation but higher dispersion. Optical amplifiers operate here. Difficult and expensive to make light sources and detectors. Used for almost all long distance and DWDM applications today.

The International Telecommunications Union (ITU) has defined the following spectral bands for single mode fibre systems:

Band Name	Wavelengths (nm)	Description
O-band	1260 – 1360	Original band (second window)
E-band	1360 – 1460	Extended band
S-band	1460 – 1530	Short Wavelength band
C-band	1530 – 1565	Conventional band (third window)
L-band	1565 – 1625	Long Wavelength band
U-band	1625 – 1675	Ultra Long Wavelength band

Figure 18 shows the attenuation/dispersion characteristics of SMF and the associated windows and bands.

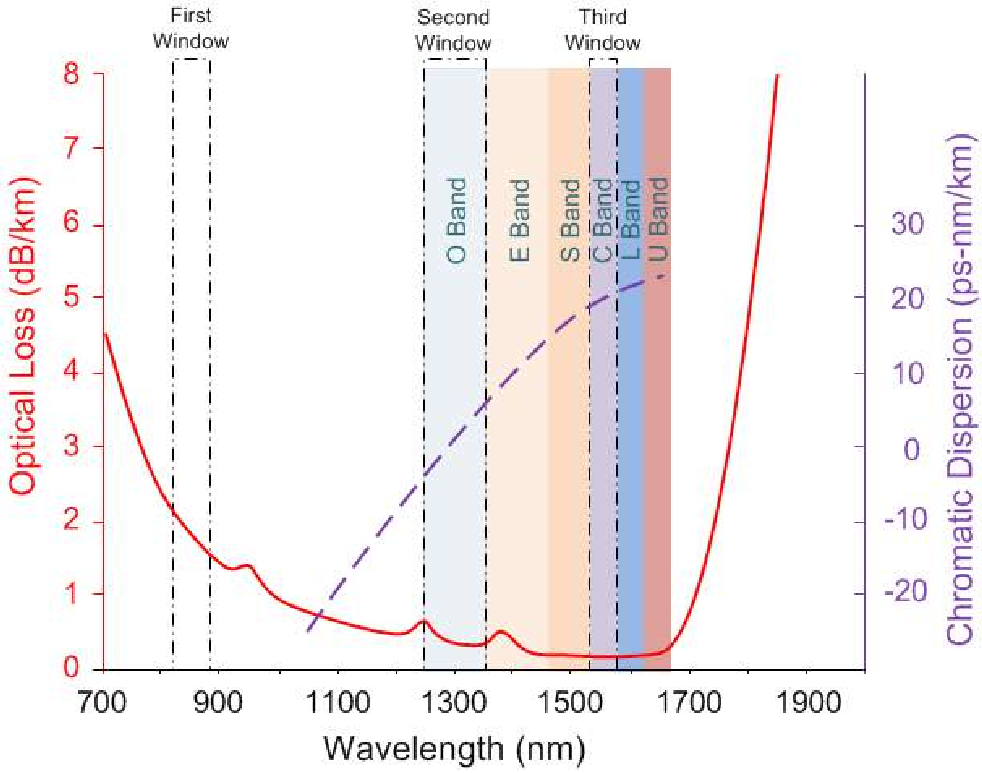

Figure 18 - Spectral attenuation/dispersion in single mode fibre.

Optical Transmission Systems

The basic elements of an optical transmission system are shown in Figure 19 below:

