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Offering fourth generation (4G) mobile services in India: a techno-economic assessment from the operators' perspective

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Abstract

This paper aims at determining the techno-commercial feasibility of a 4G (LTE) network deployment in India to provide high-speed broadband access to mobile subscribers. High-speed broadband connectivity is one of the important priorities of the '*Digital India*' initiative of the Government of India. This assessment is done using Discounted Cash Flow (DCF) approach. We have taken into account, the *radio-technical* parameters of the LTE network components, the expected subscriber populations forecast using the *Bass-Model*, and the coverage area matched to the service capacity using a *cell dimensioning* approach. We have estimated the cost of infrastructure deployment that would meet the demand, likely revenue generated from the users, and break-even period for a given average revenue per user (ARPU). With the help of three different assumed data demand scenarios, the interplay between the forecasted adoption rate and the minimum ARPU required for attaining the *break-even* is explored. To understand the profitability and the present value of investments for different demand scenarios, a modified internal rate of return (MIRR), and net present value (NPV) analyses are performed.The results of the study indicate that,for a right mix of data-volume offerings in a product package, the annual ARPU can even be both affordable to the rural population, as well as profitable for the operator. With some amount of stimulus and demand inducing initiatives from the government, investments in the rural areas can be an attractive option for 4G operators too.

Keywords: 4G, LTE, Digital India, techno-economic analysis, Bass-Model, radio-technical, cell dimensioning, ARPU, NPV, MIRR

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1. Introduction

Provisioning of Broadband has higher relevance for the developing countries, given its positive impacts on the economic growth [1]. For instance, the contribution of the services and knowledge-based activities to India's GDP is on a rise[1], and provision of Broadband is critical to India becoming a knowledge-based economy [2]. Several countries, such as Brazil, China and India, are formulating nationwide initiatives for implementing Broadband deployment and stimulating the adoption [3]. In India, major policy initiatives like National Optical Fiber Network [4] are underway for enabling Broadband connectivity to over two lakh *village-panchayats*. Various industry reports have termed Broadband as the lifeline of the recently launched Digital-India initiative [5]. The very first goal of the initiative is to provide the digital infrastructure as a utility to every citizen. This would need nationwide Broadband coverage as its precursor.It is also important to evaluate the currently accepted speed of Broadband (≥ 512Kbps) in India, which is very low when compared to a majority of other countries. This speed is found sufficient only for basic browsing, email and social networking. Higher speeds (≥10Mbps) would be fundamental to enabling services like VoIP, telemedicine, advanced browsing, and video-on-demand.

With major advances in mobile Broadband technologies, it has become possible now to deliver Broadband over the wireless networks, with lesser infrastructure costs and increased spectral efficiency and throughput [6]. Long Term Evolution, or, LTE, is one such wireless communication standard for mobile and data terminals, developed by the 3rd Generation Partnership Project (3GPP)[2]. LTE provides higher data rates (up to 100 Mbps downlink), with increased coverage capabilities, reduced latencies, and scalable bandwidth options. It becomes important, therefore, to assess the economic feasibility of LTE deployment in both the rural and the urban areas. Especially in the rural areas, a seamless deployment with efficient revenue models and high speed connectivity, could help bridge the problem of the rural-urban digital divide to a great extent.

Currently, there is a great level of anxiety amongst the operators who have acquired spectrum in the recently concluded spectrum auctions in India[3], and are willing to go ahead with the LTE deployments. This is due to a high level of investments needed (both CAPEX and OPEX), longer investment recovery periods, and absence of reliable forecasting mechanisms to assess service adoption and demand pattern. The possibilities of cost savings resulting from using a particular frequency band, or from active/passive sharing of resources, needs to be ascertained and accounted for. This would help potential investors in constructing a stable deployment roadmap, ensuring maximum possible returns, depending on the blocks of spectrum allocated and the targeted scale of service deployment. Both medium and the large-scale operators would help their case, if the estimates related to the service adoption, quality, and data volume demand, could be accurately assessed. Together, these factors, serve as the major motivation behind this work.

