Techno-economic analysis for Rural Broadband Access Networks

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***Abstract*— This paper elaborates a techno-economic cost model for deploying Broadband Access Networks in rural areas around the world. It is aimed to come up with the major benefits and challenges associated with offering broadband access/services in rural areas and also to derive an effective solution towards this problem. The complete picture including all relevant factors impacting costs and benefits of rural broadband networks have been presented. A Technology Selection Strategy is also proposed to select the best-fit solution, subject to technical and economic modelling including regulation, revenue and funding. A quantitative analysis leading to an empirical techno-economic model for computing the total cost-benefits associated with rural broadband has been developed. A short insight into a Germany-based case study for rural broadband has also been depicted.**

Keywords - Rural Broadband Access; Techno-economic analysis; Cost model; Regulation; Funding

I. INTRODUCTION

The communication network market is widely accepted to be one of the most dynamic fields of business and technology. With a multitude of fast-paced technological innovations, ever-insatiable market demands and tightly coupled regulatory obligations; dynamism seems to exist in almost every aspect of this digitally networked environment.

The Internet has been a global connector, establishing links from one corner of the world to the other through a well defined globally distributed network. A series of innovations in this field of engineering propelled different technological adoptions in all segments, leading to higher capacity networks as we see it currently.

However, not much has driven the development of broadband communication networks for rural communities globally. This is primarily due to factors such as low return on investment potential for network operators, lower spending capability of rural populace, stringent regulatory landscapes and inadequate funding resources [1].

In order to understand the issue regarding rural broadband, and thereby, derive a feasible solution, it is vital to construct the overall picture of the components involved in the business case for rural networks. Most of the studies look for particular scenarios as for Africa [2] or India [3] although they do not include important aspects as regulation and funding.

This paper is organized as follows: Section II introduces the current state of rural areas as well as an overview of the benefits and major challenges involved in provisioning broadband services such as regulatory and funding aspects.. Section III revolves around the technology options for rural broadband services and their techno-economic benchmarking. An innovative approach to model the cost-benefits of rural broadband networks, including the relevant factors, has been described in Section IV. This is achieved using the Technology Selection Strategy elaborated in the same section. Section V describes the process of identifying the best fitting technical choice and its application to a German rural area.

II. RURAL BROADBAND ACCESS

A. *Rural Broadband – Motivation*

Rural broadband access aims to deliver efficient solutions to connect the rural (un- and underserved) community with access to the Internet at appropriate bandwidth. It is aimed to provide a previously un-served or underserved community with access to the Internet at a sufficient speed as to not be left behind or be disadvantaged from the subscribers in the city/localities with a proximity to regional/backbone networks. The connection will allow the subscribers to fast and efficiently use all services available on the Internet.

Multifarious e-services, triple play and specified services for rural areas are the main drivers to develop the rural broadband access. As illustrated in Fig. 1, broadband brings along tremendous amount of opportunities for growth and development. The direct and indirect effect of broadband Internet has been thoroughly researched and proposes substantial benefits in terms of economic growth [4, 5].

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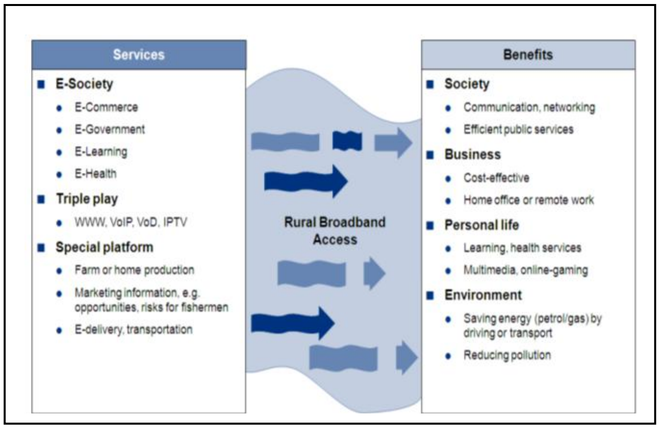

