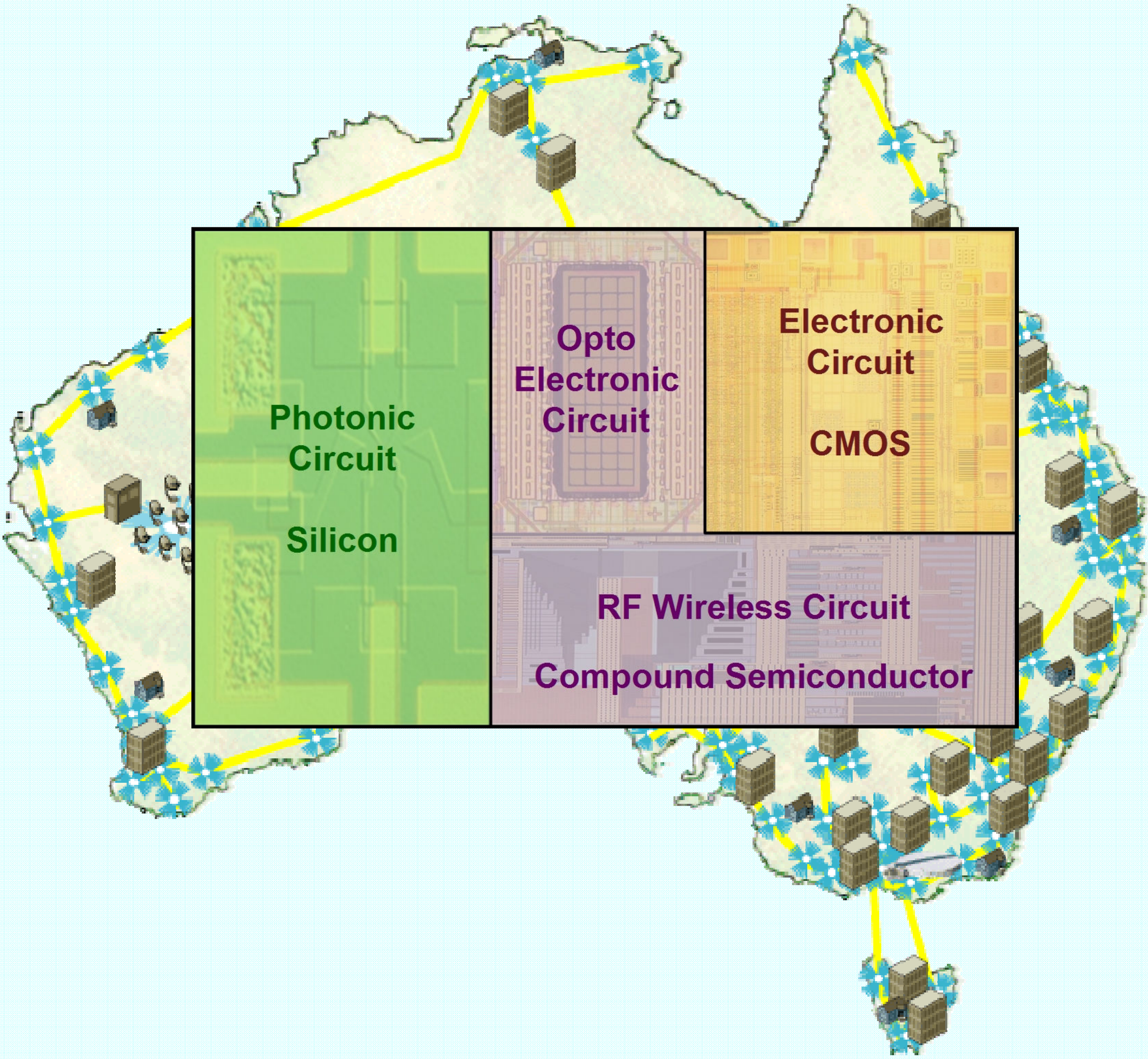
Prospectus

for participating in a proposed

Fibre to the Premises Cooperative Research Centre



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Fibre to the Premises CRC – Prospectus

1. Introduction

The forthcoming large-scale rollout of high-speed fibre-based broadband access networks (called Fibre to the Premises or FTTP), not only in Australia, but worldwide, is creating a 'once-in-a-generation' opportunity for the telecommunications technology supply industry in and to Australia.

The main focus of broadband rollouts in Australia, and globally, is to upgrade the old copper access networks to new fibre access networks, thus creating broadband freeways to the premises. In the case of Australia, the target capacity is 100Mbps average capacity to each premises in the near future and 1Gbps by 2020. However, as illustrated in Figure 1, achieving the full potential of this physical infrastructure, and also reaching the more remote population centres, will depend on finding solutions to a number of problems – some of these already exist, and others will arise as network traffic increases.

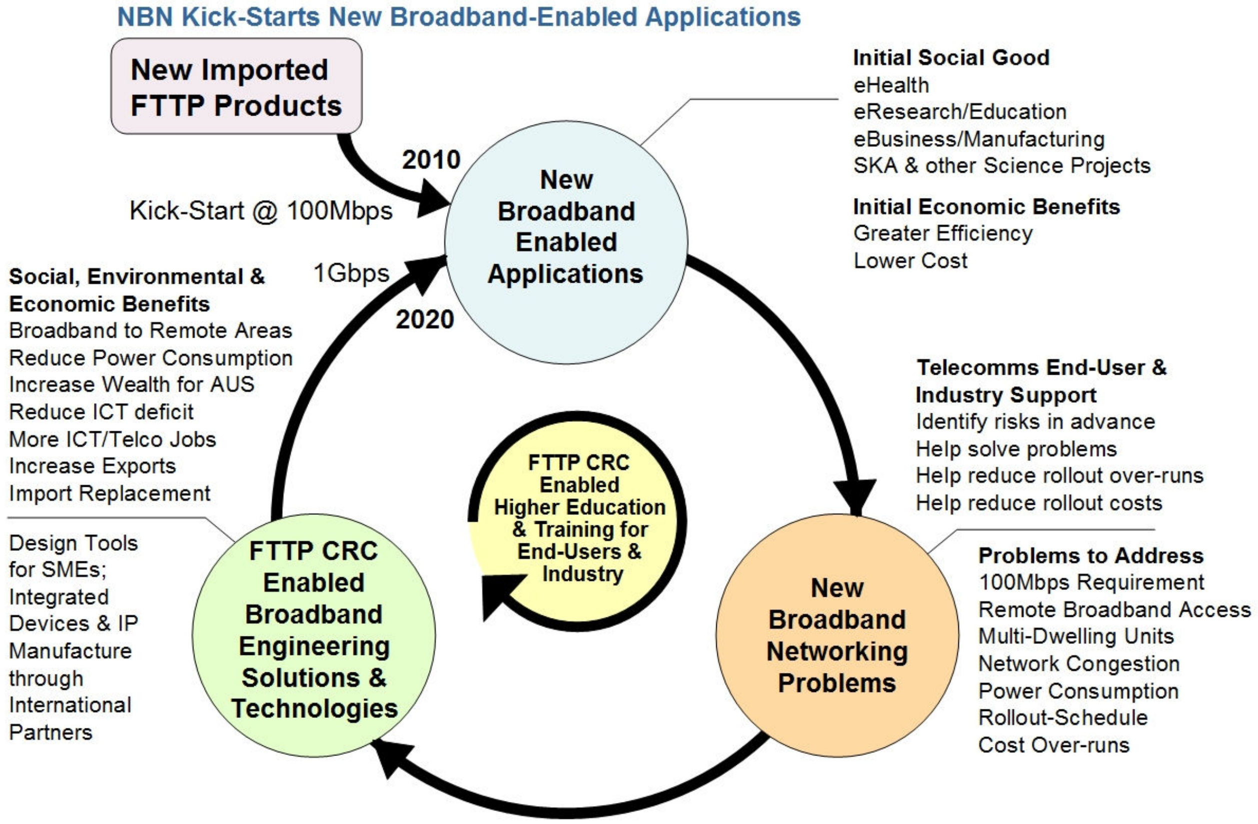

Figure 1 FTTP Broadband Rollout Problems & Technology Upgrade Cycles

Extensive discussions with Australian-based technology suppliers and key Australian research groups have identified a number of such problems in which an end-user-driven collaborative research program would have excellent prospects of successfully developing globally deployable solutions.

This document outlines the case for joint investment in a proposed Fibre to the Premises Cooperative Research Centre (FTTP CRC).

Such a research consortium would be eligible to apply for substantial funding under the Australian Government's Cooperative Research Centres (CRC) Program.

As an indication of the scale of funding available, a number of existing CRCs have received grants of between $30 million and $40 million over periods from seven to ten years.

The vision for the proposed CRC is to develop the technology to enable local and worldwide implementation of the solutions to these problems through the application of integrated nano-devices.

The CRC Program Guidelines state that a CRC must be “end-user-driven”, and that the business plan for the CRC must include a convincing strategy for ensuring that the research outputs lead to real economic and social outcomes and impacts.

- It is therefore essential that the proposed FTTP CRC has strong participation of end-user beneficiaries of this research, including suppliers of components and equipment that will be used in broadband rollouts in Australia and worldwide.

2. There are real prospects for success

In Australia, the Commonwealth Government has decided to invest $43 billion in a National Broadband Network (NBN) rollout.

The scale of this Australian broadband rollout, to be undertaken by a new company (‘NBN Co’), is such that it will make Australia a globally substantial market for FTTP technologies and products. For example, while the global annual passive optical network (PON) market is growing to 24.5 million optical network terminal (ONT) ports by 2013[1], NBN Co will be rolling out over 5 million Gigabit PON (GPON) ONT ports between 2010 and 2018.

The demand from NBN Co and hence, from its global component and equipment suppliers, provides a local market opportunity for locally developed next-generation technology, both directly and via global supplier channels. This opportunity has the potential to generate substantial returns through two paths:

- Increasing local share of Australia's ICT market – in which Australia is currently running a $28 billion trade deficit, even before the NBN rollout.
- Increasing exports into the extra-ordinarily high 130% p.a. growth rate FTTP access network rollouts worldwide, with 55% of this market in Asia-Pacific, right on Australia’s doorstep.

Moreover, for the next 8-10 years, global component & equipment suppliers will be focused on Australia as one of the new leaders in FTTP rollout – they are expecting both to earn and to learn from Australia's rollout, especially given NBN Co's Layer 1 & 2 (Ethernet) open-access wholesale provider model.

Developers and suppliers who can find solutions to the problems associated with FTTP access, transit & backhaul networks will be particularly well placed to attract worldwide attention.

Discussions concerning the proposed FTTP CRC have identified three key end-user problems in which collaborations involving local research institutions promises good prospects of leading to marketable solutions:

- Broadband to remote communities – not just to homes in cities
- Multi-dwelling unit (MDU) networks – enabling Gbps broadband to individual units
- Core & backhaul capacity upgrades – overcoming congestion due to new FTTP speeds

Additional background to these problems is provided in Appendix 1.

These three identified end-use problems are not the only ones that will be thrown up in broadband rollouts. However, they are three that Australian researchers are well-placed to develop solutions. To this end, the CRC focus is on Australia's research community's core competencies, being Photonics and Wireless RF. To-date, these two research communities have been following different paths, however, through convergence of technologies it is clear that the time is ripe when research collaborations involving these two communities can develop integrated Photonics and Wireless solutions.

The discussions to date have identified the following research participants as potential participants who could undertake key elements of proposed CRC’s research programs:

Edith Cowan University	through the Centre of Excellence for Micro-Photonic Systems; Electron Science Research Institute and relationships with GIST in Korea and IOE-CAS in China, ECU are well placed to develop integrated photonic &

[1] Infonetics Research: PON and FTTH Equipment and Subscribers Quarterly Market Share, Size and Forecasts, Sept. 2009.

	electronic solutions, such as optical substrates, WDM PON laser and receiver arrays and opto-VLSI chips;
Macquarie University	through their Concentrations of Research Excellence (CoREs) in Photonics and in Wireless (located in Physics and Engineering, respectively), bringing expertise in both wireless (terrestrial and satellite) and optical technology platforms and systems, as well as their capabilities in electronic design automation (EDA);
LaTrobe University	through the Centre for Technology Infusion - have wide local and international industry support and contracts with local VLSI manufacturer Sapphicon and the CSIRO ASKAP group. LaTrobe have demonstrated their deep knowledge and understanding of the design of RF electronics on silicon on sapphire substrates;
Victoria University	through the Centre for Telecommunications and Micro-Electronics (CTME) - have experience in MIMO & LTE wireless technologies, Cognitive Radio for Fourth Generation (4G) Wireless Systems; OFDMA, micro-electronics design and photonics research, all applicable to fibre & femtocell wireless MDU applications;
University of Sydney	through the Institute of Photonics and Optical Science, Bandwidth Foundry and CUDOS linkages, Sydney Uni have relevant knowledge and experience in optical communications theory such as the non-linear Shannon limit, photo-lithography and nano-technologies for the development of photonic integrated circuits (PICs);
RMIT University	through the Microelectronics and Materials Technology Centre, RMIT Uni brings capabilities and experience in 40GHz microwave and siicon photonic “systems on a chip technologies”. They have a class 100 clean room with 6” wafer fabrication, mask design, flip chip bonding, wafer-scale optical and electronic test stations.
University of Adelaide	through the ChipTec microelectronics design centre, Adelaide Uni bring many years expertise in high speed, mixed analog/digital microelectronics design, much of which was under-taken for DSTO applications. Through their Institute of Photonics, they bring expertise in polymer fibres applicable to MDU applications;
University of Wollongong	through the ICT research institute, the UoW have developed expertise in Ultra-Wideband (UWB) and 4G mobile communications, MIMO systems, radio propagation theory and photonic signal processing. They are regarded as the State’s Centre of Expertise in Telecommunications by the NSW Government;
University of South Australia	through the Institute for Telecommunications Research, UniSA bring years of expertise in the design and development of satellite RF systems and broadband P2P hybrid RF and optical free-space communications networks. They have for example, developed a 60GHz integrated circuit for wireless LAN appications.