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[1] Source: Union Budget, 2015. See: http://indiabudget.nic.in/budget.asp

[2] Source: 3GPP LTE specifications, release 8

[3] DoT, Ministry of Communications and IT, GoI, Source: http://www.dot.gov.in/spectrum-management/spectrum-management/auction-spectrum-february-2015

This report is structured into 6 sections. Section 2 provides a literary review of some of the associated and relevant work done in the field. Section 3 provides a background of the evolution of wired and wireless services in India, and the general trend of Broadband adoption, along with the current state of things. Section 4 is further divided into 7 sections, and it discusses various theoretical frameworks, and their empirical models. Section 5 is again divided into 7 sections, each with detailed input and output data tables, and illustrated results section, for the respective models that were used. Section 5 also includes short discussions and implications of various results. Section 6 provides final conclusions, along with the recommendations from the author.

2. Literature Review

Researchers are evaluating the option of using LTE network as a vehicle for delivering high-speed Broadband access for sometime now. Various comparative studies between LTE and contending technologies like High Speed Packet Access, or HSPA/HSPA+, have proven LTE is to be the global mobile broadband solution of the future [7]. The findings report LTE to be spectrally more efficient for best effort data in the downlink and uplink, and having twice the VoIP capacity as compared to HSPA+. Adoption of LTE, for provisioning of Broadband service, is seeing a rapid growth across continents [8]. The reports indicate 90% coverage of LTE in the developed markets, and 15% in the developing world, as at the end of December 2014. The prediction is that for the next 5 years, global LTE coverage would be driven by deployments across countries in Asia Pacific and Latin America. For the case of India, LTE deployments are on a rise, and GSMA predicts India to be the world's second largest mobile Broadband market by 2016, with 367 million mobile Broadband connections[9].

The radio propagation characteristics depend on the band of frequency chosen for communication. Various studies have emphasized the suitability of 800 MHz frequency band for LTE ([8], [10]). Especially for rural areas, which are coverage constrained, use of 800 MHz band is recommended for a cost efficient provisioning of mobile Broadband service ([11], [12], and [13]). The 800 MHz frequency band is also, harmonized for the WiMAX and LTE technologies. Telecom Regulatory Authority of India, TRAI, has taken note of the opportunities associated, and has made numerous provisions in its spectrum allocation frameworks for the 800 MHz band[14]. The recommendations include, provisioning of large contiguous blocks (at least 5MHz), and sufficient quantum of spectrum to the operators in order to achieve better efficiencies and throughputs, recovering the spectrum from operators such as BSNL/MTNL, who cannot utilize it optimally, and reconfiguring the allocated frequencies so as to make contiguous allocations[14].

The rural part of the world, across various countries, still does not have sufficient Broadband coverage [15]. Cost of Broadband, low levels of digital literacy, and lack of a computing device are some of the factors found responsible [16]. Studies point out that only 70% household haveBroadband subscriptions, in-spite of the near universal coverage,even in the United States[6]. Feasibility assessments or techno-economic assessments, which essentially mean the investment recoverability at the end of the study period, therefore, are very closely related to the service adoption rate.Similar techno-economic assessments of LTE deployment have been done, for the case of rural areas of Spain [10]. It is found that due to the existence of other Broadband products (3G & 3.5G), very high adoption rates are needed for LTE deployment to be considered as profitable undertaking for an operator. However, for a single network deployment, which encourages service competition, Broadband prices would be as competitive as that of the urban case. This coupled with appropriate policy measures, which stimulate demand, can make LTE Broadband delivery in the rural areas an appealing investment opportunity for the operators[10].

