Conclusions and Further Work

The aim of this study has been to answer this basic question: How can the "Last-Mile" challenge be addressed to supply broadband to underserviced communities by combining existing and emerging technology? In the process, a substantial body of multi-disciplinary technical literature was reviewed over a period of 2 years (with a special focus on recent publications) in order to create a forward-thinking body of knowledge.

The first chapter attempted to set the scene by providing background information and introducing key concepts, including the "Digital Divide" and addressing why it is necessary to bridge the "Last-Mile" to connect the un-connected. Secondly, it explored the barriers to internet adoption that are preventing connection of under-serviced remote communities—most of which are poor and lacking infrastructure. Key to the connectivity problem is solving the infrastructure problem in terms of "Last-Mile" availability of electricity and communication. A technology overview was done to investigate how current rapid simultaneous technological development in a number of fields could be harnessed to "connect the unconnected"—including renewable power and broadband satellite technology. Currently the satellite broadband segment is well poised for growth having already recorded a significant (50%) revenue growth over the initial 5 year period since introduction of High Throughput Satellite technology in 2010, with an average subscriber growth rate of 11%.[1] With a number of very large constellations planned from various operators, the available bandwidth is expected to grow significantly, and the increased competition is expected to put downward pressure on subscription rates. The chapter put forward the idea of a self-contained, infrastructure independent, apparatus to supply broadband internet and ancillary enabling services to remote underserviced communities. The proposed concept was named BARC (**B**roadband **A**pparatus for Underserviced **R**emote **C**ommunities).

The second chapter had it as goal to produce a requirements definition for the BARC product concept. It introduces the reader to a number of basic considerations

[1]State of the Satellite Industry Report. 2017. *State of the Satellite Industry Report.* Washington DC: SIA.

C. Kotze, *A Broadband Apparatus for Underserviced Remote Communities*,
Southern Space Studies, https://doi.org/10.1007/978-3-030-15766-1_7

surrounding new product development: defining the concepts, delineating functional and non-functional requirements for the rest of the study. A "FURPS+" model was used as framework to develop the requirement set. A product story was used to position the product in terms of the "what, how & why" with regards to its intended audience to unmask the requirements and in the process conducting a FAB (Features, Advantages and Benefits) analysis. The process involved defining all the key actors and imagining scenarios involving their expected interactions with the BARC product. In total, nine of these use-case scenarios were identified and explored in a template format detailing the interactions between the actors and BARC: including pre/post-conditions and any expectations impacting the use-case scenario. From the use-case analysis, eight Functional Requirements, nine Acceptance Requirements and seventeen Performance Requirements were defined—they set the stage for the concept development.

In Chap. 3 the reader was introduced to the design philosophy which revolves around the idea of creating a product that will not only satisfy all requirements technically, but to do it in such a way as to encourage the intended user to want to use the product. The goal was to create a familiar form to blend into any environment with the ability to add function over and above the technical performance to serve the community in a larger way. A product design was chosen that can provide shade in the day and supply light at night and in so doing combat "light poverty"—a condition affecting many people in infrastructure-deprived areas.

The first artefact produced by the process was a rough basic design concept outlining additional design requirements: a modular approach and the desire to have a smooth design featuring flat surface areas. The master design concept identified a number of essential modules which were applied to common forms typically associated with people gathering to come up with a shortlist of three design concepts. The three designs were evaluated against a reference-design using an adapted Pugh Matrix to come up with a very basic design resembling a car port featuring symmetrical flat faces.