In addition to these listed above, the Australian National Fabrication Facility (ANFF) and its seven university-based nodes also have highly relevant capabilities and facilities to process materials and transform these into structures that have application in nanophotonics and nanoelectronics. Nodes include the Melbourne Centre for Nanofabrication (which includes LaTrobe & RMIT universities); ACT; Materials (which includes UoW); NSW; OptoFab (which includes Macquarie University and the University of Sydney Bandwidth Foundry); QLD and SA (which includes the University of SA).

3. The key problems that the proposed CRC will aim to solve

The outcomes sought from the applications-oriented research programs will be world-class fabless design centres and design tools, including a world class Australian design and manufacturing capability for prototypes and small-medium volume production. This capability will be targeted at the design and prototype manufacture of broadband WOESOC (wireless optical & electronic system on a chip) devices.

In order to develop deployable research outputs the proposed CRC, as currently conceived, would undertake three applications-oriented R&D programs, supported by a fundamental technology research program that would have its focus on further developing the common underlying nano-scale integration technology. The proposed research programs are outlined below.

3.1 Broadband to remote communities – not just to homes in cities

Governments worldwide see enormous economic and social benefits in maximising the proportion of their populations that have access to high-speed broadband connections. However, connecting the more isolated sectors of the community is relatively expensive. This is a particular concern in Australia, as a nation with large areas and dispersed population, but is also a vital consideration in China, Russia, Canada, the United States and most South American and African countries.

All such nations would benefit greatly from new, highly integrated technologies that lower the cost of high-speed broadband connections to remote communities.

The CRC envisages developing lower-cost solutions to the problem of connecting the more dispersed elements of the network through integrated wireless and opto-electronic devices for high-speed, low-power broadband transit networks between fibre backbones and fibre or wireless access networks.

The background to this program is described in more detail in Appendix 2.

3.2 Multi-dwelling unit (MDU) networks – enabling Gbps broadband to individual units

Within cities, there are also problems to be solved within the mainstream FTTP network deployments, notably the delivery of next generation broadband to individual units within Multi-Dwelling Units (MDUs).

As for FTTP deployments to MDUs in Asia, Australian Fibre Access Nodes (FANs) will be connected by Point to Point (P2P) fibre to an access multiplexer in the MDU basement, although research program 2 above will also enable broadband wireless as a realistic P2P option. In Australia, most units within a MDU are only wired with copper and even with very high bit-rate digital subscriber line (VDSL) technology, this may not grow to support future capacity demands of 1Gbps or greater per unit by 2020.

The proposed CRC aims to develop hybrid, low cost fibre and Gbps femtocell wireless premises networks for connecting all units within a MDU to the access multiplexer in the basement (or roof) so that next generation capacity demands to each unit can be met.

The background to this program is described in more detail in Appendix 3.

3.3 Core & backhaul capacity upgrades – overcoming congestion due to new FTTP speeds

New broadband-enabled applications will drive up the network traffic, resulting in congested laneways in the backhaul and core networks. These existing laneways must similarly be upgraded to super-freeways if this traffic congestion is to be avoided, otherwise the promise of 100Mbps broadband to the premises today and 1Gbps by 2020 will not be realised.

New, 100+Gbps per wavelength coherent optical technologies targeted at dynamic optically switched networks will be required in the backhaul and core networks soon, growing to Terabit/s backhaul and core networks by 2020. New modulation technologies are being developed for such networks, but the underlying technology to implement them is not efficient in terms of size, power and cost.

The proposed CRC aims to develop such new technologies through the integration of photonics, high-speed opto-electronics and nano-scale electronic signal processing.

The background to this program is described in more detail in Appendix 4.

3.4 *Underlying technology – nano-scale optics and electronics integration*

The underlying nano-scale optics and electronics integration program will build on, and further develop, the CRC's fundamental base of research expertise in wireless, photonic, opto-electronic and electronic functions in one device. Methods and processes will be sought to more efficiently integrate multiple disparate photonics, electronics, opto-electronics and wireless (radio frequency, RF) technologies and materials into 'System on a Chip' (SOC) solutions.

This underlying technology research program will draw on the capabilities of participants (both end-users and research institutions) in the following device technology areas:

- Substrate materials and fabrication processes for:
  - Photonic planar waveguides;
  - Silicon on sapphire devices;
  - Compound semi-conductors;
  - Nano-devices;
- Integration of hybrid silicon & compound semi-conductor substrate materials;
- Designing, integrating and fabricating:
  - VLSI (very large scale integrated) electronic devices including sub-micron lithography;
  - Photonic Integrated Circuits (PICs);
  - DWDM (dense wavelength division multiplexing) and single wavelength lasers and PIN/APD (positive-intrinsic-negative/avalanche photodiode) detectors;
- Flip-chip or other integration of best-of-breed Opto-electronic devices;
- Power management systems for VLSI and Opto-electronic devices; and
- Thermal design of VLSI and Opto-electronic devices for final packaging.

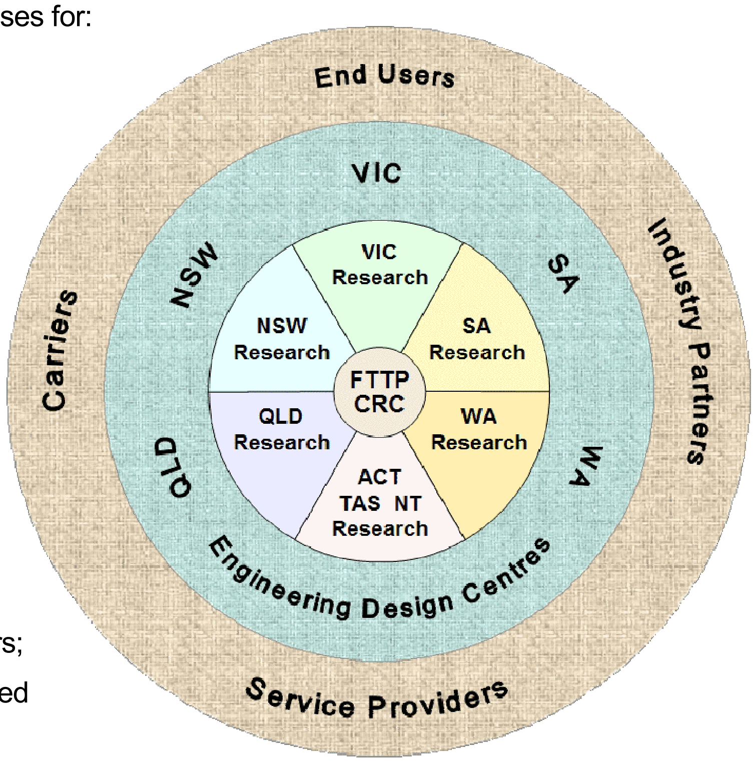

Figure 2 Engineering Design Centres

The background to the underlying technology research program is described in more detail in Appendix 5.

The knowledge, skills and experience needed to implement the applications-oriented research programs are somewhat different, but complementary, to those for the underlying nano-scale optical and electronic technology research program. For example, applications research programs require research organisations and end-user/industry participants having knowledge, skills and experience in the:

- Electronic design of broadband RF amplitude & phase modulation technologies;
- Integration of soft IP (intellectual property) cores that implement for example: OTU-2 (optical channel transport unit) framing and multiplexing; EPON, GPON and 10GPON MAC and PHY-layer protocols;
- Design of external optical modulators, DWDM laser current stabilisation and TIA (trans-impedance amplifier) receivers;

As illustrated in Figure 2, it is proposed that Engineering Design Centres (EDCs) akin to LaTrobe's "Centre for Technology Infusion" be established (or extended as the case may be) in association with participating universities, to support the applications-oriented research programs. Such EDCs will attract highly-skilled engineers not interested working in a university environment, but who may be interested in undertaking post graduate research and higher degree programs through affiliated universities. EDCs also provide the end-user participants with a project management interface to the university research.

3.5 Phased Development Plan

Figure 3 illustrates the research and development phases that are envisaged for both the Technology and Applications Research Programs. This plan uses generic references P1, P2 & P3 for the Applications Research Programs with the Technology Reseach Program referred to as P4.

Application-Specific Prototypes & Demonstrations	**P1**: Specify & Design - Determine requirements - Develop application code - Determine WOESOC1 partitioning - Acquire soft IP cores if needed - Integrate soft IP cores - Design high speed circuits - Design 1^{st} prototype WOESOC1 based on Tech. Program 4 - ϕ1 - Build and test 1^{st} prototype device	**P1**: WOESOC Proto-2 - Investigate options to further integrate devices & substrates - Design 2nd prototype WOESOC1 based on Tech. Program 4 - ϕ2 - Build & test 2^{nd} Proto WOESOC1 - Design demo boards & packaging - Package WOESOC1 devices - Integrate WOESOC1 onto boards - Test WOESOC1 on boards	**P1**: Integrate & Trial - Design prototype system and any new prototype equipment - Build prototype equipment and/or integrate into partner's equipment - Integrate other equipment - Lab test total solution - Field / Customer / User trials - Report & publish results - Ongoing Customer / User trials
	P2: Specify & Design - Determine requirements - Develop application code - Determine WOESOC2 partitioning - Acquire soft IP cores if needed - Integrate soft IP cores - Design high speed circuits - Design 1^{st} prototype WOESOC2 based on Tech. Program 4 - ϕ1 - Build and test 1^{st} prototype device	**P2**: WOESOC Proto-2 - Investigate options to further integrate devices & substrates - Design 2nd prototype WOESOC2 based on Tech. Program 4 - ϕ2 - Build & test 2^{nd} Proto WOESOC2 - Design demo boards & packaging - Package WOESOC2 devices - Integrate WOESOC2 onto boards - Test WOESOC2 on boards	**P2**: Integrate & Trial - Design prototype system and any new prototype equipment - Build prototype equipment and/or integrate into partner's equipment - Integrate other equipment - Lab test total solution - Field / Customer / User trials - Report & publish results - Ongoing Customer / User trials
	P3: Specify & Design - Determine requirements - Develop application code - Determine WOESOC3 partitioning - Acquire soft IP cores if needed - Integrate soft IP cores - Design high speed circuits - Design 1^{st} prototype WOESOC3 based on Tech. Program 4 - ϕ1 - Build and test 1^{st} prototype device	**P3**: WOESOC Proto-2 - Investigate options to further integrate devices & substrates - Design 2nd prototype WOESOC3 based on Tech. Program 4 - ϕ2 - Build & test 2^{nd} Proto WOESOC3 - Design demo boards & packaging - Package WOESOC3 devices - Integrate WOESOC3 onto boards - Test WOESOC3 on boards	**P3**: Integrate & Trial - Design prototype system and any new prototype equipment - Build prototype equipment and/or integrate into partner's equipment - Integrate other equipment - Lab test total solution - Field / Customer / User trials - Report & publish results - Ongoing Customer / User trials
Underlying WOESOC Technology	**P4**: Basic Research ϕ1 - 3 years researching & developing basic technology - Lower levels of substrate & device integration initially - Start developing WOESOC-specific design & test tools - Capabilities and processes support 1^{st} prototype WOESOC devices for Applications Programs 1, 2 & 3	**P4**: Basic Research ϕ2 - 2 years technology improvement - Greater levels of substrate and device integration & better tools - Better capabilities and processes support 2^{nd} prototype WOESOCs	**P4**: Basic Research ϕ3 - 2 years technology improvement - Improve and better document design and test tools to support industry going forward - Report and publish final results
	Technology Research Program 4 - Nano-scale Optics & Electronics Integration		

← 7-year FTTP CRC Research Program →

Figure 3 FTTP CRC – Research & Prototype Development Phases

Underlying Technology Research - Program 4

The underlying "Nano-scale Optics & Electronics Integration" technology research program would focus on the basic research aspects of various substrate materials and processes for each technology area (photonics; opto-electronics; high speed/density electronics processing & storage; and RF electronics). The basic research would investigate, design and demonstrate various methods for integrating different materials and processes, with the objective of minimising the number of materials and processes as far as possible and practical. The basic research would also address the fundamental need to be able to integrate soft IP cores from global suppliers (both integrated foundries and fabless design centres) but would not focus on any specific application.

Basic Research Phase 1: The first 3 years of the technology research program would build sufficient capabilities and processes to support the development of simple 1^{st} prototype WOESOC devices. This may result in larger and higher power consuming 1^{st} prototype WOESOC devices compared to the target objective envisaged for the final technology outcome of the FTTP CRC.

Basic Research Phase 2: The next 2 years would aim at improving the underlying technology through improved substrate material and process integration. These improvements would flow on to the development of smaller and lower power consuming 2^{nd} prototype WOESOC devices for the Applications Research Programs.

Basic Research Phase 3: The final 2 years would aim at further improving the underlying technology through improved substrate material and process integration and would set its sights on a single nano-material and process if this is deemed possible (eg, silicon photonics & electronics). Otherwise, if this is not deemed practical at that time, the objective will be to minimise the number of materials and processes required to integrate photonics, opto-electronics, high speed/density electronics processing & storage; and RF electronics into a single low power, small size device.

Additionally, in the last 2 years of Technology Research Program 4, all the design and test tools researched and developed along the way would be cleaned-up and documented for later use by end-users/industry, including component suppliers, SMEs and MNCs.

Applications Research Programs 1, 2 & 3

As shown in Figure 3, the Applications Research Programs will each apply the underlying technology developed within the Technology Research Program to research and develop prototypes of application-specific WOESOC devices and associated prototype modules/boards which may integrate into existing industry participant's equipment and/or may integrate into new prototype equipment designed and built to demonstrate their capabilities and benefits to end-users. The Applications Research Programs will not just stop at lab testing but will include field/customer trials that are relevant to each application. The field/customer trials are expected to continue beyond the CRC research leading to commercial deployment of the technologies within Australia and globally.