Various techniques are present currently, for making an optimum use of spectrum, and minimize the operator's cost of investing in the network infrastructure. Resource sharing mechanisms such as, active sharing which allows mutual sharing of the Radio Access Network (RAN) and the spectrum, and passive sharing which allow the operators to mutually share the site related expenditures (site, tower, antenna, power transmission, and personnel cost), exists ([17], [18]). Cognitive Radio technology employs the active sharing concept,to allow the presence of both the primary and secondary operators on the same spectrum band [19]. Supporting studies for business case of mobile operators, to offload the network using Cognitive Femtocells, have been done [20]. The Femtocells were aided by a sensor network, and used frequencies other than that of the mobile network, thereby increasing the outdoor area coverage of the mobile network. This study, however, does not consider such techniques, since the study is of a short-term duration, and assumes a Greenfield deployment scenario, similar to that of the Spanish LTE deployment case [10].

While various works in the literature have done individual assessments related to the feasibility of LTE deployment in specific countries, and have suggested novel ways to address the challenges, very little study has been done for the Indian scenario. Firstly, we found that in the Indian scenario, 800MHz frequency band is not fully explored for leveraging its potential. It has started to garner attention only very recently, and there is a lack of research work done to assess the potential of LTE deployment in India using 800MHz frequency band. This is an important area, which should be explored in greater detail, since, the adoption of 800MHz as the carrier for LTE, is receiving global acknowledgement. Secondly, studies related to determining the feasibility of a countrywide deployment, as well as the individual rural and urban deploymentin India, are unavailable. As explained in [14], there are varying operator viewpoints, without a general consensus, on various aspects of both technical (coverage and capacity) as well as economic feasibilities for LTE deployment, in the 800MHz band. Thirdly, the challenges and possibilities related to a high-speed Broadband access (30Mbps in our case), for ensuring the maximum possible coverage have not been fully explored for the case of India, which we have attempted to do.

3. Background

3.1 Broadband in India

Broadband is defined as a high-speed Internet access, which is always on and faster than the traditional dial-up access[4]. Different countries have different benchmark speed of what is referred to as the Broadband speed in that country. In India, a speed

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[4] Source: FCC. Source: https://www.fcc.gov/

higher than 512 Kbps is considered to meet the criteria for Broadband[5]. India currently ranks 122nd in the fixed Broadband category (1.1% penetration against a global average of 9.9%), and 106th in mobile Broadband category (4.9% penetration against a global average of 22.1%)[6]. There is a target of achieving 175 million Broadband connections by 2017 (NTP 2012), out of which only 61 million have been achieved so far.

Top five States (Maharashtra, Tamil Nadu, Delhi, Karnataka and Andhra Pradesh) have a total of 54.4% of overall connections. Metro and category A circles account for 61% of overall connections. Though, the presence of wireless Internet subscribers has increased significantly with almost 233 million subscribers, the adoption is considered relatively weak in a mobile phone dominated country.

The Broadband market in Asia Pacific is expected to grow at 12% annually for the next 5 years where as the Indian fixed Broadband market is expected to reach $2.12 billion by 2017[7]. Top 10 service providers have the maximum subscriber base (96%), out of a total of 149 providers. State owned companies viz. BSNL and MTNL together have about 74.9% market share for Wireline Broadband and 30.5% for overall Broadband subscriptions. The complex ecosystem and huge investments required to attain the economies of scale serve as hindrances to a majority of licensed service providers.