Chapter 4 took the reader through the steps of refining the chosen concept design introducing an overall design-statement; identifying the primary component set and producing architecture overviews of all identified modules to ensure conformance to the initial requirements definition. A formal technology review was conducted as a substantial part of the study—to identify applicable technology which could be used to satisfy the design statement. The flat structure necessitated the use of FPA, as opposed to the more traditional parabolic dish. A FPA not only suits the design very well, but since it features tracking ability, importantly, will be able to utilise the new planned mega-constellations in a variety of orbits. On the down side, these are very new products currently directed at the high-end of the application market such as aviation and super yachts and are still very expensive for an application such as BARC. Market observers are not optimistic that the technology will be any

serious mass commercial competition for traditional parabolic antennas for a number of years due to scalability and cost concerns.[2]

Market predictions are however not a reason to ignore the technology in the design. In 1980 McKinsey predicted the cell-phone market in the USA will be worth only 900,000 units by 2000 (less than one 1% of the actual market), convincing AT&T, who commissioned the report, not to invest in the market.[3] With more than 21 companies actively developing the technology, the adoption curve will more than likely be significantly faster than currently predicted, primarily driven by the "in-flight" connectivity market. Other current technological developments might prompt an even quicker adoption than anticipated, such as the possibility of mass adoption of autonomous vehicles. This scenario will open up a very big market with the expected benefits of rapid cost reduction due to scale-up of production.[4] Therefore, though FPA technology is in a starting phase it does hold promise for a number of markets currently excluded from satellite applications due to antenna constraints.

The design statement emphasises the use of environmentally safe and energy-efficient technology. Responsible technology selection is crucial to ethical environmental design, not only regarding disposal, but also importantly, responsible sourcing, free of damaging mining practices involving child labour and conflict resources. From an environmental perspective especially, the negative aspects of battery technology, have become the focus of public attention as the adoption of electric and hybrid cars are increasingly moving into the mainstream.[5] To counter the very real concerns regarding the environmental impact of sourcing metals such as Nickel, the Global Battery Alliance[6] was created. This initiative of the World Economic Forum (created in 2017) as a public-private collaboration effort to ensure an ethical "inclusive, innovative and sustainable battery value chain" in support of the UN 2030 SDG. A fast-growing niche segment in the PV market is the manufacturing of stable cost-effective, high efficiency (16–22%) CIGS (Copper, Indium, Gallium & Selenide) "thin-film" PV cells—a technology which opens up new design opportunities ideally suited for the BARC design.[7] Though

[2]Pultarova, T. 2017. *Kymeta ships first 400 flat-panel antennas, confirms talks with OneWeb.* https://spacenews.com/kymeta-ships-first-400-flat-panel-antennas-confirms-talks-with-oneweb accessed 23 November 2018.

[3]Lozano, A. 2018. *The Hall of Innovation - Cellular telephony: just a niche market.* https://www.dtic.upf.edu/~alozano/innovation/index.html#mckinsey accessed 12 May 2018.

[4]Erwin, S. 2018. *U.S. military a potential big customer for satellite industry's new low-cost terminals.* https://spacenews.com/u-s-military-a-potential-big-customer-for-satellite-industrys-new-low-cost-terminals/ accessed 19 November 2018.

[5]Eckart, J. 2017. *Batteries can be part of the fight against climate change—if we do these five things.* https://www.weforum.org/agenda/2017/11/battery-batteries-electric-cars-carbon-sustainable-power-energy/ accessed 27 December 2018.

[6]Global Battery Alliance. 2018. *Global Battery Alliance.* https://www.weforum.org/projects/global-battery-alliance accessed 27 December 2018.

[7]NREL. 2018. *Copper Indium Gallium Diselenide Solar Cells.*

the toxic material cadmium is often associated with the manufacture of thin-film PV, there are manufacturers producing cadmium-free thin film CIGS.[8]

Another consideration of technology selection was to consider the impact of the intended function of the technology on the ambient implementation environment. New generation LED technology offers an environmentally friendly option with no equivalent in traditional lighting technology, especially in the form of super thin ultra-efficient printable LED sheets which are ideally suited to a novel application such as BARC. However, implementation of broad-spectrum blue-white LED lighting into previously unlit areas does have a potential environmental concern. Firstly, according to the International Dark-Sky Association—a critic of the roll-out of LED citing perceived light-pollution—it can create "sky glow", which might lead to loss of celestial detail at night which could be culturally significant for the community.[9] From a health point of view, LED's with very high Kelvin ("blue") values can influence circadian rhythms causing sleep disturbances (Hatori 2017). Even though these problems can be countered by using shielding and lowering of the Correlated Colour Temperature (CCT) to less than 3000 K, it is important to take note of the challenges posed. Collection of data is a primary function of BARC, which is driven by sensors. One of the emerging technologies identified from a design point of view is printable thin-layer sensors using materials like graphene that are opening up many new opportunities such as direct integration of sensors into the frame and roof surfaces (Banerjee 2016).