Figure 1. Services and Benefits of Rural Broadband

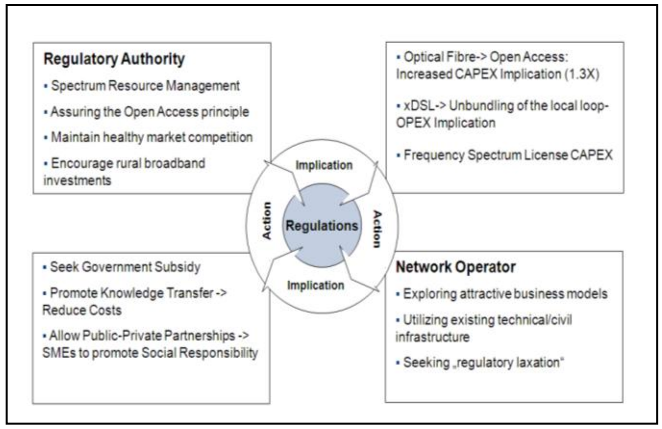

Figure 2. Regulatory Concerns of Rural Broadband

B. *Rural Broadband – Challenges*

Although the benefits of providing rural broadband access are countless, deploying rural networks face a number of challenges from multifarious domains. In general, the overall scope of factors hindering such initiatives can be summarized as follows:

Technical factors

A number of technical considerations must be taken into account while making the choice for a broadband technology.

- Distance and Topology: Technologies suited for special distance and topography
- Scalability: Technologies with expected bandwidth, and easily upgraded to future technology
- Resource Contention: reuse of existing infrastructure, shared or dedicated last mile platform
- Cost Efficiency: Technologies with low Capital and Operational Expenses (i.e. CAPEX and OPEX), e.g. lower energy consumption, access to solar technology
- Implementation and Maintenance: Technologies suited for installation and maintenance, both for network operators and end users
- Reliability: Simpler/Robust Equipment offering better reliability; Technologies less affected by weather or other environment conditions

Regulatory factors

In general, telecommunication regulations involve a complex domain of obligatory directives for a free and fair competitive telecom market within any country. An apex administrative body, like the “Bundesnetzagentur” in Germany, is usually responsible for enforcing such directives to protect the interests of the subscribers and prevent monopoly.

While regulatory issues involving frequency spectrum license fees/open access networks are fairly common; there are different regulatory concerns that need to be taken care of, for different technologies. Additional expenditure on account of regulatory requirements hinders the ambitions of network operators in rural broadband deployments. Fig. 2 shows the interaction between the parties involved and their concerns.

Digital Dividend: The radio frequency spectrum, (790-862 MHz) which has been derived out from the transition of terrestrial radio from analog to digital mode, is expected to be one of the important steps promoting Rural Broadband in Germany. Due to its physical wave propagation capabilities, this spectrum is particularly suited for supplying large areas with broadband utilizing lesser radio infrastructure.

Optical fibre based PON/AON: Open Access Network policies promote usage by a number of different providers that share the investments and maintenance cost. However, they come with an additional price of enhanced CAPEX which is around 20%-50% more than the actual CAPEX [6].

xDSL: In order to ensure a fair regulatory landscape, directives for ensuring unbundling of the local loop are enforced for network operators. This translates to an OPEX implication (multiple providers accessing the same copper loops). A suitable factor can be assumed for related calculations.

Socio-Economic factors

Economy status, revenue potential, actual demand for broadband services must be considered to construct the overall business case. Moreover, an account of funding/subsidy availability for the project must also be taken into account.

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C. Rural Broadband – Global Developments

Realizing the significance of broadband services for rural areas, different state aid programs and national strategies of most of the developing/developed economies have proposed substantial funding resources towards this cause:

Europe: The European Commission (EC) has approved ~ €1bn to be available for funding of rural broadband projects. The subsidy amount will be distributed among all Member States, which are responsible for project identification and documentation submission to EC for funding approval. Finally, the EC can fund up to 90% per project [7].The domains selected for funding involve: Creation of new broadband infrastructure including backhaul facilities (e.g., fixed, terrestrial wireless, satellite-based or combination of technologies); Upgrade of existing broadband infrastructure; Laying down passive broadband infrastructure (ducts, civil work, dark fibre). In particular for Germany, there is Broadband project, which aims to achieve 75% population coverage with at least 50 Mbit/s until 2014 [8]. Similarly for UK, the "Digital Britain" project proposes 2 Mbit/s for all users by the end of 2012.

USA: As part of the American Recovery and Reinvestment Act adopted in 2009, $7.2 billion was allocated for accelerating of deployment of broadband technologies in USA through the Broadband Stimulus Program. Two agencies, the Rural Utilities Service (RUS) under Department of Agriculture and National Telecommunications and Information Administration (NTIA) under Department of Commerce are responsible to distribute the money in terms of grants/loans to facilitate broadband deployment in rural areas and grants for deploying broadband infrastructure in un-served and underserved areas, enhance broadband capacity in public computer centers, thus, promote sustainable broadband adoption.

Asia-Pacific (APAC): The Federal Government of Australia has spent up to $258 million during its operation of connecting rural areas with broadband Internet services. The Department of Broadband, Communications and the Digital Economy established the program in 2007 as a subsidy to service providers for the setup cost of Internet connections that do not meet metro-comparable broadband speed benchmarks [9].