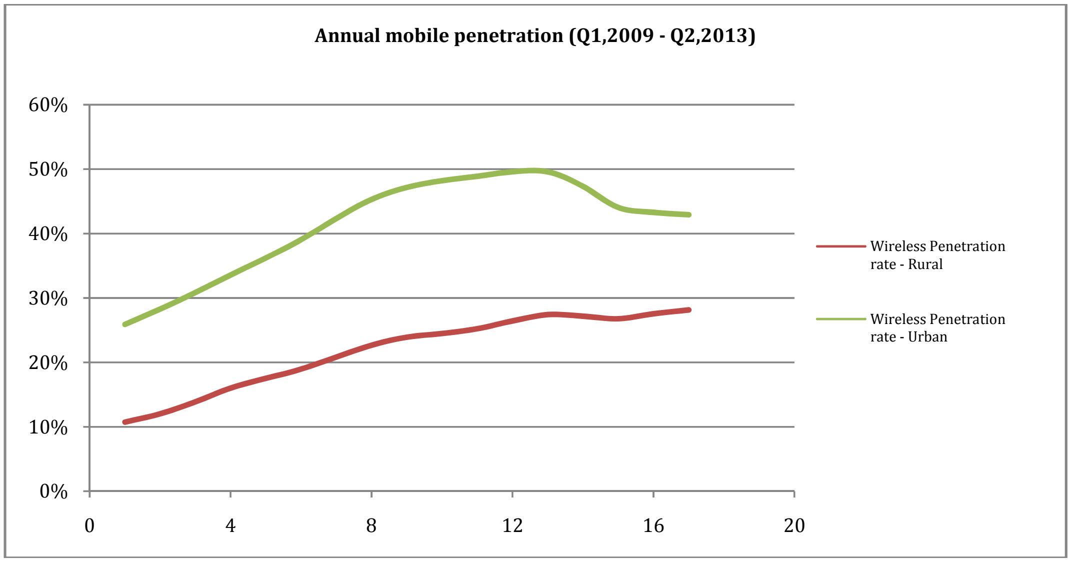

Figure 1: Growth of mobile and fixed-line services in India (Quarter 1, 2009 – Quarter 2, 2013)

Figure 1 explains the recent trend of mobile telephony adoption in India[8]. 2G and 3G services are the major contributors to the wireless Broadband services currently. Much of the user base lies in the urban parts and the penetration is extremely poor in the rural India. The current data rates offered by the existing services, namely 2G and 3G, however, will not be sufficient if India is to become a knowledge economy, and for provisioning the governance utilities to all the citizens via ICT as envisaged in the

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[5] Source: TRAI, Telecom Consumers Complaint Redressal (Third Amendment) Regulations, 2014

[6] Source: A report by the Broadband Commission, 2013

[7] India's fixed Broadband market to reach $2.12 billion by 2017: IDC, Economic Times, June 2014. See: http://articles.economictimes.indiatimes.com/2014-06-20/news/50739148_1_idc-Broadband-revenue-growth

[8] Source: TRAI annual report, 2014

Digital India initiative Other than the wireless Broadband, currently DSL (Digital Subscriber Line) is the most preferred technology used by the operators to deliver Broadband services constituting 84.81% of total Broadband subscribers, followed by Ethernet LAN (6.14%) and cable modem (5.26%).

3.2 LTE- Global trends and current Indian scenario

The operators worldwide, on both GSM and CDMA technology paths, are deploying long Term Evolution (LTE) networks. Based on the spectrum availability, LTE networks can deliver speeds of up to 100 Mbps (downlink) and 50 Mbps (uplink). The first LTE network was launched in Sweden in December 2009. The global LTE market is moving to a more matured phase of development with around 230 commercial LTE networks in operation now, and over 2.5 billion connections expected by 2020. Four out of five mobile operators, who have acquired new spectrum since 2010, have been allocated airwaves aimed at supporting the launch of LTE networks [9]. 700MHz, 800MHz, 1800MHz, 2300MHz and 2600MHz are the frequency bands used for LTE deployment. Currently 19% of the LTE networks are TDD-LTE and remaining 81% are FDD-LTE. This figure will rise to 26% for TDD-LTE and 74% for FDD-LTE. The more advanced version of LTE i.e. LTE-Advanced would be capable of delivering peak data rates of up to 1Gbps.

Bharti-Airtel launched the first LTE service in India in April 2012, using TDD-LTE technology. The coverage currently includes Kolkata, Chennai, Pune, Hyderabad, Vishakhapatnam and Chandigarh region[10]. In the recently concluded Indian spectrum auctions[11], Tata-Teleservices, Reliance-Jio-Infocom, and Reliance-Communications have won the licenses in 800 MHz spectrum band, and are planning to provision LTE services in this band. RIL is launching the LTE services through its subsidiary Jio-Infocom, and has plans to cover 700 cities, including 100 high priority markets in 2015. Aircel has also launched LTE services in four circles including Andhra Pradesh, Assam, Bihar and Odisha.