A substantial contribution to the body of knowledge of the study came from investigating the impact on society, economics, sustainability and government of "connecting the unconnected"—as described in Chap. 5. Education and health are cornerstones of the social wellbeing of any community. The study emphasised through examples the potential gains which could be obtained through broadband connectivity of underserviced communities. The economic impact was approached in a similar fashion, framed against broadband internet as a General Purpose Technology. The chapter introduced the reader to the importance of sustainable development as a key component in ensuring a fair dispensation for future generations. Broadband connectivity has a crucial role to play in supporting sustainability. The chapter also presented the advantages of e-Governance which could be enabled by the availability of pervasive broadband connectivity.

Though the scope of the study did not include a formal costing study, it does acknowledge the importance of sustainable funding. In Chap. 6 a funding model was explored in terms of the value proposition presented by the Network Effect and revenue streams available to the BARC product, primarily based on the increasing monetary value of data.

According the UN's Department of Economic and Social affairs, the global population passed the 7 billion mark in 2011 already and by the time the SDG reach

[8]Midsummer. 2018. *Environment.* http://midsummer.se/technology/environment accessed 1 May 2018.
[9]IDA. 2018. *LED Practical Guide.* http://darksky.org/lighting/led-guide/ accessed 28 April 2018.

the 2030 deadline, the global population will surpass 8.5 billion.[10] Africa is expected to have the highest population growth, with Sub-Saharan countries expected to experience rapid growth and account for 50% of global population growth between 2015 and 2050. Ironically, according to data from the World Bank, this region is also home to the largest population—41% in 2013—affected by poverty.[11] The greatest percentage of people with no connection to the internet is also to be found in Sub-Saharan Africa. Adoption of connected technology is increasingly crucial to participate in the modern economy to enable economic growth, which in turn is the key to poverty reduction, as is managing and understanding the implications of the effects of rapid population growth to ensure sustainable development.

Finally, some thoughts on future work. The study has identified that creation of a device like BARC is technically possible, but its scope did not include proving the feasibility of such a project. Future work on the topic could include the following:

- Financial—conduct a study to test the financial viability of the device in terms of the target demographic and the proposed funding model.
- Users—a detailed user interface study should be conducted to provide insight into challenges resulting from the placement of such a product in areas dominated by a target demographic with little to no digital skills. Such a study should also take into consideration how emerging technologies such as natural language processing and AI can be integrated to bridge the skills gap.

Some final thoughts: working through this project has left the researcher with a profound appreciation for the need to create the opportunity to hand the nearly four billion currently "un-connected" entry into the "broadband ecosystem". The research also indicated a sense of urgency in dealing with this problem as there are already very strong indicators that the digitally "rich" economies are accelerating ahead of economies with a low digital penetration. Failing to intervene timeously will increasingly relegate a substantial portion of the global population to the digital equivalent of the Medieval Period—excluding them from partaking in the spoils of the Fourth Industrial Revolution. Such a situation will amplify existing inequalities to significant new levels, to the point where the "unconnected" will have no way to trade with the "connected." This is a scenario which should be avoided at all costs.

[10]UNDESA. 2017. *World Population Prospects The 2017 Revision.* New York: United Nations Department of Economic and Social Affairs.

[11]Wadhwa, D. 2018. *The number of extremely poor people continues to rise in Sub-Saharan Africa.* https://blogs.worldbank.org/opendata/number-extremely-poor-people-continues-rise-sub-saharan-africa accessed 29 November 2018.