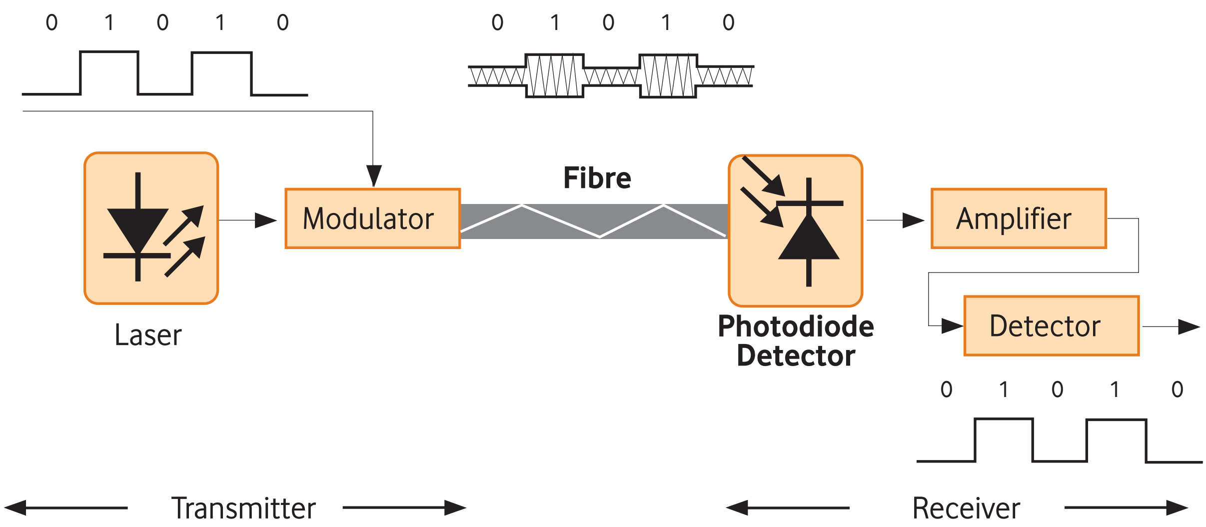

Figure 19 – Optical Transmission System Components

A Laser light source provides a stable carrier wave to a modulator

A serial bit stream in electrical form is used to modulate the carrier wave producing a narrowband optical signal which is focused into the fibre.

The modulated light travels down the fibre (during which time it may experience dispersion and loss of strength).

At the receiver end the light is fed to a detector and converted to electrical form.

The signal is then amplified and fed to another detector, which isolates the individual state changes and their timing. It then decodes the sequence of state changes and reconstructs the original bit stream.

Single Channel Optical Systems

Networking equipment commonly used by enterprises (such as Routers or Ethernet Switches) that is capable of optical transmission will typically have single channel interfaces. With this type of interface only one optical channel (i.e. one wavelength or frequency) is present on the optical fibre linking the equipment ports.

Figure 20 shows an example of two Ethernet switches with single channel interface ports each located in separate sites linked by a short distance (2km) fibre connection.

As illustrated, the switch ports contain a combined optical transmitter and receiver (transceiver) with one fibre used for each direction of transmission. The digital signals being transmitted modulate an optical carrier signal that is applied to the fibre line. The modulated signal can be shown to contain a band of frequencies around the optical carrier centre frequency of 1310nm (O band) whose width is dependent on the data rate.