4. Techno-economic model

4.1 Concepts and methodology

A techno-economic model is used to determine the business feasibility taking into account all the system parameters. The approach of the assessment is simulation based, and it spans from cost modeling to financial results. This method has been used to evaluate the feasibility of LTE deployment in the rural areas of Spain [10], for evaluating the cooperative relaying transmission technique in OFDM cellular networks [21], and for Femtocell deployment in LTE networks [22].

Figure 2 below, explains various components of the techno-economic model as adopted for our case. We discuss the theoretical backgrounds and determination of the key input parameters of the model in further sections.

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[9] Source: GSMA prediction on Global LTE trend, 2014

[10] Source: Times of India See: http://timesofindia.indiatimes.com/business/india-business/Airtel-launches-4G-in-Kolkata/articleshow/12617622.cms

[11] Source: TRAI, spectrum auctions 2014

We start with the forecasting of LTE Broadband service adoption, for the next 20 years, with 2014 as the base year. 'Bass-model' is used for calculating the adoption percentages, which we use to calculate the number of subscribers, based on the base year population and its annual growth rate (taken from the census data). With our assumptions of specific service demands and monthly data usage patterns, combined with the LTE spectral efficiency, and the given block of spectrum, we obtain the cell capacity for a month. The user demand patterns and hence the cell capacity is assumed to remain constant for an entire year. The data demands do increase annually with an assumed growth rate. For a given cell capacity, and population base, we can determine the maximum number of subscribers which could be served by a given base-station. This is the real capacity for a given specification of LTE radio equipment, and the available spectrum.

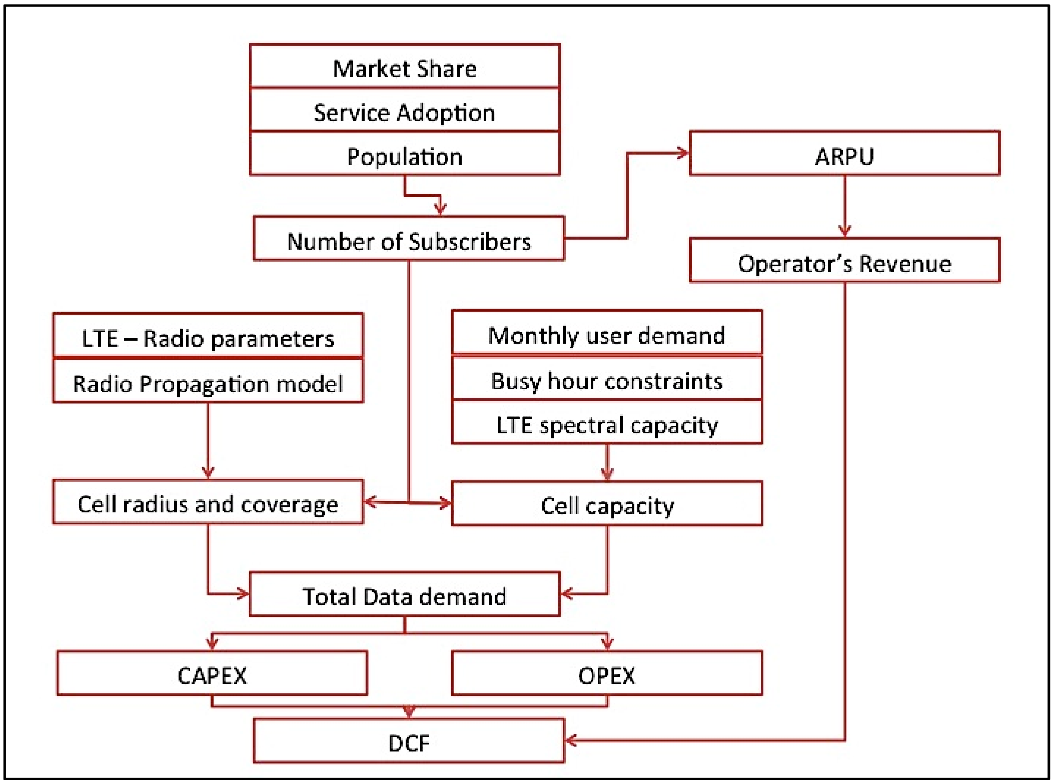

Figure 2: Techno-economic modeling for LTE

The LTE radio parameters are used to calculate the total allowable loss value for a given transceiver specification, which is again used in the radio-propagation model (Okumura-Hata in our case) for cell range calculations. The cell range provided by the radio propagation model, gives us an estimate of maximum coverage possible. However, in case the coverage does not match the capacity as calculated earlier, we need to recalibrate the cell radius values.