III. Technical Options

Although most of the developing/developed economies possess extensive copper cable infrastructure, with basic telephony services present almost in every nook and corner of the country; these copper based networks are limited in providing the requisite broadband services (through xDSL) due to longer distances between the DSLAM (Digital Subscriber Line Access Multiplexer) and the end-user. Moreover, rural and remote areas are generally characterized with no or limited telecommunication services, lower and limited economy, varying and rough geographical terrain, longer distances from COs (Central Office) of wireline networks or RBSs (Radio Base Station) of wireless networks. In such a scenario, a significantly large portion of the rural population is either un-served or underserved with respect to broadband Internet services.

Connecting rural areas with broadband Internet does not only involve evaluation of the potential technology candidates in terms of their technical capabilities but also considering the total value they bring along and the cost required to be paid in return. Thus, an extensive benchmarking of technical options for rural broadband is a necessary step before deciding on the potential choices for rural broadband solutions.

We adopt the following methodology to benchmark technical options based on a set of technical Key Performance Indicators (KPI), as follows:

- Maximum range
- Maximum throughput
- Next generation capabilities
- Quality of Service
- Interoperability
- Mobility
- Market status
- Innovation potential
- CAPEX/OPEX

While wireline networks are traditionally suited for high bandwidth data communications, wireless networks provide mobility support for voice and limited data requirements Technical evolutions in both these network classes promise almost comparable bandwidth intensive services with the possibility to be mobile. Ranking each technology on the basis of the aforementioned KPIs yielded the potential candidates for enabling broadband services in rural areas.

It is, however, important to note that in many cases, the maximum reach of a particular technology is already reached and serving a remote rural community requires a hybrid solution of technologies (for Backhaul & Access Network) to extend the maximum reach and bandwidth requirements.

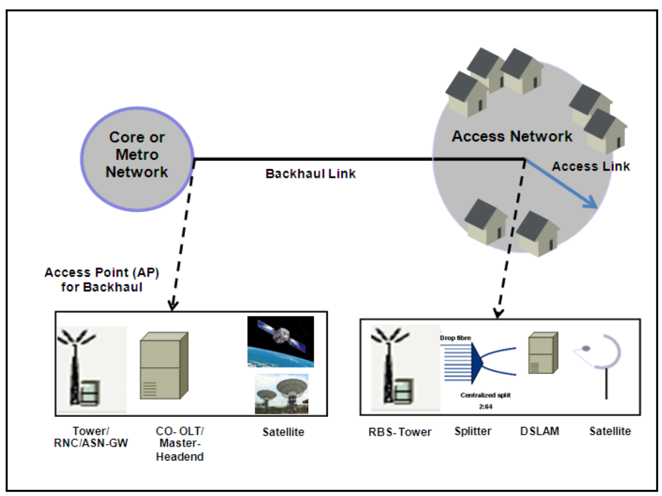

Figure 3. Hybrid Solutions for Rural Broadband- Backhaul+Access

Hence, the resulting combination solutions could be of the form- Optical Fibre (e.g. with PON) in the backhaul (connected to the CO which houses the OLT (Optical Line Terminal) at the Access Point for Backhaul Link) with WiMax as the access network technology or Microwave Point to Point as backhaul (connected to the RNC (Radio Network Controller) at the Access Point for Backhaul Link) and xDSL in the access region. These can be conveniently represented by the notation Optical Fibre+WiMax and Microwave P2P+VDSL respectively. We evaluate the cost-benefit implications for all of these resulting combinations, as illustrated in Fig. 3. This can then lead to an extended KPI set, particularly, for evaluating the hybrid technical solutions for rural broadband.

Technically, a number of possible alternatives can be utilized to connect rural communities. However, cost-wise, the choice of the scenario specific best-fitting solution is governed by factors like existing infrastructure, respective regulatory implications, revenue and funding opportunities. While abundant resources pointing towards the cost of network deployment [8, 9] are available, it is still difficult to comprehend the exact impact of these aforementioned factors affecting rural broadband costs and their interdependence.

IV. SOLUTION SELECTION STRATEGY

A. Process

A detailed analysis on any Rural Broadband deployment project yielded the following considerations that must be taken into account for complete cost-benefits modeling. The most significant heads along with their respective decisive parameters are as follows.

Technology feasibility analysis **-** Restricting the technical options to a set of feasible solutions for a given Capacity (Bandwidth) versus Distance (Reach) requirements (KPI based) for each technology.