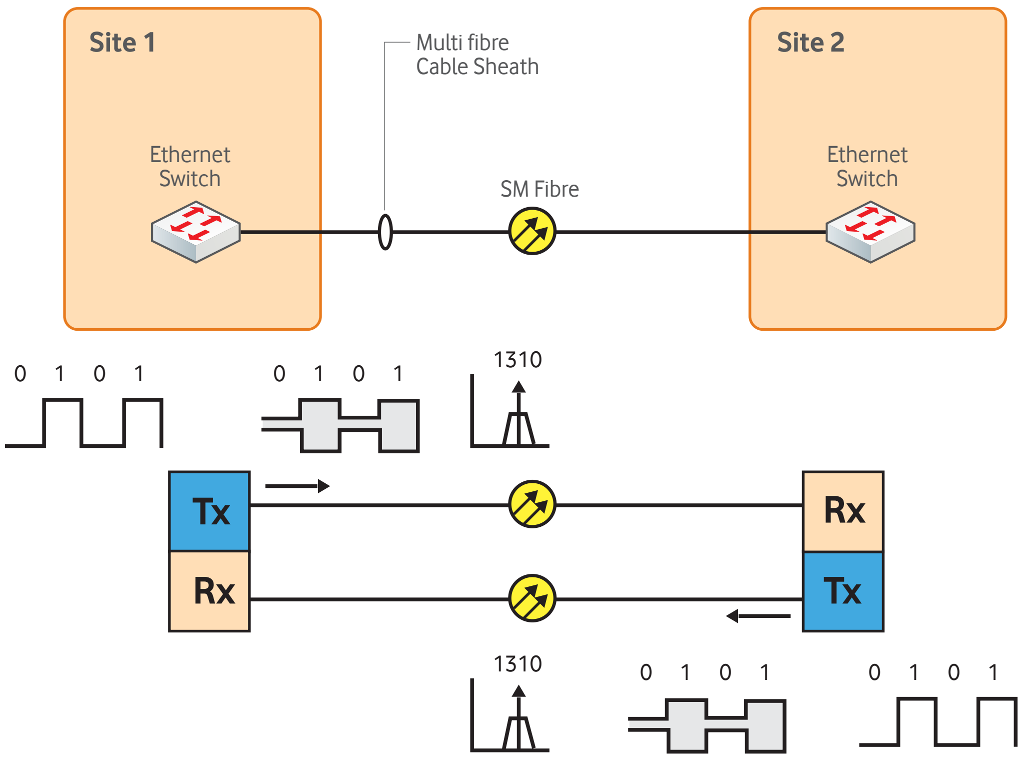

Figure 20 – Single Channel Interfaces

Single Channel Interfaces are often referred to as "black and white" or "grey" optics and are generally available in medium (up to 10km) and long (up to 80km) reach versions.

Multiple Channel Optical Systems

Single channel optical transmission systems are commonly used when traffic volumes are lower and fibre is more plentiful (which is typically the case for short haul communications e.g. within a building, campus or metro city).

Where traffic volumes are larger and/or fibre is scarcer (which is often the case for long haul communications i.e. inter-city) then multiple channel optical transmission systems are often a more cost effective alternative than multiple single channel systems.

In a multichannel system several optical channels (several wavelengths or frequencies) are present on the optical fibre line that links the terminal equipment.

A multichannel system is generally described as a wavelength division multiplexing (WDM) system. Better utilization of the transmission capacity of an optical fibre can be obtained with the WDM technique.

Figure 21 shows an example of one direction of transmission of a WDM system.

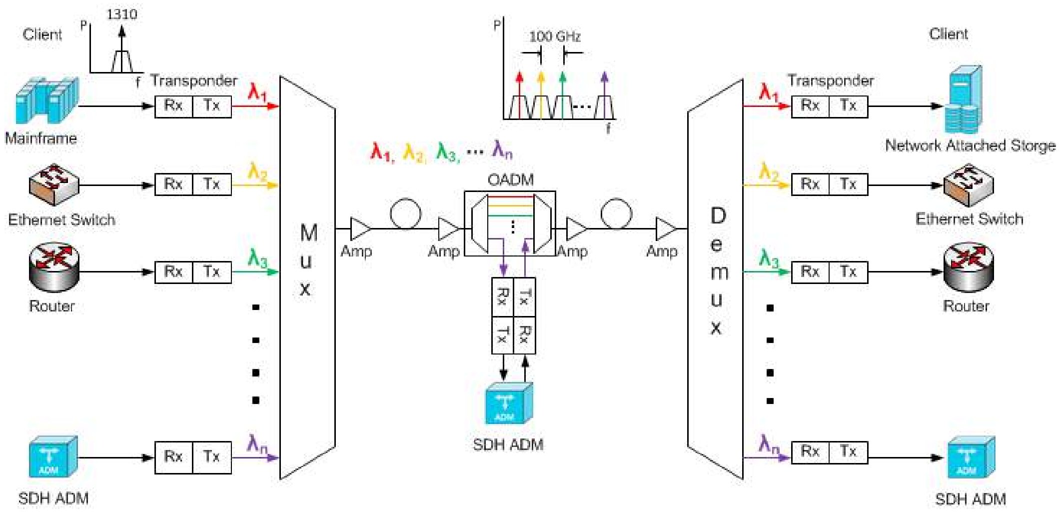

Figure 21 – WDM System example

The WDM near end terminal has transponders with single channel non-WDM interfaces so can accept optical inputs from a variety of client equipment from many different vendors.

Each input may run at its own rate (speed) and use its own encodings and protocols without any dependence on the other channels

The transponder takes the received "black and white" client optical signal converts it to electrical form and uses it to produce a laser modulated "coloured" signal that is tuned and fits within an assigned wavelength slot in the low attenuation C band
(1530 – 1560nm)

The transponders coloured outputs are combined onto a single fibre using an optical multiplexer.