The aggregate data volume demand and the cell capacity, provide us with an estimate of the number of cells (essentially base-stations) required to cover a given population. Using the cost for a single base-station, the aggregate CAPEX in network infrastructure is determined. Similarly, the OPEX per unit base-station is used to calculate the total network OPEX incurred in a particular year. This combined with the CAPEX and OPEX for spectrum licenses and annual usage, gives us the total operator cost. With different assumptions of average revenue per user (ARPU) values, we obtain the total annual operator revenue. We have tried to get a picture of how the results change for many values of ARPU. The discounted cash flow analysis is then done, which results in the net present value (NPV) and modified internal rate of return (MIRR) for different combinations of user adoption and ARPU values.

Figure 3 below, is the basic LTE network architecture considered in the techno-economic model, as also considered in the study done by [22].

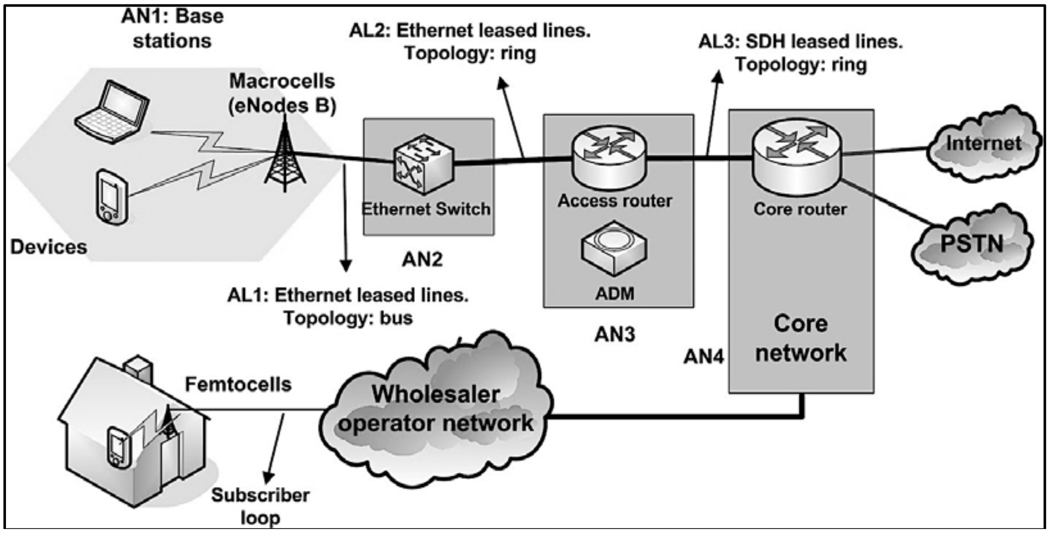

Figure 3: Basic LTE network architecture. Description: The Femtocell deployment is out of scope for our work. Source: [12]

4.2 LTE Broadband adoption forecasting using the Bass-Model

To forecast the service adoption for a new technology, researchers frequently use the Bass-Model [23]. Studies done, to estimate the Broadband diffusion for the case of European OECD countries, have also used the Bass-Model[24]. This particular study negates the possibility of European OECD countries achieving 100% Broadband adoption, and concludes that the peak adoption has already happened. Findings suggest that rather than investing on infrastructure promotions, further increase in adoption requires focus on educating individuals with low propensities of adoption, regarding the benefits of Broadband access. The model was also usedin the study done to forecast the 3G mobile subscriptions in China[25], and to study the diffusion patterns of Internet-based communications applications [26].