Allowance has been made for two WOESOC applied research & prototype development phases in-line with the underlying basic Technology research phases. The 2nd phase WOESOC devices are expected to achieve a higher level of integration, with reduced power and size compared to the 1st phase WOESOC devices. The first phase WOESOC development is needed as part of the learning curve, to not only better understand the integration of different substrate materials and processes and the application designs that are overlaid onto them, but to also better understand how to integrate multiple soft IP cores from multiple suppliers across multiple substrates. It is important that the FTTP CRC research stands on the shoulders of all previous research & development and does not try to replicate this and thus does not try to achieve everything in-house or in-country. The CRC is as much about the underlying research as it is about the applications of research and technology integration.

4. Structure and management of the proposed CRC

According to the CRC Program Guidelines, a CRC does not have to be incorporated, but must be managed according to Australian Securities & Investment Commission (ASIC) principles applicable to an incorporated body.

- On this basis, the Board of the CRC will have an independent Chair, and a majority of end-user Board Members, and will appoint a CEO to lead the CRC's management team.

The FTTP CRC Board will establish Intellectual Property (IP) management and licensing principles on the basis that ownership of and beneficial rights to IP developed during the course of a project will be:

- IP rights will be project-based, and negotiated in advance by project participants in each particular project.
- The CRC Program Guidelines are designed to ensure that IP is actively managed to Australia's benefit, thus IP management principles will include, for example, the option for other CRC participants to license under reasonable commercial terms, project IP that is not licensed and used by the actual project participants.

5. Investment sought

Funding from the Commonwealth Government CRC Program is limited and is awarded on a competitive basis. Thus, the total investment that participants make to the CRC (in cash and in kind) is critical in influencing both the amount of Government funding that can be awarded, and in the prospects of success in the face of competition from other Applicants.

For a commercially focused CRC, as is proposed, to attract Government funding approaching $30 million, participants' contributions would typically have to account for a total investment of around $2 million per year in cash, and in addition, in-kind investments totalling around $3 million per year, for the duration of the CRC. There are provisions for participants to withdraw from a CRC, though these have potential consequences for the continuation of Commonwealth funding.

In order for an Application to proceed with reasonable prospects of success, it will be essential that a number of key end-users/industry partners commit to participating in the proposed CRC.

- A number of levels of participation are being considered. In view of the total cash commitment required, a number of top-level participants, each investing $250k per annum, is sought;
- A number of medium-level participants, each investing $100K per annum is also sought;
- Involvement by SMEs, at much lower level of annual commitment, is envisaged as be through a membership -based incorporated entity, which would itself be a formal participant in the CRC.

The Australian Government has recently announced revised taxation guidelines relating to R&D expenditure. Depending on individual circumstances Australian-resident industry cash contributions to the CRC may be able to attract new R&D tax credits of up to 45% p.a. (typically equivalent to a cash benefit of around 10 to 15% of expenditure, subject to various conditions).

6. Timing of decisions and investment

Currently CRC Program Application Rounds are called annually, in July. Successful Applicants are announced in December, and funding starts in the following July. Thus, the first payments by participants are not required until twelve months after the Application is made.

The next CRC Application Round closes on 2 July 2010

- Agreement to project proposals and commitment to cash and in-kind contributions have to be signed-off well in advance of the closing date.

7. Contact

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Appendices

Appendix 1 Overview of Applications Research Programs

Appendix 2 Broadband to remote communities – not just to homes in cities

Appendix 3 Multi-dwelling unit (MDU) networks – enabling Gbps broadband to individual units

Appendix 4 Core & backhaul capacity upgrades – overcoming congestion due to new FTTP speeds

Appendix 5 Technology Research Program 4 - Nano-scale Optics and Electronics Integration

A1 Applications Research Programs

A1.1 Overview

It is not sufficient for the proposed FTTP CRC to stop at the research and development of the fundamental WOESOC technology under Technology Research Program 4. The FTTP CRC needs to demonstrate the application of this technology to solve real broadband deployment and application-specific problems, both in Australia and globally. Examples are summarised below with reference to the pyramid of end-end networking technology areas shown in Figure A1-1.

It is anticipated that each Applications Research Program with comprise multiple projects. Some projects will be categorised as “Centre” projects and some as “End-User/Industry sponsored” projects. Centre projects would be funded from core CRC funds and would be defined by CRC Management in consultation with End-User/Industry participants and other sources. Additional End-User/Industry sponsored projects are defined by the End-User/Industry participants. Intellectual Property ownership, commercialisation and licensing arrangements for each project would be negotiated between the participating Research organisation and the End-User/Industry participants.

The Applications Research Programs are summarised below and further application details are provided in subsequent appendices.

1) Broadband to remote communities – not just to homes in cities

This program focuses on technologies for more cost-effectively bringing broadband to remote communities. The aim is to reduce the digital divide from 10% to <5% of Australian premises. Such technologies could include new low cost fibre networking solutions, free-space optical networking solutions, terrestrial wireless RF networking solutions or satellite RF networking solutions.

As an example, broadband wireless transit networks have been identified as a possible solution for bridging the bandwidth-distance gap between regional fibre backbone networks and remote communities that due to their size and housing density, could easily justify the deployment of FTTP access networks. To achieve this, a range of WOESOC devices can be implemented that integrate aspects of Technology Areas 4, 5 & 6. The resultant “fibre-wireless” networking solutions as they are called in this document would also have application to delivering Point-to-Point (P2P) broadband to Multi-Dwelling Units (MDUs) for example.

Broadband to remote communities is considered the highest social priority and thus has been selected as Application Research Program 1.

2) Multi-dwelling unit (MDU) networks – enabling Gbps broadband to individual units

Broadband will most likely be delivered to MDUs via P2P fibre or P2P broadband wireless links (whichever is the easiest and fastest to deploy). The real problem is the delivery of broadband to units within the MDUs. Solutions may comprise P2P Ethernet over plastic fibre, PON and/or Femtocell wireless. These solutions require elements of Technology Areas 4, 5, 6 & 7 in Figure A1-1 and can be implemented using WOESOC technologies. At the time of writing, MDU Premises Networks has been prioritised as Application Research Program 2.

3) **Core & backhaul capacity upgrades – overcoming congestion due to new FTTP speeds**

Core & backhaul capacity upgrades is allocated to Application Research Program 3 - corresponding to Technology Areas 2, 3 & 4 in Figure A1-1.

This first requires an understanding of the new broadband-enabled applications traffic loading; then teletraffic engineering to analyze the statistical multiplexing that occurs in the Layer 2 PONs, Layer 2 Ethernet Switches and Layer 3 IP Routers and the resultant backhaul and core network traffic.

Once this is known, Technology Area 3 in Figure A1-1 could include for example, the research & prototyping of 40-200Gbps per 50GHz wavelength coherent transceivers and packet multiplexing for optical transport systems. Another project could focus on faster optical switching for dynamic wavelength routed core optical networks.

This applications research program could be directed at implementing the new generation of packet over optical transport systems with demonstration on partner supplied optical transport equipment and core network fibres or wavelengths.

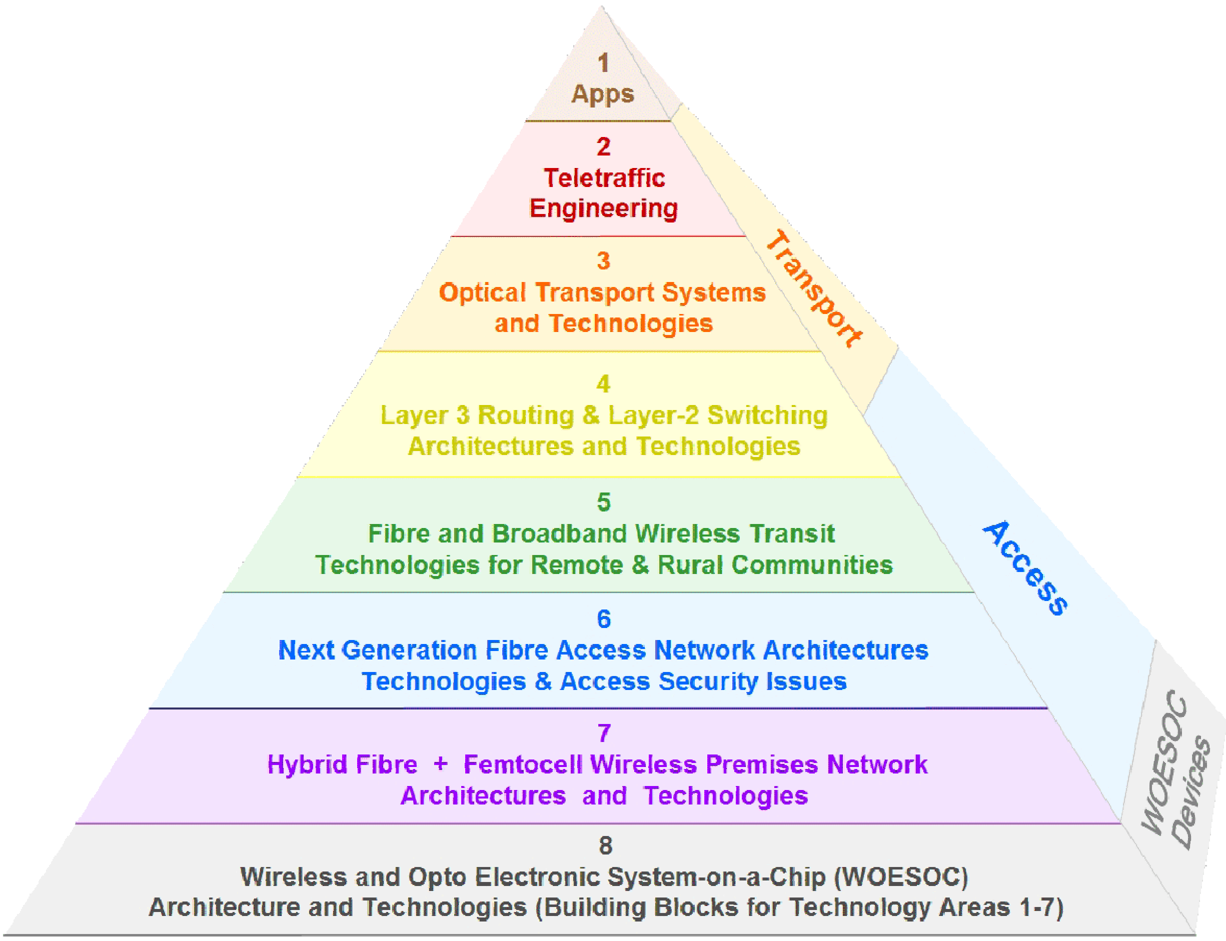

Figure A1-1 FTTP CRC – Relevant Technology Areas

A1.2 Benefits of Applications Research Programs

The research knowledge, skills and experience needed to implement the Applications Research Programs is substantially different to, but also complementary to the knowledge, skills and experience needed to undertake the underlying Technology Research Program (nano optical and electronic integration). For example, Application Research Program 1 requires research organisations and industry partners having knowledge, skills and experience in the electronic design of broadband RF amplitude & phase modulation technologies; the integration of soft IP cores that implement OTU-2 optical transport framing and multiplexing; the design of external optical modulators, DWDM laser current stabilisation and TIA receivers; and the flip-chip integration of best of breed tuneable DWDM laser chips.

The outcomes of the Applications Research Programs are world-class Fabless Engineering Design Centres which are complementary to the outcomes of the Technology Research Program, which includes for example, world class Australian broadband WOESOC design and prototype manufacturing capabilities and new design tools.

A2 Applications Research Program 1 - Broadband to Remote Communities

The following research program outline is provided for illustrative purposes only, regarding the type of research that can be undertaken within the CRC to facilitate bringing broadband to remote communities.

A2.1 Bridging the Digital Divide

Networks connecting remote communities are today somewhat antiquated by virtue of their use of narrowband trunk wireless and satellite technologies. Governments worldwide see enormous economic and social benefits in maximising the proportion of their populations that have access to high-speed broadband connections, thus minimising the "digital divide" between those with broadband and those without broadband. However, connecting the more isolated sectors of the community is relatively expensive. Typically, the Pareto Principle applies, such that the cost of connecting the hardest-to reach 10% of a population is comparable to the cost of connecting the easiest-to reach 90%.

In general, the private sector will not invest in making the more expensive connections unless it receives subsidies from the public purse. Consequently governments are likely to have to meet a substantial part of the cost of connecting remote communities. This is a particular concern in nations with large areas and dispersed populations, notably Australia, but including China, Russia, Canada, the United States and most South American and African countries.

Such nations, like Australia, would benefit greatly from technology that lowers the cost of high-speed broadband connections, especially connections to remote sectors of their populations. If this were available, a greater proportion of the population could be connected with high speed broadband for a given cost, thus shrinking the digital divide to <5% for example, rather than 10% as is the current target for Australia's NBN rollout.

A2.2 Technological Problems & Solutions

As illustrated in Figure A2-1, remote communities comprising for example 100 – 300 premises, look a lot like metro communities. As such, they should have equal rights to 100Mbps broadband FTTP solutions like their city cousins. However, the digital-divide in their case is reflected by a geographic-divide between the FTTP Access Nodes and the nearest NBN or other Backbone Fibre – which may be hundred's of kilometres away. There are currently three feasible technologies for connecting such new FTTP Access Nodes in remote communities to the nearest Fibre Backbone or Point of Interconnect (POI): **i)** optical fibre; **ii)** terrestrial broadband wireless and **iii)** satellite broadband wireless:

i) Optical fibre is often expensive to lay and to optically amplify over long distances, especially in difficult terrain. It is more cost-effective within and between densely populated areas where costs can be defrayed over a large number of users per unit length of laid fibre. In Australia, new Regional Backbone Blackspots Program (RBBP) fibre is being laid within a few hundred kilometres of many remote communities, but branch connections to all remote communities may be expensive.

ii) Terrestrial Broadband Wireless technology is more cost-effective than optical fibre in some situations, but is currently limited in capacity and is still expensive to deploy and power in remote areas. The interconnection to the optical fibre backbone network is currently extremely energy-inefficient and the waste in energy increases as transmission speeds increase. Such is the extent of this waste of power and the consequent need for cooling that present wireless interconnections that transmit only a few watts of radiated power can consume kilowatts of electrical power including cooling and have to be housed in largish huts, leading to high capital and operating costs. In the case of remote deployments, powering of these huts requires large and expensive arrays of solar panels and large banks of high capacity rechargeable batteries. In some cases, electrical generators are used which automatically start-up when there is loss of alternative natural power and these require continual replenishing of fuel.

iii) Satellite Broadband Wireless technology is available with the latest satellites, however, existing Optus satellites have limited transponder capacities and 100x greater round-trip latencies (compared to terrestrial) due to their higher orbits. Nevertheless, an asymmetric mix of satellite broadband wireless downstream using multi-transponder aggregation and terrestrial wireless upstream may be a reasonable interim solution for upgrading the capacity of the transit networks to remote communities.