The combined composite signal may pass through a number of fibre spans and may be optically amplified to compensate for attenuation.

At intermediate sites an Optical Add Drop Multiplexer (OADM) may be used to selectively add or drop certain WDM channels while passing other channels through without disruption.

At the far end WDM terminal the different wavelengths are separated in an optical de-multiplexer.

The receiving transponder is tuned to the appropriate wavelength and converts the signal from WDM form to black and white and in the process re-amplifies, reshapes and retimes i.e. 3R regenerates the digital bit stream.

WDM Categories

The ITU defines two main categories of WDM systems namely Coarse (CWDM) and Dense (DWDM). The difference between the two systems relates to the channel spacing used.

ITU Grids define the location of the nominal centre frequencies for CWDM and DWDM systems.

CWDM can support channel spacing between 8nm and 50nm. Typically however 20nm spacing is used (approx. 3000GHz) giving around 16 useable channels (with grid centres ranging from 1270nm to 1610nm).

DWDM supports channel spacing less than 8nm (1000GHz). Typically 0.8nm (100Ghz) spacing is used giving around 44 useable channels (Grid centres 1530.33 to 1564.68nm) or alternatively 0.4nm (50GHz) spacing giving around 88 channels (Grid centres 1530.33 to 1565.09nm).

Figure 22 shows a comparison of CWDM and DWDM channel spacing. The 20nm CWDM channel allocates 13nm for modulated signal with a 7nm guard band to accommodate laser frequency drift. The much wider CWDM channel permits the use of cheaper system components e.g. uncooled lasers and low cost filters. CWDM systems can operate at distances up to 120km and tend to be used in metro network linking.

In contrast the narrow DWDM systems channel spacing requires components with much greater stability and consequently usually greater cost. DWDM systems with amplification can operate at distances up to 2000km and tend to be used for regional and national network linking.

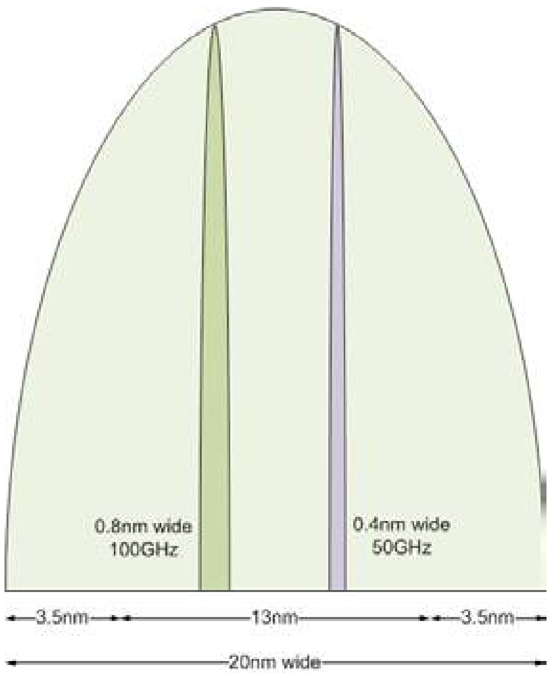

Figure 22 – Comparison of CWDM/DWDM channel spacing

Optical Amplifiers

Amplification of signals in the optical domain allows span lengths between DWDM terminal equipment to be significantly increased. The erbium-doped fibre amplifier (EDFA) is the most commonly deployed fibre amplifier. These devices have an amplification window that coincides with the third transmission window of silica-based optical fibre.

EDFA amplifiers use a silica fibre doped with trivalent erbium ions as a gain medium to amplify the optical signal. The signal to be amplified and a pump laser are combined into the doped fibre, and the signal is amplified through interaction with the doping ions.

Two bands are generally used in the third transmission window – the Conventional, or C-band, from approximately 1525 nm – 1565 nm, and the Long, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands.

Appendix B – Fibre Channel / FICON Overview

Fibre channel is a general purpose high speed data communications technology that can be used to transport both server to storage peripheral Input / Output (I/O) communications and other multimedia and networking protocols over a single communication channel.