The model is based on the rationale that the portion of the potential market that adopts at a time ‘t’ is a linear function of the previous adopters. The Bass Model equation we have used in this work is shown below and is similar to the one used in [26].

$$\mathbf{a(t) = (M*p) + [q-p]*A(t) - (q/M)*A(t)^2} \qquad \text{---(1)}$$

Here, a(t) is the adoption, and A(t) the cumulative adoption, at a time t. M is the potential market, p the coefficient of innovation, and q the coefficient of imitation.

4.3 LTE RF Link budgeting model

All Radio Network Access planning begins with the link budgeting calculations. A link budget accounts for all the losses and gains from a radio transmitter, through the medium (free space, cable, waveguide, fiber etc.), to the receiver, in a telecommunication network. The results of link budget calculations are an estimate of the maximum allowed signal attenuation between a user device and the mobile base station antenna. A suitable radio propagation model then calculates the maximum possible uplink and downlink cell radius, using the results of a link budget.

The RF link budget calculations (uplink and downlink) involve the following steps, with the stated formulas [27].

$$\mathbf{EIRP_{Tx} = P_{Tx} + G_{Tx} - L_b} \qquad \text{---(2)}$$
$$\mathbf{R_{SENS} = NB_{noise} + Th_{noise} + SINR} \qquad \text{---(3)}$$
$$\mathbf{MAPL = EIRP_{Tx} + R_{SENS} - IM - L_{cable} + G_{Rx} - M + G_{soft}} \qquad \text{---(4)}$$

Here, $EIRP_{Tx}$ is the 'Equivalent Isotropically Radiated Power' of the transmitter, P_{Tx} is the maximum transmitter power, $G_{Tx}$is the transmitter antenna gain, L_b is the body loss, R_{SENS} is the receiver sensitivity, NB_{noise} is the noise value for Node-B, Th_{noise} is the thermal noise, SINR is the signal to interference noise ratio, MAPL is the maximum allowable propagation loss, IM is the interference margin, L_{cable} is the cable loss, G_{Rx} is the receiver antenna gain, M is the fast-fade margin, and G_{soft} is the soft handover gain. The typical values for the given parameters have been taken for the case of LTE, as also explained in [27].

4.4 Radio propagation model for coverage calculation: Okumara-Hata

The radio propagation models characterize the radio wave propagation as a function of frequency, distance and other antenna parameters. They are given in the form of various empirical mathematical formulations, and are used to determine the coverage area and the propagation loss parameters. We have chosen the 'Okumara-Hata' model for our calculations, since it is relevant for the 800MHz frequency band and LTE base station characteristics. As explained in [28], the cellular radius (d) is given by the following equation.

$$\mathbf{d\ (km) = 10^{((MAPL - A - B)/C)}} \qquad \text{---(5)}$$
$$\mathbf{A = 69.55 + 26.16 \log_{10} (f_c) - 13.82 \log_{10} (h_b) - a\ (h_m)} \qquad \text{---(6)}$$
$$\mathbf{B = 44.9 - 6.55 \log_{10} (h_b)} \qquad \text{---(7)}$$

While parameters A and B remain common across all the scenarios, parameter C and the factor $a(h_m)$ depend on the environment, and have different values depending on the rural, urban and sub-urban case [28]. Here, f_c is the carrier frequency (Mhz), h_m is the effective antenna height of the mobile station (m), and h_b is the base station antenna height (m). The cell radius (d) is then used to calculate the coverage area using the following formula [10].

$$\mathbf{Coverage\ area = 1.9485 * (d)^2} \qquad \text{---(8)}$$

4.5 Data rate based cell dimensioning

A data rate based approach [27] has been used to estimate the monthly data volume capacity for a cell. The monthly data volume capacity per cell, for the given bandwidth and equipment configuration, is then used to estimate the maximum number of subscribers possible. To find the area that can be covered given this cell throughput, we divide the maximum number of subscribers possible by the population density value. If the desired traffic for the given coverage area is greater than the base stations capacity for the area, then we reduce the cell radius.