Along the lines of option **ii)**, some remote communities are already connected by 34Mbps trunk wireless links which were once adequate to meet the needs of telephony and narrowband Internet access. Many who have worked a few decades in the Telecommunications industry will think of 34Mbps as being quite adequate. However, the NBN promise of delivering 100Mbps to 90% of Australian premises puts this in perspective – 34Mbps is not even enough to service the broadband capacity needs of a single remote homestead.

As illustrated in Figure A2-1 a typical remote community comprising 300 premises could have a peak broadband capacity demand of up to 30Gbps, although statistically, 1-10Gbps aggregated traffic capacity would be expected. A new generation of 10Gbps Terrestrial Broadband Wireless technology is needed to meet this capacity demand, with the flexibility to gracefully reduce capacity to 1Gbps to save electrical power and/or to continue to provide some throughput under adverse weather conditions. An example of a 10Gbps Terrestrial Broadband Wireless link is illustrated with add/drop access so that two or more remote communities can share the same broadband wireless infra-structure.

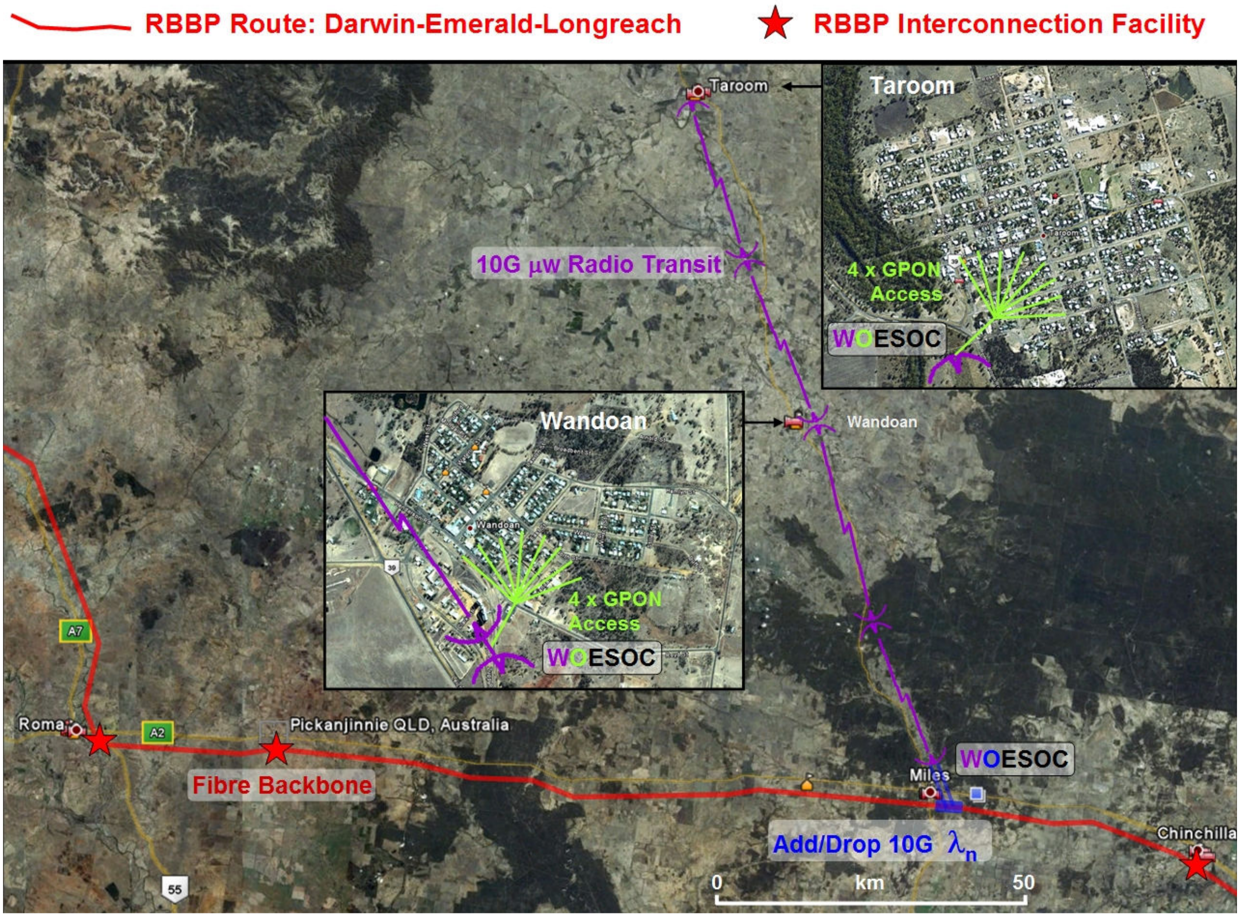

Figure A2-1 Fibre Backbone and Terrestrial Broadband Wireless Network Architecture

Connection of the 1-10Gbps Terrestrial Broadband Wireless links to the RBBP (or other) fibre back-bone may be made in a couple of ways.

a) Connecting to a local tributary fibre in the same cable as the backbone fibres. The tributary fibre would connect into the backbone network via optical add/drop multiplexing equipment located at the nearest RBBP Backbone Interconnection Facility (labelled: ★);

b) If option a) is too wasteful of available backbone capacity (dedicating a whole fibre to 10Gbps of remote traffic), then instead, insert a pair of single wavelength DWDM filters in-line to a pair of backbone fibres, so that only 1/80th of the backbone fibre's potential capacity is used by the 10Gbps wireless link.

For both connection options a) and b), separate east and west connections to the RBBP backbone can be made if needed for protection switching and fault tolerance in the event of a RBBP backbone failure (expected at least once per year due to cable cuts or cable damage due to natural disasters).

As shown in Figure A2-1, the 1-10Gbps Broadband Wireless network can either add/drop to, or terminate at, a number of Gigabit Passive Optical Network (GPON) Optical Line Terminals (OLTs) serving each remote community. The interface to each GPON OLT is just a single fibre, so for 12 x GPONs serving 300 premises, only a 12-fibre ribbon is required to interface to the 1-10Gbps Broadband Wireless network.

In accordance with global networking trends and NBN Co's Layer-2 network approach in particular, all traffic between the GPON OLTs and the 1-10Gbps Broadband Wireless interface will pass through a relatively small 30-50Gbps capacity Ethernet Switch. The Ethernet Switch will also provide both the 2x10Gbps wireless add/drop function and will support the multiple VLANs needed to connect multiple services between each customer premises and each Retail Service Provider (RSP). The VLANs will be transported transparently over the 1-10Gbps Terrestrial Broadband Wireless and Fibre Backbone networks to the nearest POI which may be hundreds of kilometres away. The Ethernet Switches also support statistical multiplexing so that a single 1-10Gbps Terrestrial Broadband Wireless Network can support many more than 300 remote premises.

A2.3 Backbone WOESOC

To minimize interface cost, size and power wastage, a Backbone WOESOC device is a preferred solution to interface between the RBBP (or other carrier's) Fibre Backbone and a 1-10Gbps Wireless Transit Network. A functional block diagram of the Backbone WOESOC device is illustrated in Figure A2-2. In its simplest form, it may include a 10Gbps optical interface to the Fibre Backbone and a 10Gbps RF interface to the Wireless Transit Network.

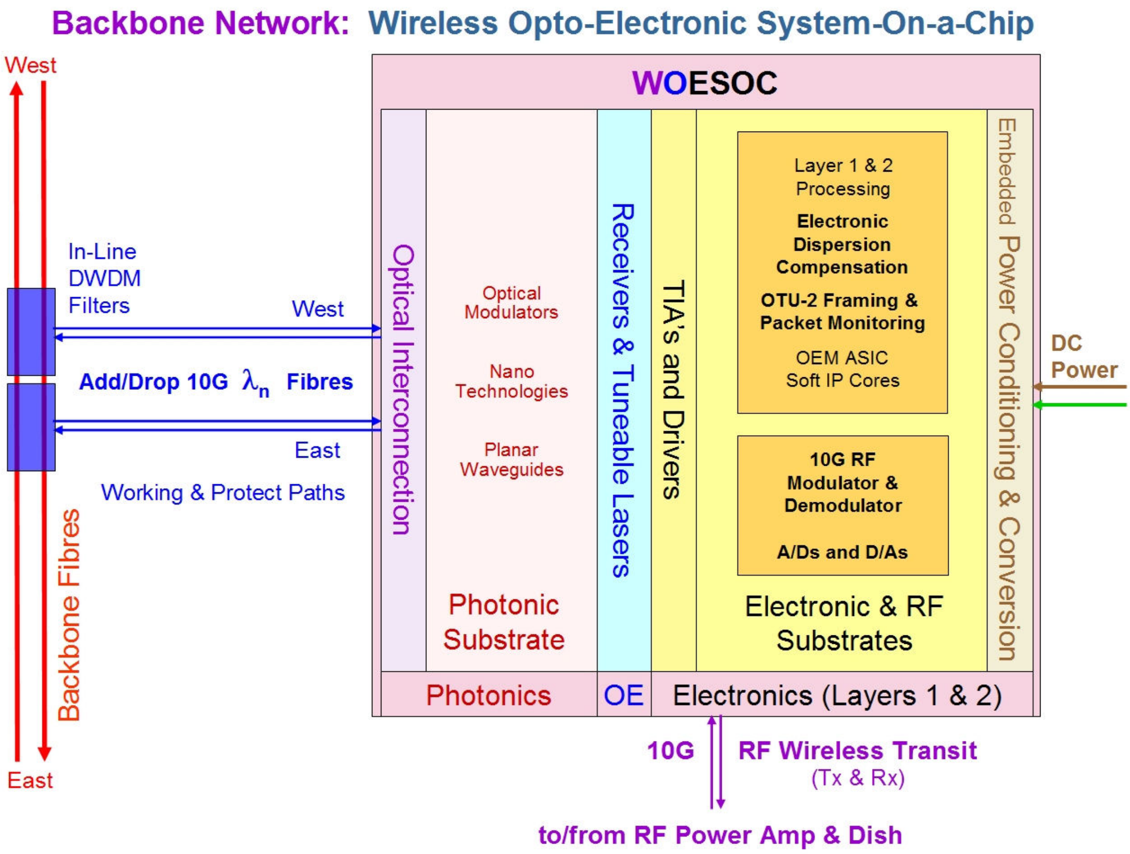

Figure A2-2 Backbone WOESOC Device

The 10Gbps optical interface may comprise 10 Gigabit Ethernet mapped into a standard 10.7Gbps OTU-2 frame format. Electronic Dispersion Compensation may also be included to maximize the transmission distance to the next optical 3R regenerator. Tuneable DWDM Transceivers may be used for connecting to the RBBP fibre backbone. These may interface directly to the fibre backbone via a DWDM add/drop filter or indirectly via a tributary fibre link to the nearest RBBP Backbone Interconnection facility. Duplicated DWDM Transceivers with 4 fibres may be included for redundancy and fault tolerance against backbone fibre failures/breaks.

The 10Gbps wireless interface will comprise a very sophisticated RF modulator and demodulator. The RF power amplifier may be external to the WOESOC device. Like most trunk wireless systems today, it is important that the 10Gbps wireless modulation scheme support multi-rate operation to cope with varying path loss and interference. 10Gbps may be the maximum wireless rate and the instantaneous rate may drop to 1Gbps under extremely adverse environmental conditions or to save electrical power under low traffic loads. The 10Gbps wireless link is expected to transport Ethernet packet traffic only with no TDM capacity required for legacy services. Legacy TDM services can easily be supported using Pseudo-Wire Emulation technologies which are widely available. Ethernet flow control may be required.

A2.4 Access WOESOC

At a remote community, the Access WOESOC is required to interface between the 10Gbps Broadband Wireless Network and a FTTP Access Network which may be based on current generation GPON technology or next generation 10G-PON or WDM-PON technologies. A functional block diagram of the Access WOESOC device is illustrated in Figure A2-3. In its simplest form, it may include: the same 10Gbps RF interface to the Broadband Wireless Network as the Backbone WOESOC device; a 30-50Gbps Ethernet Switch; 12 x 2.5Gbps GPON OLTs and 12 Fibres.

A more useful variant of the Access WOESOC would comprise a Short-Reach (SR) 10Gbps optical expansion port so that two Access WOESOCs can be concatenated in an Add/Drop arrangment. The latter option has the benefit of providing additional groups of 12 x GPON ports for larger remote communities (eg. having 600 premises) and would be suitable for 1-10Gbps Broadband Wireless repeaters & spurs. As shown in Figure A2-3, the Add/Drop capability is needed so that 1-10Gbps Broadband Wireless Networks can connect multiple remote communities to the same Backbone fibre.