Solution evaluation **-** Calculating costs (CAPEX/OPEX) for every feasible technology solution and **e**valuating them with respect to the following related aspects:

- *Existing infrastructure*: Deriving the value of the existing reusable resources
- *Regulatory inclusions and exemptions*: Establishing a cost towards regulatory obligations involved in the broadband technology deployment

Solution selection - Choice of the best-fitting technical solution in terms of costs, deployment feasibility and next generation network capabilities.

- *Revenue forecast*: Assessment of the market through a current estimate and forecasted revenue results
- *Funding resources*: Total Cost and State-dependent funding availability for the Rural Broadband project

A step-wise strategy, involving the aforementioned cost-related parameters that we developed to systematically model and evaluate the best solution, is illustrated in [1]. It would be worth noting that the following can be valid for a Greenfield or a Brownfield network deployment in rural areas. The value assigned for existing technical infrastructure in a Greenfield network is however, null.

B. Cost-Benefits Modeling

As is explicit, this step-wise approach comprehensively covers the most relevant aspects involving Rural Broadband and can also be utilized to obtain an accurate estimation of the Total Cost of Ownership of a project implementing any particular technology solution. This methodology laid the foundation for the development of the MS-Excel based Techno-Economic Model for Rural Broadband as part of this project work. It accepts the real scenario as the input and computes the Cost-Benefit values for the corresponding case as illustrated through Fig. 4.

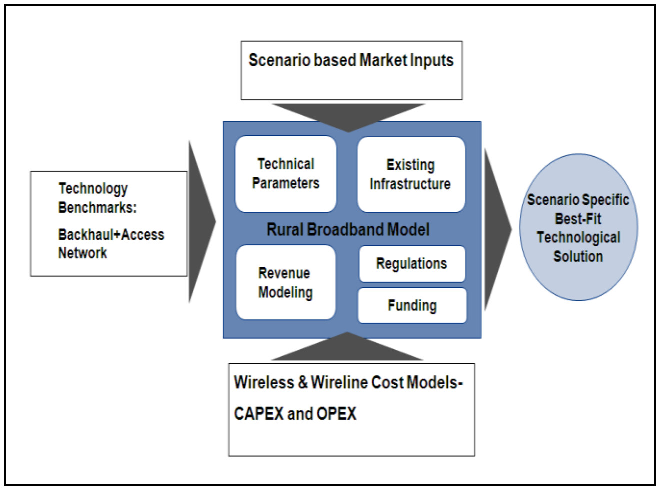

Figure 4. Cost Benefits Modeling for Rural Broadband Networks

C. Key Parameters & Objective Function

The cost-benefits value for any technical solution is modeled as NPC (Net project cost) expressed in € which encapsulates all the significant key parameters associated with rural broadband. NPC is essentially, the final cost required to be paid by a rural community in exchange for broadband services. The key parameters associated with modeling the cost-benefits of rural broadband are described as follows:

- CAPEX consists of the fixed infrastructure and equipment for a network operator or provider and it takes into account the number of targeted users, etc.
- OPEX deals with the costs for running the operations of a network operator during a certain period of time.
- Time period (“T”) is the number of years, the project can be funded (Project duration)
- Regulatory cost implications (“REG”)

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- Existing infrastructure value deductions ("INF")
- Revenue per annum ("REV")
- Available funding amount for the rural broadband project ("FND")

Hence, the objective function describing the total costs payable by the rural community after including the relevant funding available, could be defined as NPC (Net Project Cost) which could have the following representation:

$$NPC(T) = CAPEX - INF + \sum_{\forall T} (OPEX + REG - REV) - FND \quad (1)$$

We adopt the aforementioned equation while implementing the Rural Broadband Cost-Benefits Model and it is worth mentioning that although REG represents a fixed cost value per annum; yearly values of OPEX and REV vary, depending on the rate of increase/decrease which could be defined in the quantitative model.

V. RESULTS AND ANALYSIS

We consider the example of a German community. It lies around 7 Km (Length of Backhaul Link) from the nearest district (Gemeinde) of Dietingen and is sparsely populated with just over 100 households (Access Network Demand). Although small, it is completely connected externally through the old POTS copper infrastructure, boasts of an accessible 2G Radio Base Station nearby and forms the prefect picture for any rural community which, although connected, is detached from the broadband network services. Gößlingen lies in the German state of Baden-Württemberg. Fig. 5 shows the funding potential in Germany and the rural case description.