Fibre channel technology operates over both copper and fibre optic media and can be applied to many different applications including storage, computer networking, video transmission and data acquisition.

Storage Area Networking (SAN) is one of the predominant uses for Fibre Channel. SANs allow collection and distribution of large quantities of data. A Fibre Channel based SAN provides the connectivity between data storage devices (e.g. disk and tape drives) and servers. A typical user would access data stored in a SAN via a server that is accessible through an IP network. The basic structure of Fibre Channel based SAN is illustrated in Figure 23.

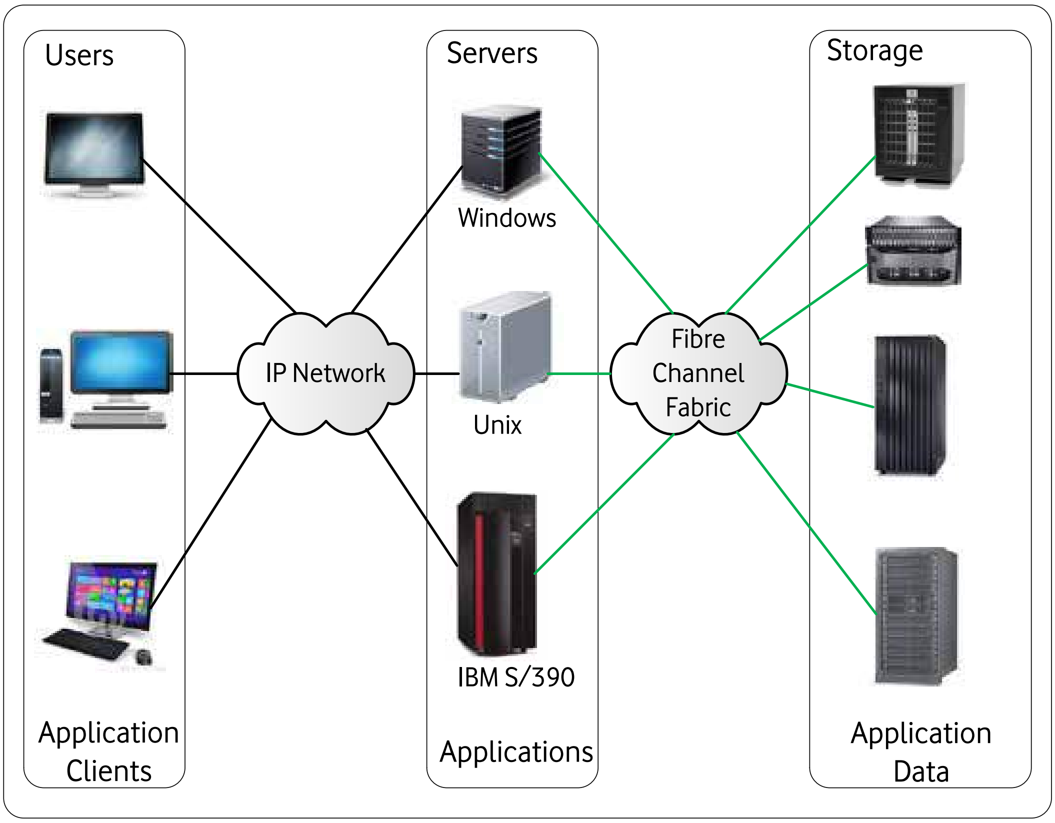

Figure 23 – Fibre Channel SAN basic structure

The Fibre Channel protocols are standardized in the T11 Technical Committee of the International Committee for Information Technology Standards (INCITS), an American National Standards Institute (ANSI)-accredited standards committee.

Fibre Channel user data is sent on Fibre Channel links in frames. Frames can be variable in length, up to a maximum of 2148 bytes long. Each frame contains a four-byte Start of Frame delimiter, a 24-byte header, up to 2112 bytes of FC-4 payload consisting of zero to 64 bytes of optional headers and zero to 2048 bytes of ULP data, a four-byte CRC, and a four-byte End of Frame delimiter. The frame structure is illustrated in Figure 24.