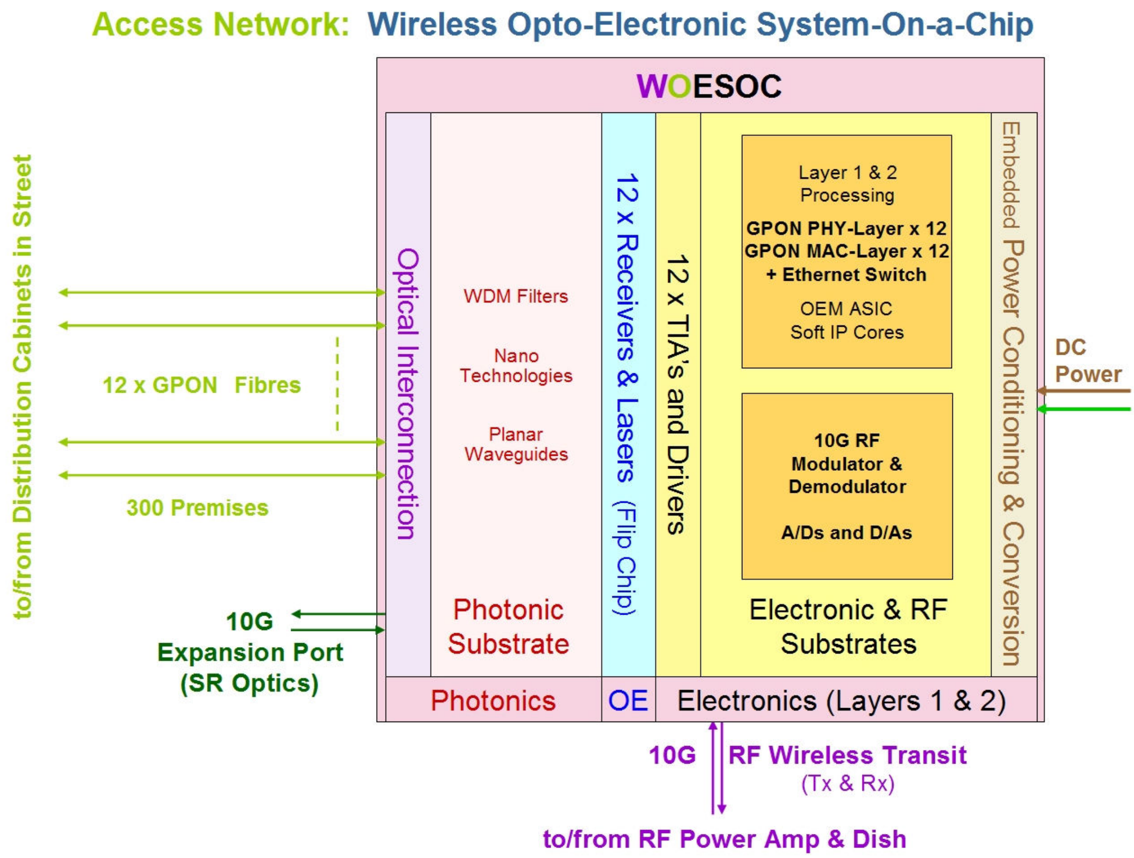

Figure A2-3 Access WOESOC Device

Apart from reducing size and saving power, a design premise behind the integration of GPON OLT functions with the Broadband Wireless functions is that the 1-10Gbps Broadband Wireless interface will be quite complex and most likely proprietary initially, whereas the GPON OLT functions will become low cost, commodity standard soft IP-cores which can be readily integrated with multiple (eg, 12) instances on the same integrated WOESOC device. The cost increment of integrating the GPON OLT functions will be negligible compared to the cost of the Broadband Wireless functionality.

A2.5 Prototype Product & System Demonstration

It is envisaged that the very low power and small size offered by the Backbone and Access WOESOC devices will enable remote, standalone deployments of 1-10Gbps Broadband Wireless Networks as illustrated in Figure A2-4. Power and space savings will be achieved through the integration of the photonics, opto-electronics, electronic & RF interfaces and signal processing in the one WOESOC device. It is anticipated that the RF Transmit power amplifier may be external to the WOESOC and mounted on a PCB with the WOESOC. Rechargeable batteries will power the devices and these will be charged by a small solar cell array. The PCB and Batteries will be fitted to a metal housing at the back of the dish antenna. The Transmit and Receive RF signals will connect to the dish antenna which will be mounted on a pole. The optical fibres to/from the WOESOC devices will be physically protected and will run down the pole to an above-ground splicing cabinet or a waterproof pit under the ground.

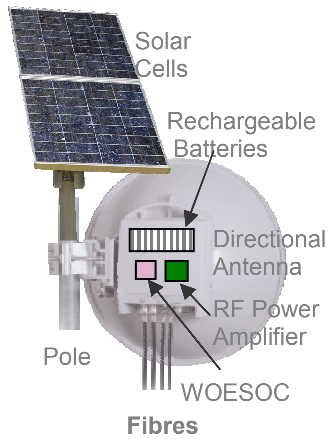

Figure A2-4

For the Backbone Fibre end of the Broadband Wireless Link, an underground pit may include DWDM optical add/drop multiplexers comprising DWDM filters and circulators. For the Access Network end of the Broadband Wireless Link, an above-ground splicing cabinet may include the multiple PON splitters for distribution to the individual premises in the remote community. Such a prototype product would fit well with the capability of SMEs to design, integrate, test and trial with one or more end-users (regional or national carriers for example).

A2.6 Research outputs needed to generate this technological solution

The solution for Terrestrial Broadband Fibre-Wireless is to miniaturise and further integrate the components that interconnect the optical, electronic and wireless elements of the technology:

- Currently, most of the power wastage in fibre-optic to wireless connections is a consequence of the distances and the number of electrons that have to move per second within and between components, which is exacerbated by multiple layers of unnecessary conversion due to the lack of technology integration. This power loss is multiplied by the frequency of signal switching in the devices, and hence increases as the speed (bandwidth) of the device is increased. Miniaturisation fundamentally reduces the distance that electrons travel within the device, and integration reduces the need to move electrons between devices. Miniaturisation and integration are therefore key to low power consumption and high bandwidth operation.

- Miniaturisation and greater integration also lead to lower material usage, and historically (as shown with the development of computer chips) has led to low-cost fabrication.

The objective of the research would be to miniaturise and integrate wireless, optical and electronic technologies to produce prototype WOESOC devices to convert signals from the backbone optical fibre network to a broadband wireless transit network and then back again to a FTTP access network, operating at up to 10Gbps statistically aggregated capacity per broadband wireless trunk.

Confidence that these research outputs might be achievable

Work at ECU with combining optical and electronic elements into integrated opto-electronic devices, and work at other universities in integrating electronic and wireless elements into single devices gives us confidence that these two technologies can be successfully combined in miniature form, and then integrated into a single device: wireless optical & electronics system on a chip (WOESOC).

Additional benefits to investors in the research

- There are potential national security benefits in having a local capacity for design of key components within the national communications network in general, and in broadband wireless networks in particular.

Furthermore, there are further spin-off benefits. For example:

- Low-cost WOESOC devices would have a place within some parts of the mainstream fibre access network. A similar WOESOC device would enable rapid deployment of 10Gbps broadband wireless links from a Central Office to multiple MDUs with internal PON fibre and femtocell wireless premises networks within each MDU, delivering 100Mbps to 1Gbps broadband to each unit.

A2.7 Research Usage

A mission and vision of the proposed FTTP CRC is to co-operate with Australian and International partners to create new, highly integrated wireless, optical and electronic manufacturing technologies, processes, know how and design tools in support of the NBN and specific applications such as the Square Kilometre Array (SKA). Fabless WOESOC engineering design, prototyping and small volume manufacturing centres are an expected outcome for Australia, not high-volume manufacturing plants. The proposed Backbone and Access WOESOC devices are representative examples of the range of devices that can be designed. These particular devices have been selected as examples for this Research Program due to the level of technical challenge required to research and develop them; the high value of the social innovation that they enable to remote communities (such as education and e-health); and the expected wealth and job creation that will occur as a result of Australian researchers & industry exporting the technologies through international partners to global markets having similar remote communities such as North & South America, China, Russia, Middle East and Africa. These same 1-10Gbps Fibre-Wireless technologies & products may also be used to more rapidly deploy PONs to Multi-Dwelling Units and Business Parks for example – thus tapping into the 90% segment of the Australian & Global FTTP markets.

A3 Applications Research Program 2 - Multi-Dwelling Unit (MDU) Networks

The following research program outline is provided for illustrative purposes only. It demonstrates the type of research that can be undertaken within this applications research program. Other similar research projects are also possible to solve the MDU premises broadband networking problems.

A3.1 Problems to be addressed

Broadband will most likely be delivered to MDUs (as shown in Figure A3-1) via P2P fibre or P2P broadband wireless RF or free-space optical links (whichever is the easiest and fastest to deploy) with up to 10Gbps link capacity for larger MDU complexes. P2P is preferred since capacity delivery to the premises via a PON splitter port does not meet the 100Mbps per unit requirement. The 100Mbps to the premises (MDU) gets shared across all units, typically resulting in <10Mbps per unit.

The real problem is the delivery of 100Mbps broadband to each unit within the MDUs since in Australia, these are currently wired with telephone-grade, twisted-pair premises networks. This problem is solveable today with VDSL technology, which can deliver 50-100Mbit/s to each unit over a single telephone grade copper-pair from a VDSL multiplexer located in the basement (for Fibre to the Premises) or on the roof (for broadband Wireless to the Premises).

However, a more long term solution is needed so that by 2020, 1Gbps per unit can be delivered over a MDU premises network.

A3.2 Potential premises network solutions

For each MDU, premises network solutions and associated projects are expected to comprise all-fibre or a hybrid mix of fibre backbone (eg, up the risers) and femtocell broadband wireless Local Area Network (LAN), such as on each floor of the MDU.

All-fibre solutions from the basement/roof to each unit may be either PON-based or P2P Ethernet based. The former requires singlemode fibre and the latter can use either singlemode or multimode fibre (which may already be installed). For the particular case where the fibre premises network is GPON-based and the P2P access network to the premises is broadband 10Gbps wireless, then the solution is identical to that described for Application Research Program 1.

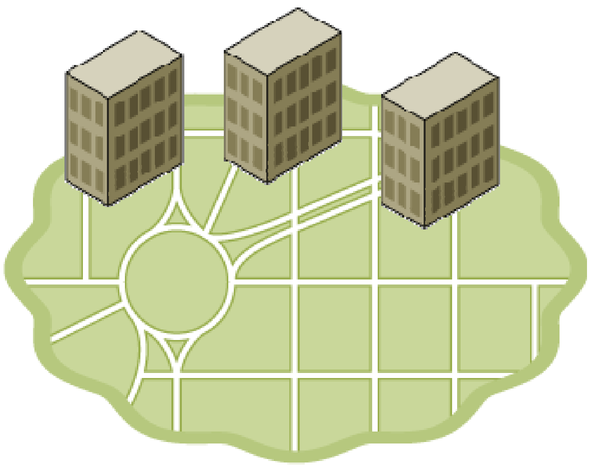

Figure A3-1 Multi-Dwelling Units

Hybrid fibre backbone and femtocell wireless LAN solutions offer another opportunity for WOESOC device research and prototype development, aimed at reducing size, power and cost of the device on each floor which interfaces between the fibre backbone and the femtocell wireless LAN. As for the all-fibre solutions, either PON or P2P Ethernet options are possible for the fibre backbone network. The femtocell wireless LANs need to be able to deliver 100Mbps in the short-term and 1Gbps by 2020 to each unit within the MDU. Transmission distances of femtocell RF signals within building environments and through unit walls will dictate the size of each femtocell. Frequency band allocations will also determine the wireless carrier frequency, maximum wireless data rate and femtocell size.

For both all-fibre and hybrid fibre-wireless premises network solutions, the option for multimode P2P Ethernet offers the opportunity to include new, easy to install plastic optical fibre cabling. Nano manufacturing of polymer fibres for such applications is an area of research being undertaken by Sydney and Adelaide Universities for example.

A4 Applications Research Program 3 - Core & Backhaul Capacity Upgrades

The following research program outline is provided for illustrative purposes only, regarding the type of research that can be undertaken within the FTTP CRC. However, other research areas are also possible within the scope of this applications research program to solve core congestion problems.

A4.1 The Problem - FTTP Enabled Traffic Jams

FTTP will provide social, education and business benefits to Australian users by enabling new broadband applications. This new FTTP access network infra-structure is like providing a broadband freeway to the home and office. Resultant broadband-enabled applications will support digital economy initiatives such as: e-Health, e-Learning, e-Research, e-Business and e-Manufacturing.

As Senator Stephen Conroy quoted at the UNSW Realising Our Broadband Future – Keynote Address in December 2009: “the key is not to seek the killer application, but to build the killer environment so that every industry sector can use the infrastructure to its advantage”. In support of this new vision, NBN Co is tasked by the Australian Government to initially deliver 100Mbps committed data rate to 90% of Australian subscribers. For Australia to maintain this “killer environment”, by 2020 the new FTTP infra-structure network must be upgradeable through changes in the opto-electronics, electronics and embedded software to support anticipated 1Gbps committed data rate requirements for the next generation of broadband applications.

However, as illustrated at a high-level in Figure A4-1 and analytically in Figure A4-2, both the forthcoming 100 Mbps and later 1Gbps FTTP capacity upgrades will place an enormous strain on all parts of Australia’s telecommunication network, from the access to the backhaul to the core and even including the electrical backplanes within the core equipment. Essentially, the new freeways to the home and office can result in traffic jams in the optical core. As an example, Figure A4-2 foreshadows that by 2020, core interface bit rates could be as high as 5 Terabit/s. It is therefore insufficient to focus just on the FTTP access networks to achieve the “killer environment”. The entire end-end telecommunications network of Australia (as illustrated in Figure A4-3) needs to be upgraded to achieve this objective.