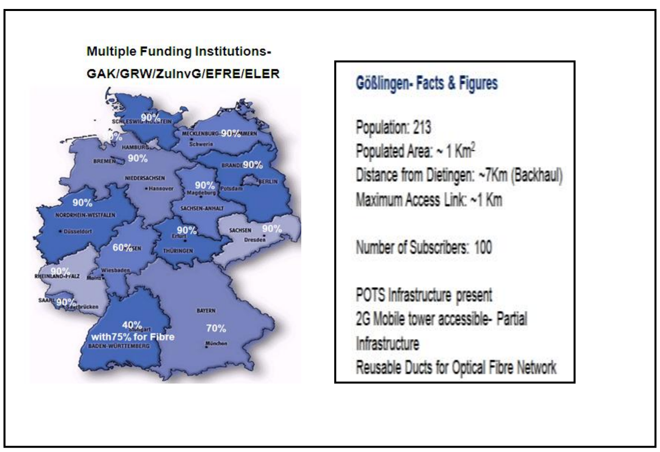

Figure 5. (a) Germany- Fundng Potential (b) Rural Case-Description

Although Germany has an extensive copper cable infrastructure, with basic telephony services present almost in every nook and corner of the country, these copper based networks are limited in providing the requisite broadband services (through xDSL) due to longer distances between the MDF (Main Distribution Frame)/ local exchange and the end- user. Thus, connecting any rural community today, not only involves developing the access network of the concerned region but also deploying or upgrading the link between the nearest access point (at the nearest town/district) and the community network, which we denote as "backhaul network" in this article.

Establishing or upgrading both these network segments, i.e. backhaul network and access network with technologies capable of providing broadband Internet at sufficient data rates to the end-user is of prime importance while working out the technical solution.

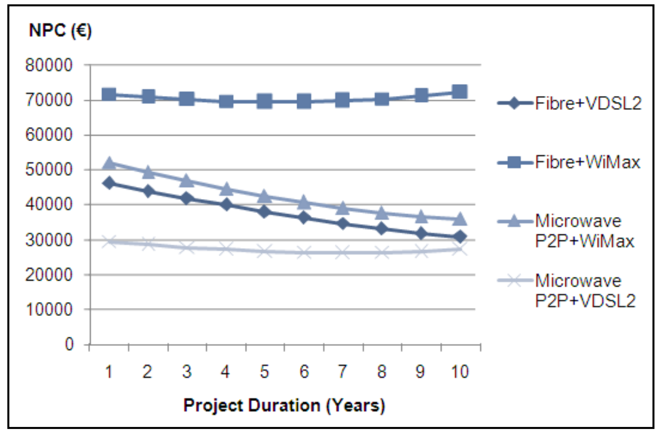

Figure 6. Comparing NPC for varied project duration

While optical fibre based wireline technologies have the potential to be sufficient for such scenarios, they come with an enormous price tag. Wireless technologies from the 3G/4G family and ones like WiMAX offer cheaper alternatives. However, longer stretches of the backhaul link (between the access point and the rural access network) and sufficiently higher access demands make these technologies unfavorable in many circumstances. Consequently, a combination of wireline and wireless technologies or mediums for the backhaul and access network seems to be a better proposition for this issue.

On plotting NPC with reference to the payback period (duration of the project) the following result, as illustrated in Fig.6, are typically obtained for the given example scenario. As explicit, the NPC is on a downward track for technical solutions which are profitable in the long run (less OPEX, more revenue). Also, utilizing the existing copper infrastructure through the VDSL2 access network is always advisable.

While results such as those obtained ín Fig. 6, must seem obvious for dense urban and suburban regions, it is important to note that they also hold good for rural networks with where demands as well as revenue potential are limited. The cost-revenue model developed during this project comprehensively considers all relevant parameters affecting the deployment costs of rural broadband network and can be

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extended to other country scenarios with individual market, network, regulatory and funding data.

It should also be pointed out that the current project work was carried out to study the effect of all key parameters described in Fig.6. Moreover, this process based methodology can be extended to different settings and varied geographies.

VI. CONCLUSION

It is widely believed that providing broadband services for rural communities can be quite a challenging as well as an expensive assignment. However, solution models such as the one presented in this paper, can help presenting the total business case comprehensively and to reach a logical conclusion regarding the technical choice for network deployments. The key take aways include, but are not confined to:

- Reusing technical or civil infrastructure for Rural Broadband deployments can significantly reduce the costs of network establishment.
- A regulations friendly network implies larger investments. However, with sustained efforts on the part of the Regulator to promote Rural Broadband, some regulatory cost contributing aspects could be diminished or at least reduced by a substantial margin.
- In terms of a final technical solution for Rural Broadband; in addition to the cost of deployment, it is primarily important to consider the technical capabilities and NGN characteristics of the technologies before deciding on the potential candidates for the pool of technical solutions for Rural Broadband.

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