<table>
<tr><td>4 Bytes</td><td>24 Bytes</td><td colspan="2">0 – 2112 Bytes</td><td>4 Bytes</td><td>4 Bytes</td></tr>
<tr><td rowspan="3">Start of Frame</td><td rowspan="3">Frame Header</td><td colspan="2">FC-4 Data Payload</td><td rowspan="3">CRC</td><td rowspan="3">End of Frame</td></tr>
<tr><td>0 – 64 Bytes</td><td>0 – 2048 Bytes</td></tr>
<tr><td>Optional Headers</td><td>Data Payload (e.g. IP Packet, SCSI Command)</td></tr>
</table>

Figure 24 – Fibre Channel Frame Structure

The Fibre Channel protocols have a five layered structure similar to the layering found in the TCP/IP or OSI protocol suites. The five Fibre Channel layers are illustrated in figure 25 and their functions are briefly described below:

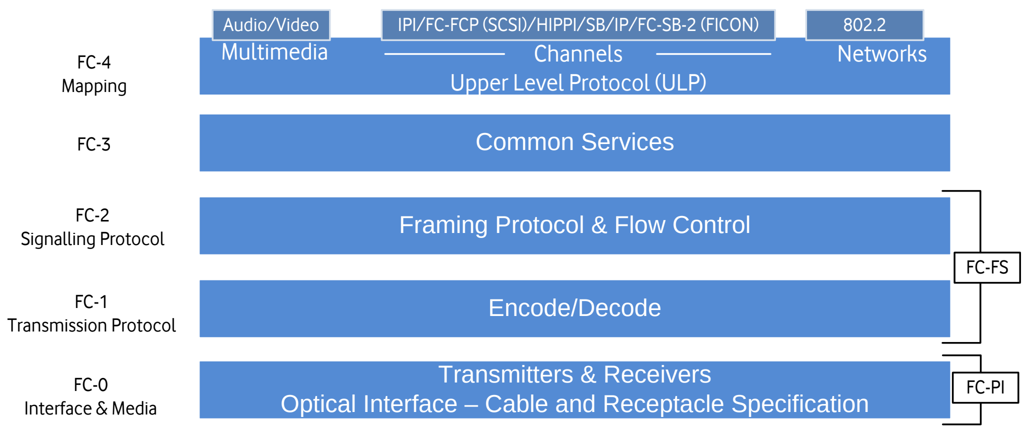

Figure 25 – Fibre Channel Architecture Levels

The user protocol being transported over the Fibre Channel (e.g. SCSI or FICON) is known as the upper level protocol (ULP) and is outside the scope of the Fibre Channel layers.

FC-4: The Protocol Mappings Layer.

The topmost Fibre Channel level defines the mapping of Upper Layer Protocol (ULP) interfaces to the lower Fibre Channel levels. Fibre Channel can be used to transport multiple existing protocols, including FICON; Internet Protocol (IP) and Small Computer System Interface (SCSI).

Each ULP supported by Fibre Channel requires a separate FC-4 mapping and is specified in a separate FC-4 standards document. As an example, the Fibre Channel protocol for SCSI, (known as FC-FCP), defines a Fibre Channel mapping layer that uses the services of the lowest three Fibre Channel layers (FC-0 to FC-2) to transmit SCSI command, data, and status information between a SCSI initiator and a SCSI target. Similarly FC-SB-2 is the mapping definition for the IBM Fibre Connection protocol (FICON).

FC-3: The Common Services Layer.
Nodes can be computer systems or peripheral devices. The FC-3 level defines a set of services that are common across multiple ports of a node. The FC-3 layer is still being formulated in the ANSI committee and no functions have been formally defined.

FC-2: The Framing Protocol Layer.
This level defines the signalling protocol, including the frame and byte structure, which is the data transport mechanism used by Fibre Channel. Included in this level is the framing protocol used to break sequences into individual frames for transmission, flow control, 32-bit CRC generation, and various classes of service

FC-1: The Encode/Decode Layer.
This layer defines the transmission protocol; including the 8B/10B encode/decode scheme, byte synchronization, and character-level error control

FC-0: The Physical Layer.
The fibre channel physical interface (FC-0), specified in FC-PI, consists of the transmission media, transmitters, receivers, and their interfaces. The physical interface specifies a variety of media and associated drivers and receivers capable of operating at various speeds.