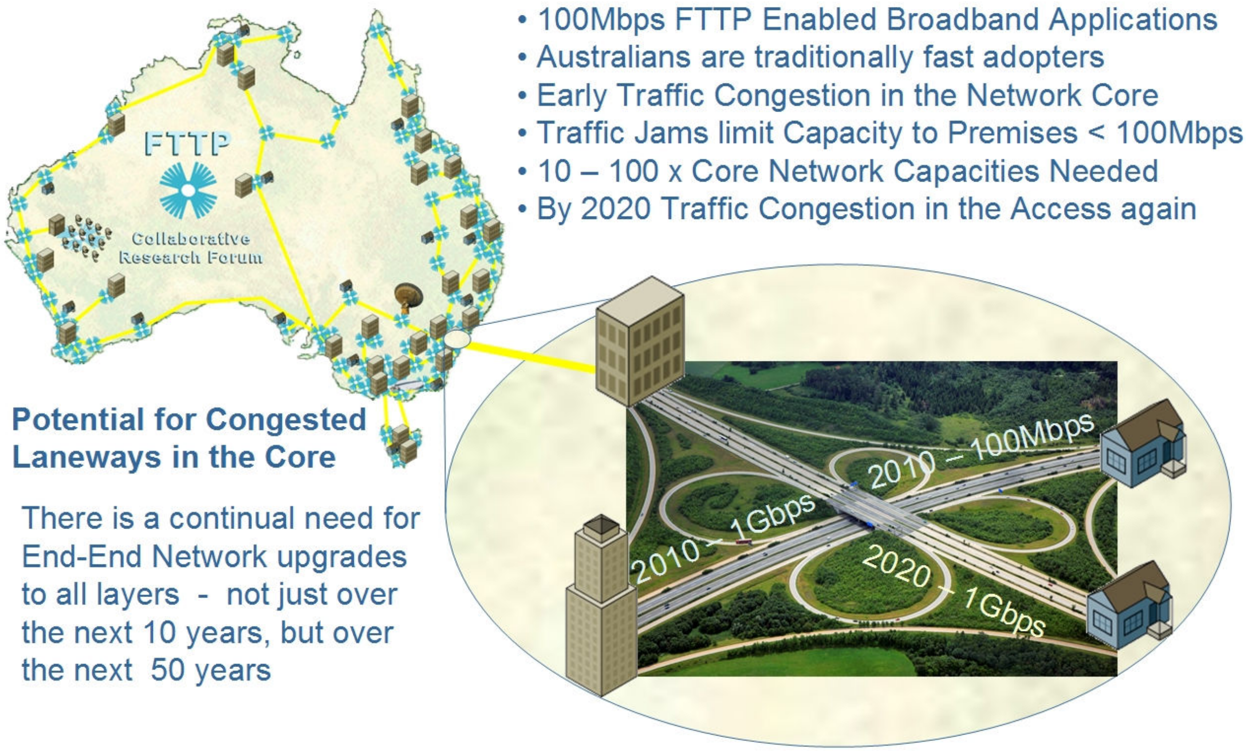

Figure A4-1 Freeways to the Home – Congested Laneways in the Core

As previously illustrated in Figure 1 of this prospectus, this is a cyclic process and Figure A4-2 indicates that the cycle repeats itself every 5-10 years. Throughout the 50-year life of the new FTTP fibre infrastructure, we can expect to go through this cycle of demand growth and network equipment upgrade at least 5 times and up to 10 times. The underlying technology will have a similar cyclic upgrade periodicity.

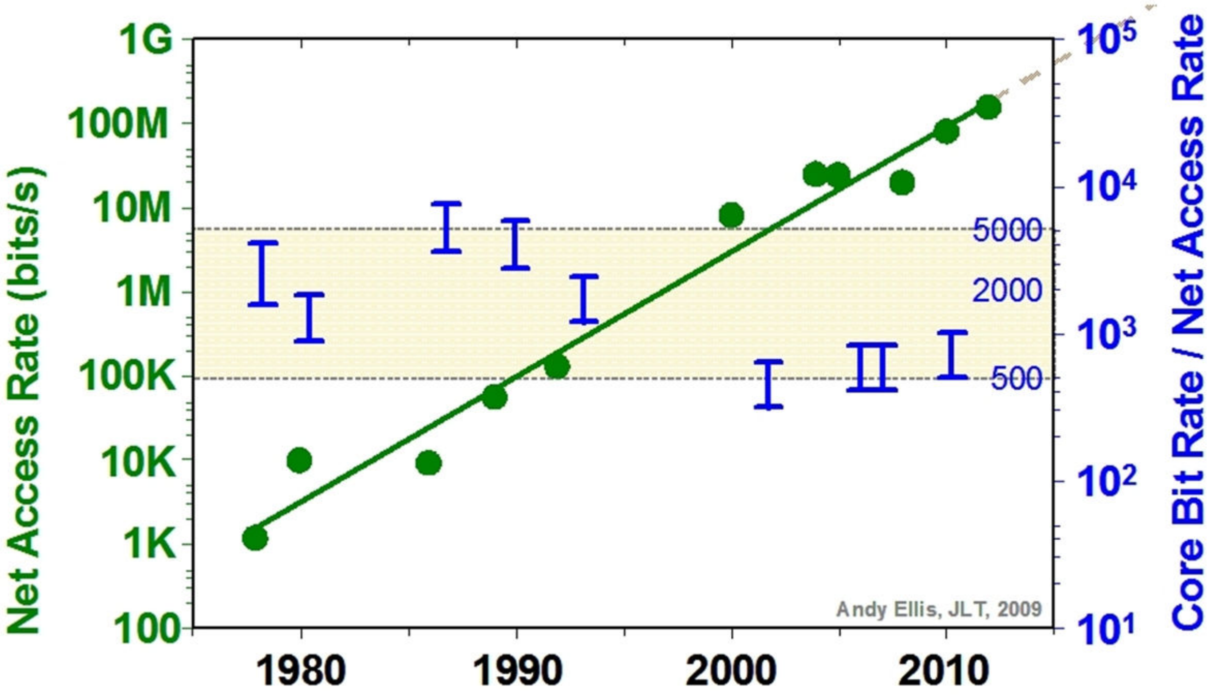

Figure A4-2 Access vs Core/Backhaul Interface Capacity

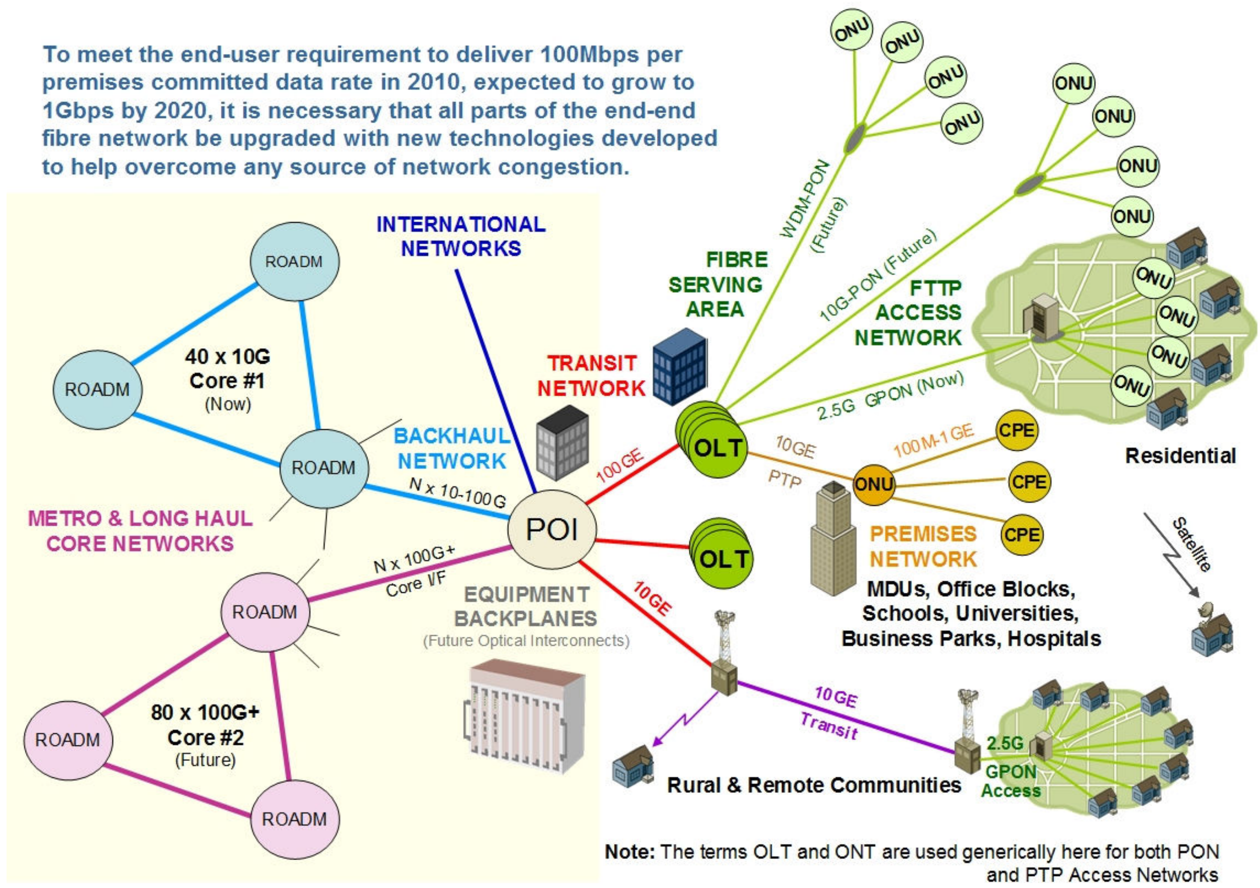

Figure A4-3 Access & Transit Networks Feeding Traffic to Backhaul & Core Networks

A4.2 Potential Core/Backhaul Upgrade Solutions

Building on Australia's Photonics heritage, this Applications Research Program 3 will extend our understanding of the latest advances in packet over optical transport networks and sub-system designs. Applications Research projects that build on Australia's core competency in this field will be undertaken and opportunities identified to develop enabling integrated optical and electronic nano technologies in SOC form. An example could be the design & demonstration of dynamically reconfigurable, multi-rate, "network aware" 40-200Gbps coherent modulation schemes and faster WSS/ROADM switching for later generations of Packet Optical Transport Systems (P-OTS). Such advances in "network aware" and coherent optical technologies and more flexible packet-oriented transport rates will greatly improve the core network resiliency and capacity - factors that will become increasingly important as we approach the non-linear Shannon capacity limits.

As a result of initial input from several potential FTTP CRC collaborators, the vision and objectives for Applications Research Program 3 are two-fold:

1) Overcome the inevitable network congestion in the core and backhaul optical networks caused by the new FTTP-enabled broadband applications. A primary project objective is to maintain all-optical transport in the core and to the edge of the network so as to eliminate very expensive and power-consuming Optical-Electrical-Optical (OEO) regeneration, switching and routing of future multi-wavelength Terabit/s networks having 40Gbit/s and greater (eg, up to 200 Gbps) capacity per 50GHz wavelength.; and

2) As illustrated in Figure A4-4, leverage all-optical Point-To-Point (PTP) access network connectivity to bandwidth-intensive end-users (premises) combined with dynamically switched and modulated optical connectivity in the network core, to demonstrate distributed, Australia-wide access by researchers, industry and other high-end users to very expensive centralised research resources such as the SKA and the Synchrotron. The initial focus is on research applications since these will lead the commercial applications of the future.

To achieve the above all-optical vision and objectives does not exclude the need for electronics. Electronics is most important at the OEO edge of the network and for the high-end premises applications to modulate and demodulate the optical signal such that it can be transported over hundreds to thousands of kilometers through dispersive optical fibres and through many Reconfigurable Optical Add/Drop Multiplexers (ROADMs), each of which is a filter which constricts the bandwidth of the modulated optical signal.

Each ROADM is an access point for local traffic to join the multi-wavelength backbone and to be wavelength-switched to another town or city. The number of ROADMs between two OEO nodes or end-points along a wavelength path ultimately limits either the maximum all-optical transmission distance or in the case of multi-rate P-OTS networks, the maximum packet capacity that can be transmitted over a wavelength between two OEO nodes.

A4.3 New Core/Backhaul Technology Implementation & Trials

A possible project outcome of Applications Research Program 3 is a dynamically configurable P-OTS modulator/demodulator implemented as an Optical & Electronic System on a Chip (OESOC) device developed using Technology Research Program 4. A schematic representation of this device is shown in Figure A4-5. The development of the P-OTS modulation algorithms and firmware will most likely be undertaken by industry participants in the FTTP CRC and supplied as soft IP cores to be integrated with other soft IP cores and optical and electronic processing functions custom-developed by researchers as part of Applications Research Program 3 and Technology Research Program 4.

Other industry and end-user participants having optical telecommunications transport equipment and access to core and backhaul fibre infra-structure and/or wavelengths will be important to the demonstration of the new core/backhaul multi-rate P-OTS technologies so developed.

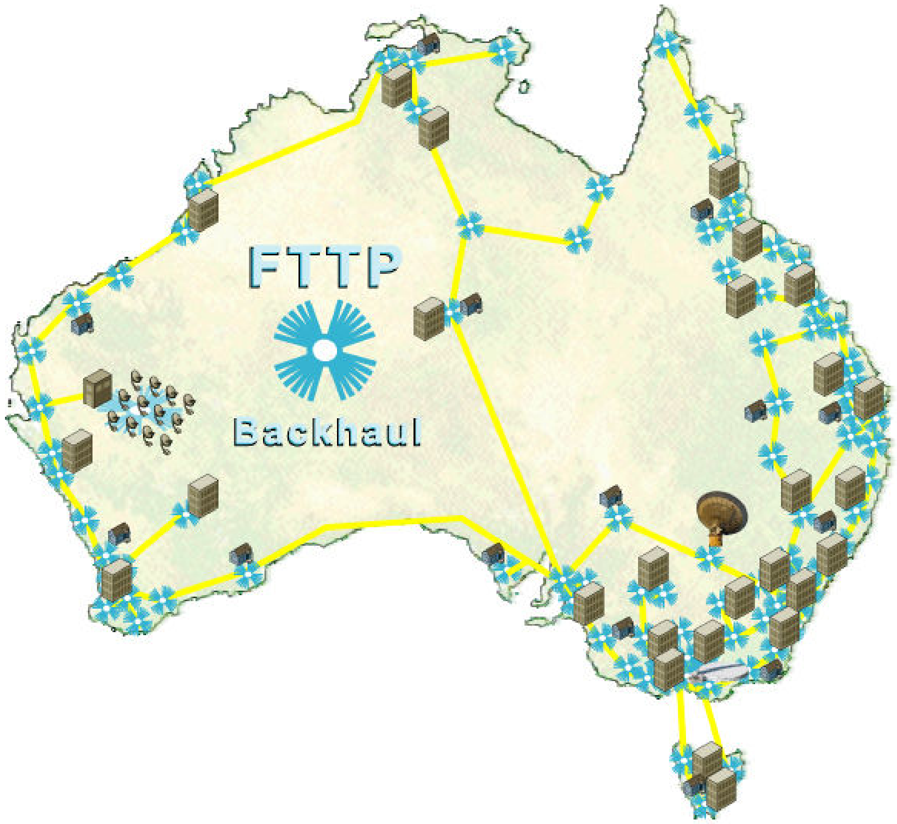

Figure A4-4 National All-Optical Connectivity to SKA & Synchrotron Resources

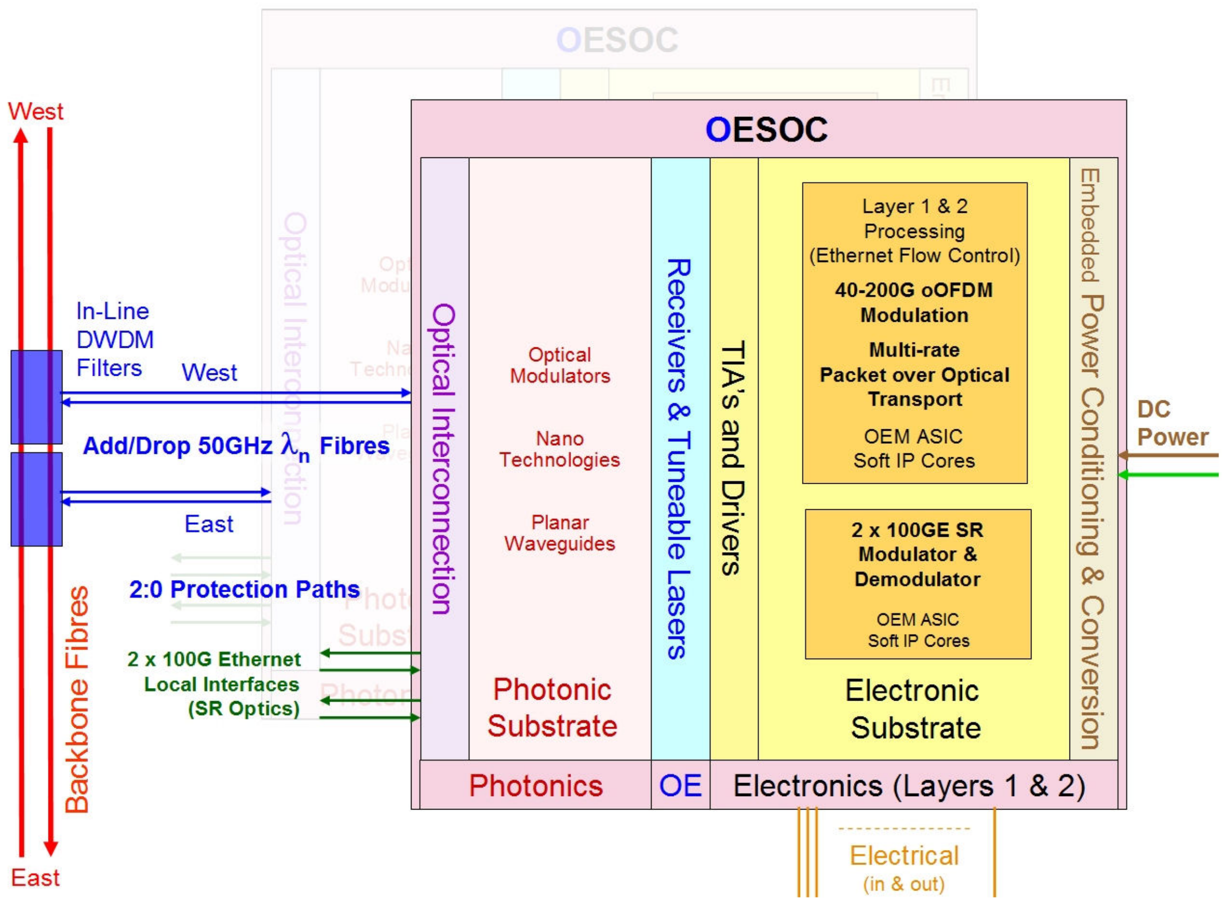

Figure A4-5 OESOC for Multi-rate Packet over Optical Transport System

A5 Technology Research Program 4 - Nano-scale Optics and Electronics Integration

All 3 applications research programs identified for the proposed FTTP CRC require to varying degrees, the nano-scale integration of optics and electronics. Technology research program 4 addresses this underlying technology need. The following provides an overview of networking trends that lead to this technology need.

A5.1 The Need for Electronics

Today, users of multiple data, audio and video services in both metro and remote communities individually demand broadband network capacities that can best be delivered over short distances (<100 metres) to their Laptop, PC or Digital TV via broadband wireless or high quality (Cat-6 twisted or coaxial) copper cabling. The aggregation of these multiple data, audio and video services and associated capacities is driving the network access capacity per premises towards 100Mbps and new broadband enabled applications will similarly increase this demand to 1Gbps by 2020.

The underlying technology needed to deliver the above broadband services (up to 1Gbps) over 100 metres of wireless or copper media is fundamentally “electronic” technology. Even wireless RF signals are ultimately formed in the electronics domain, although for higher power, higher bandwidth and associated higher RF frequency applications, the compound semi-conductor materials needed to generate the RF signals are quite different to the CMOS semi-conductor materials used in most other electronic devices that we commonly use. As a wireless RF example, for MDU applications with many units and greater than 100 metre distances, hybrid fibre and femtocell wireless network technologies require optics & electronics integration, being the basis of applications research program 2.

From an even simpler perspective, electronics is increasingly needed to convert, process and sort enormous amounts of data, decompress or compress it as the case may be to match the information processing capacity of the human brain and finally to generate the final visible optical and audio signals that we humans need to see and hear the information that we want to see and hear. For those all-optical protagonists, remember that “humans can’t hear light”. Electronics is a fundamental technology need as information gets closer to the user.

Even where optical-fibre is all pervasive from the customer’s premises to the telecommunications network core, there will still be the need for electronics within edge exchanges and metro-core central offices. This is because today’s and the foreseeable future’s optical multiplexing and switching technologies can only efficiently handle 1Gbps to 100Gbps streams. Electronics is therefore still needed to process, switch and aggregate lower capacity streams from hundreds to thousands of premises into the higher capacity, 1-100Gbps optical streams. Improved and lower cost electronic to optical conversion technologies are becoming increasingly important as user capacities increase.

Notwithstanding the increasing pervasiveness of optical fibre, connecting the more isolated communities to their nearest backbone fibre network is expensive. This is a particular concern in Australia, as a nation with large areas and dispersed population. New ultra-wideband (UWB) wireless transit network technologies (which again requires RF electronics) will help bridge the digital divide to remote communities. The development of such technologies and their interfacing to optical backbone and access networks is the basis of applications research program 1.

A5.2 The Need for Optics

Whereas previously asymmetric digital subscriber line (ADSL) and coaxial copper based technologies were adequate for delivering Telephony, Internet and PayTV services to the premises from the nearest exchange, these copper-based technologies have reached the end of their useful life due to the 100 metre transmission distance limitation of 100Mbps to 1Gbps capacities over copper. Both Telstra and the Australian Government have already mandated that copper access networks will no longer be used for any new estates. This is a global trend driven ultimately by the cost of delivering 100Mbps broadband to each premises. All new access networks will be predominantly optical fibre based and in Australia, NBN Co are investing $43Billion to replace older copper access networks with optical-fibre access networks and associated electronic switching systems.

Optical fibre access networks using passive optical network architectures and wavelength division multiplexing further reduce the access network costs and power consumption through the sharing of feeder fibre and more expensive lasers in the exchange between 24-32 premises. Again, electronics is required at each end of the access network to time-division-multiplex the upstream and downstream transmissions of multiple premises' traffic per feeder fibre and multiple services (telephony, broadband Internet, pay TV and video-on-demand).

Optical fibre is well recognised as the preferred transmission medium for transporting high capacities over longer distances. Additionally, the use of densely spaced (DWDM) wavelengths, each carrying 10-100Gbps capacity is now enabling the backhaul and core optical networks to be upgraded with up to 10Tbps capacities. These 10-100Gbps streams can be optically amplified and switched thus saving enormous amounts of power and cost associated with optical-electronic-optical conversion within the core network. However, to maximise these savings requires more advanced electronic to optical modulation and conversion technologies at the network edge and the cost effective implementation of such technologies is the basis of applications research program 3.

A5.3 Integrated Optical and Electronic Device Trends

Over the past decade, we have seen the evolution from micro to nano-scale CMOS electronic devices and the increasing integration of functional elements into a single device, often called a System on a Chip (SOC). The resultant smaller gate and interconnect dimensions has the following benefits:

1) Lower switching and transmission delays enables faster processing speeds and faster data transfer rates, thus meeting and exceeding annual capacity growth rates according to Moore's Law;
2) Greater storage capacity, functional module complexity and greater number of functional modules that are possible within a given physical space;
3) Lower power consumption per gate and for a given bandwidth, since less energy is required to move electrons over shorter distance paths having lower capacitance;
4) Potentially smaller device size, although practical packaging and PCB assembly constraints, combined with the higher power consumption and reduced speed issues when interconnecting packaged devices on a PCB has led to a fewer number of larger, more integrated SOC devices to implement a given solution.

Just as electronics processing and storage has been getting faster and more dense, so too have optical and wireless (RF) communications interfaces been getting faster, although for maximum speed, these are implemented using compound semiconductor materials rather than CMOS. The need to maximise speed and reduce power, size and cost has led to increasing integration using hybrid, mixed signal devices. In the case of opto-electronics and electronics integration, a technique called flip-chip is used to integrate two disparate device materials. The US Defense Advanced Research Projects Agency (DARPA) are funding a program called COmpound Semiconductor Materials On Silicon (COSMOS) to achieve the integration of high-density CMOS processing and high-power, high bandwidth wireless RF signals in the one device. To reduce optical device size and fibre interconnection costs, planar waveguides, modulators, wavelength division multiplexers and other photonic signal processing functions are being integrated with opto-electronic materials and functions. As a logical evolution to the convergence of broadband services and the need to increase capacity and reduce size, power and cost, there is an emerging need in high volume or remote/isolated telecommunications applications to integrate some or all aspects of photonics, opto-electronics, CMOS electronics and RF wireless functions into one SOC device.

The following are examples of various highly integrated and/or high speed hybrid devices.

Infinera Photonic Integrated Circuit (PIC) Technology (www.infinera.com)

There are various ways to multiplex and transmit data at 100Gbps. Infinera, a US optical equipment company, were the first to do so with a commercial PIC which integrates 10x10Gbps wavelengths as shown in Figure A5-1 and replaces a large number of discrete photonic and opto-electronic components.

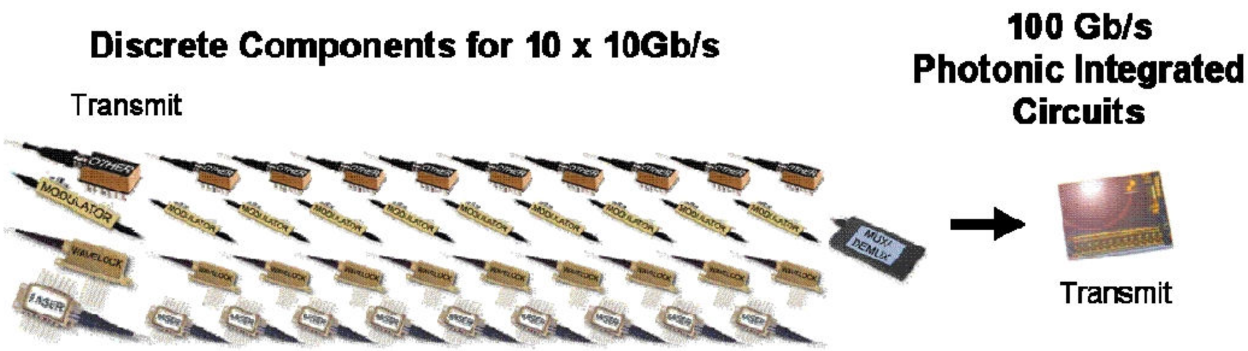

Figure A5-1 Infinera PIC Multiplexes and Transmits 10x10Gbps Wavelengths

RAD "System on a SFP" Technology (www.rad.com)

RAD, an Ethernet equipment company in Israel have developed Small Form-factor Pluggable (SFP) Transceivers which integrate Layer 2 Ethernet, pseudo-wire encapsulation and E1/T1 and E3/T3 (Layer 1) electrical interfaces. They have developed their own Application Specific Integrated Circuit (ASIC) which embodies their pseudo-wire IP and fitted this to a very small FR4 PCB (substrate) that fits inside the SFP Transceiver case. The RAD Pseudo-wire SFP would normally be fitted with other Fast Ethernet or Gigabit Ethernet optical SFPs to an Ethernet Switch. Figure A5-2 illustrates how RAD have shrunk their E1/T1 pseudo-wire / Ethernet IP from a 1RU box to a SFP.

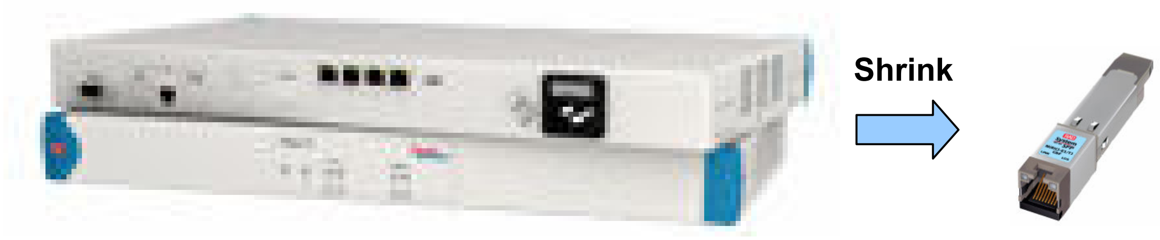

Figure A5-2 RAD Shrinks a Pseudo-wire Ethernet Box to a "System on a SFP"

One Chip Photonics (www.onechipphotonics.com)

One Chip Photonics, a China-US start-up company have developed 1G and 2.5G Ethernet Passive Optical Network (EPON) SFP Transceivers based on PIC technology. As shown in Figure A5-3, their SFP incorporates a PIC which integrates a DFB Laser, APD Receiver & TIA and a 1310nm/ 1490nm WDM multiplexer.

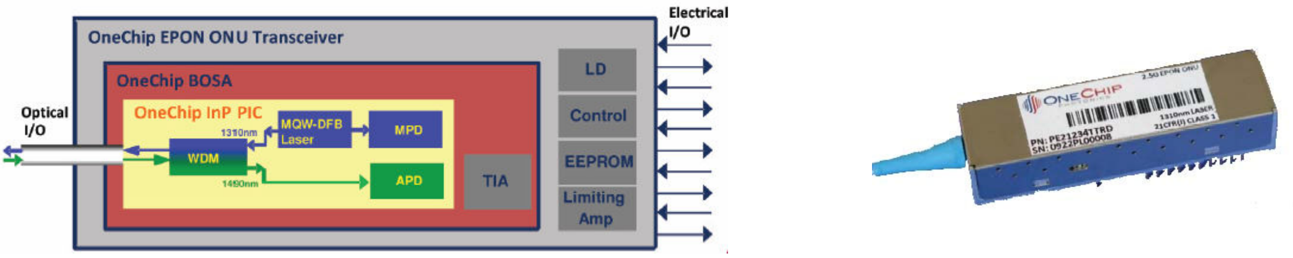

Figure A5-3 One Chip Photonics EPON SFP Transceiver

Broadway Networks (http://www.broadwaynetworks.com)

As shown in Figure A5-4, Broadway Networks have developed a 1G EPON SFP Optical Network Unit (ONU) that incorporates EPON WDM optics, opto-electronics, PHY and MAC-layer electronics and software. The EPON PHY and MAC-layer electronics and software represents an extra level of electronics integration on top of that of the One Chip Photonics SFP Transceiver. The EPON stick (SFP-ONU) as it is called is in full compliance with the IEEE 802.3ah standard. It can be plugged into the SFP port of any access equipment, such as IP routers, Ethernet switches, and DSLAMs. It integrates and shrinks what is currently a quarter card of electronics and photonics in older generation EPON equipment.

Figure A5-4 EPON SFP ONU

GPON SFP-ONU Product Prediction

The above component integration trends leave no doubt that a GPON SFP-ONU with full PHY and MAC-layer functionality will soon be available from multiple SFP Transceiver suppliers.

A5.4 Needs of Component Suppliers

Today there is as yet no technological solution for the integration of best of breed photonic, opto-electronic, wireless and electronic devices and associated soft IP cores on the one homogenous substrate. As a result, the most common substrate used today by multi-functional devices such as EPON SFPs is FR4 PCB material. Due to the need for high power inter-chip buffering and traditional PCB assembly processes, this solution is pushing the limits of speed, size, power and cost. To progress forward towards greater levels of integration and data rates that are 10-100x faster, while retaining the benefits of small modular devices with low power and cost, component suppliers need to simultaneously resolve the problems of multi-substrate material integration with the integration of best-of-breed soft IP cores targeted at different substrates.

The US DARPA COSMOS program for integrating compound semiconductor and CMOS substrates is evidence of this global problem. At the same time, the ability to integrate best-of-breed soft IP cores across multiple substrates is needed since component suppliers tend to be experts in one or at most two technology areas and they need to stand on the shoulders of other experts in other technology areas that require integration. For example, component suppliers with expertise in planar waveguide photonics and opto-electronics design would generally have little knowledge and expertise in the design of high speed, low noise RF circuits, let alone the advanced RF modulation schemes required to transport data over them. Similarly, neither the photonic/opto-electronic nor the RF wireless experts would have expertise in QinQ VLAN technologies as part of a CMOS Ethernet Switch embedded in an integrated, multi-functional SOC device.

The proposed FTTP CRC Technology Research Program 4 will address these global issues to support Australian and International component-level partners in moving forward towards the next generation of SOC devices for both mainstream FTTP applications and for the specific FTTP CRC Research Application Programs 1-3.

A5.5 Needs of Small to Medium Enterprises (SMEs)

These days, networking protocols and device technologies have become very complex and thus to combine multiple devices together to build even more complex products and systems requires detailed knowledge of such protocols (generally up to Layer 2) and high-speed, feature-rich inter-device interfaces. Laying out very high speed circuit designs on FR4 PCBs requires detailed knowledge, skill and experience. These issues often become roadblocks to market entry for SMEs that would prefer to just focus on niche applications and the simple engineering design tasks of product packaging, powering and the connection of standard fibre, wireless, broadband coax. and other copper interfaces such as 1000BaseT Ethernet.

SMEs would benefit from highly integrated photonic, opto-electronic, electronic and RF SOC devices where all the complex functions and inter-device interfacing issues were addressed internally by other experts who understand such things. The only interfaces to such highly integrated multi-functional SOC devices would be via: a modulated optical signal and fibre pigtail(s); a modulated Intermediate Frequency (IF) interface for Broadband RF applications (wireless and coax.); or one or more 1000BaseT electrical interfaces for Ethernet networking applications. SME's could then focus on what they are good at, being to solve niche telecommunications networking problems or to address niche markets that the Major Equipment Suppliers have less interest in.

A5.6 Needs of Major Equipment Suppliers

Over the past 20 years, increasing market segmentation into equipment and component suppliers, with increasing functional integration of component technologies, has led to a situation where the Major Equipment Suppliers have become marginalised – leading to the supply of vanilla products. Recent press in LightReading "Can Vendors Build Their Optical Components?" dated 19th March 2010, has highlighted that the Major Equipment Suppliers want to reinstall vertical integration strategies so that they can differentiate themselves. However, the need for integrated, multi-functional, high speed SOC devices does not go away but the existing cost and supply benefits of greater volume production does get diluted by bringing back vertical integration by the Major Equipment Suppliers.

To address the above issue, it is important that Technology Research Program 4 include a hybrid-technology ASIC and Multi-Project-Chip capability to service the specific product needs of Major Equipment Suppliers who may be partners to the proposed FTTP CRC. The ability to license and integrate soft IP cores is important, including the integration of IP cores that the Major Equipment Supplier may supply as part of their own unique, proprietary product implementation that only they have rights to supply. Developing design tools that support the integration of multiple substrate technologies and multiple soft IP cores is an important aspect of this Technology Research Program. With these capabilities, a high technology device integration service can then be offered to the Major Equipment Suppliers.

A5.7 Technology Research Program 4 – Development Vision & Challenges

Technology Research Program 4 aims to understand and solve the issues of integrating multiple different substrate-materials and processes including the integration of available soft IP cores, with the target design and manufacturing capability being to integrate nano-photonics, high-speed opto-electronics, UWB RF electronics and high density nano-electronic storage and processing functions (up to Layer 2), all in the one device or module.

To achieve this level of integration in the short to medium term requires a mix of at least three different substrate materials and manufacturing processes – such as: silicon photonics; compound semi-conductors for opto-electronics and UWB RF electronics; and CMOS for high speed, high density electronics. To minimise costs, the long term vision and challenge is to reduce all functions to one integrated substrate material and process, although only extensive research and time will determine if this ultimate vision can be realised in practice.

Rather than focus on the manufacturing process and materials integration issues, if we focus on the functional integration benefits, then the device or module that Technology Research Program 4 aims to develop is effectively a broadband Wireless, Optical & Electronic System on a Chip, which we can simply refer to as a broadband WOESOC. A schematic representation of a broadband WOESOC device or module is illustrated in Figure A5-5.

The outcome of Technology Research Program 4 will be a world class Australian WOESOC design and prototype manufacturing capability with volume manufacturing via multiple partner facilities locally and globally.

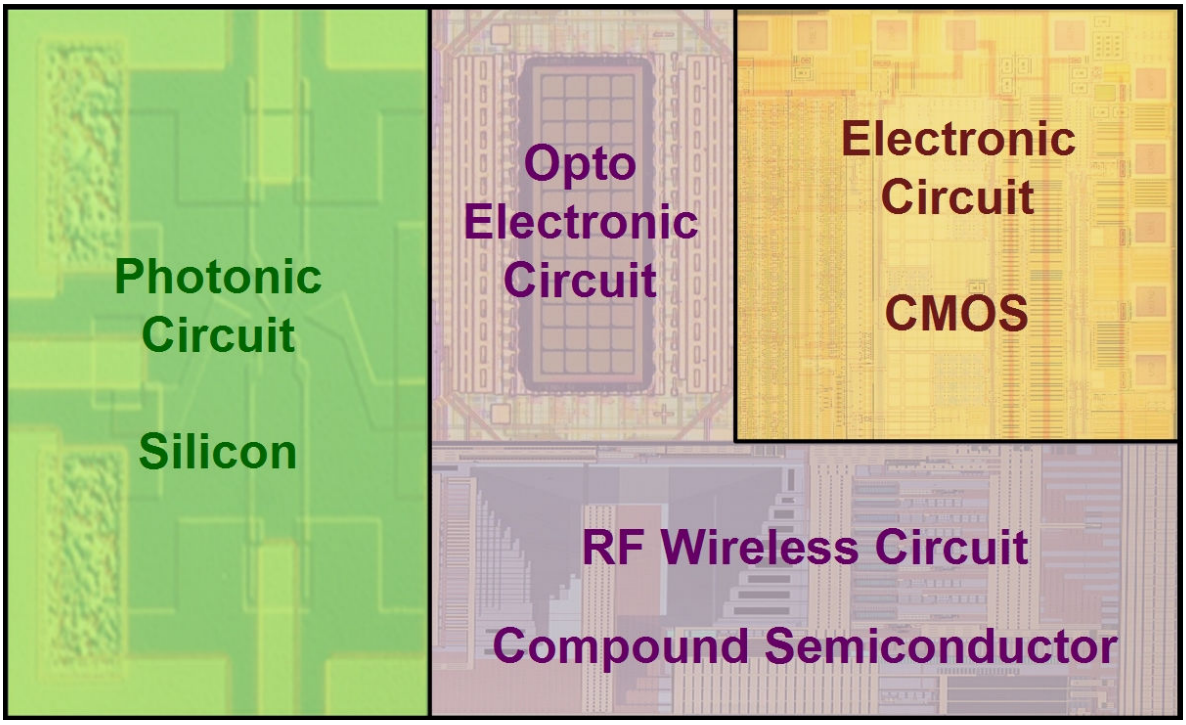

Figure A5-5 Broadband WOESOC - Schematic Representation

A5.8 Research & Prototyping Capabilities Required

Local and international research and industry participants needed to directly support and participate in Technology Research Program 4 will have knowledge, skills, experience and facilities in one or more of the following device technology areas:

1. Designing and fabricating electronic VLSI devices including sub-micron lithography;
2. Designing and fabricating Photonic Integrated Circuits (PICs);
3. Designing and fabricating DWDM and single wavelength lasers and PIN/APD detectors;
4. Substrate materials & fabrication processes for photonic planar waveguides;
5. Substrate materials & fabrication processes for silicon on sapphire devices;
6. Substrate materials & fabrication processes for compound semi-conductors for RF applications;
7. Substrate materials & fabrication processes for compound semi-conductors for OE applications;
8. Substrate materials and fabrication processes for nano-devices;
9. Integration of hybrid silicon and compound semi-conductor substrate materials;
10. Integration of soft IP cores from multiple suppliers and for multiple substrates;
11. Power management systems for VLSI and Opto-electronic devices;
12. Thermal design of VLSI and Opto-electronic devices for packaging.

The knowledge, skills and experience needed to implement the applications-oriented research programs are somewhat different, but complementary, to those for the underlying nano-scale optical and electronic technology research program. For example, these programs require research organisations and industry partners having knowledge, skills and experience in the:

a. Electronic design of broadband RF amplitude & phase modulation technologies;

b. Integration of soft IP (intellectual property) cores that implement for example: OTU-2 (optical channel transport unit) framing and multiplexing; EPON, GPON & 10GPON MAC and PHY-layer protocols;

c. Design of external optical modulators, DWDM laser current stabilisation and TIA (trans-impedance amplifier) receivers;

d. Flip-chip integration of best-of-breed tuneable DWDM laser chips.

A5.9 WOESOC Applications

There are no bounds to the applications of the WOESOC technology once developed. Essentially, the WOESOC will become the PCB of the future. The technology will be applicable to the following non-exhaustive list of applications and as shown, is not constrained to telecommunications and FTTP applications:

1. 10G WDM PON OLTs & ONUs;
2. 100Gbps Coherent DWDM Transceivers;
3. High Density P2P 10G Ethernet OLTs;
4. DWDM OADM with 10G Trunk Wireless I/F;
5. 10G Trunk Wireless I/F with multi-PON ports;
6. 1G Satellite Wireless I/F with multi-PON ports;
7. 10G PON Regenerators for >20km FTTP;
8. WDM PON Regenerators for >20km FTTP;
9. Optical Interconnects for HS Backplanes;
10. Multirate 40-200Gbps Packet Multiplexers;
11. DWDM ROADM for Metro Networks;
12. 10Gbps Fibre to Femtocell Wireless I/F;
13. Active Splitters for 10G WDM PONs;
14. Regional 100Gbps PON OLT and ONU;
15. SKA RF Receivers, Multiplexer & Fibre I/F;
16. SKA Timing Distribution over LH Fibre.

Note that whilst WOESOC technology enables the capability to integrate photonics, high speed opto-electronics, high speed & density electronics and broadband RF electronics, any subset of this capability is equally applicable as a technology derivative (eg, OESOC, WESOC) with its associated applications.