The maximum number of subscribers, N_{sub} can be calculated as

$$\mathbf{N_{sub} = (C_{cap}*L_{BH})/((N_{sector}*(R_{sub}/O_{factor}))} \qquad \text{---(9)}$$

Here, C_{cap} is the cell capacity, L_{BH} is the busy hour average loading, R_{sub} is the required user data rate, O_{factor} is the overbooking factor, A_{BH_user} is the average busy hour data rate per subscriber (same as R_{sub}/O_{factor}), and N_{sector} is the number of sectors per site. The overbooking factor or the contention ratio indicates the number of users sharing the same data capacity at the same time. The value is usually set to 20. Busy hour is the hour during a 24hr time frame that has the greatest number of calls. We have taken 50% the busy hour value but the operators can change it. Finally, the total number of base stations required to meet the aggregate data demand for the given population is calculated using the individual cell throughput value found above.

4.6 Operator's CAPEX and OPEX calculations

We use the same CAPEX and OPEX cost calculation model as expounded in [10] and [21]. Spectrum costs, physical network infrastructure costs, and Marketing and Advertising costs comprise of operators' CAPEX and OPEX related expenses. The costs related to physical network infrastructure includes Base Station, User Equipment, Sites, Backhaul, Transport network, and Core network costs, while spectrum costs comprise of the license charges (a portion paid as upfront costs, and the rest as annual installments), and annual usage charges (paid at 6% of the Adjusted Gross Revenue per circle)[12]. We have calculated the license charges from the recently concluded 800 MHz spectrum auction results[13]. Since, the annual spectrum usage charges are not available, we have kept it to be the same as the annual license charges, based on the observations of previously paid usage charges of the operators, which are close to the license charges[14]. The annual CAPEX and OPEX values are calculated in the following way.

$$\mathbf{CAPEX_i = (BS_i * NC_i) + SP_{license}} \qquad \text{---(10)}$$
$$\mathbf{OPEX_i = (BS_i * SC_i) + SUC_i} \qquad \text{---(11)}$$

Here, BS_i is the number of base stations in the ith year, NC_i is the aggregate network cost per unit base station, $SP_{license}$ is the annual spectrum license installment, SC_i is the combined site related expenses and SUC_i is the annual spectrum usage charge.

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[12] Source: TRAI consultation paper-March, 7 & December 2, 2014

[13] Source: TRAI Consultation paper – Reserve Price for spectrum auction in 800 MHz band,- 22nd February, 2014

[14] Source: TRAI report by Financial and Economic Division, for quarter ending December 2014.

4.7 Revenue and Discounted Cash Flow modeling (DCF) for the operators' costs and revenues

Revenue for the operator is calculated based on the following formula.

Revenue = Number of subscriber * market share * ARPU ---(12)

The revenue and combined CAPEX and OPEX figures are used to calculate the annual cash flows using the discounted cash flow (DCF) analysis. Discounted Cash Flow method is used to evaluate the attractiveness of an investment by taking into account the cash flows (CF) over the investment period and the discount rate (weighted average cost of capital - WACC) prevalent. The method is represented by the following equation.

$$\mathbf{DCF = \sum\{CFi/(1+ r)^{i}\}} \quad - \quad --(13)$$

Here, CF_i is the cash flow for the i^{th}(i=0,1,2…) year, and r is the discount rate or WACC (taken to be 15% in this case). The Net Present Value (NPV) and the Modified Rate of Return (MIRR) analysis are then done, for a series of different ARPU values to predict the feasibility of the investments.

5. Results

5.1 Forecasting of LTE Broadband adoptions using the Bass-Model

We have used the same parameter values for p (0.005) and q (0.06), as done in the study for forecasting 3G mobile subscription in China [25], since the process of adopting a new product by innovation and imitation is the same. Previous ITU reports [15] suggest a similar diffusion pattern for Broadband services in India and China, which also strengthens this comparison assumption between the two countries. The values predicted are for a 20-year horizon, with 2014 as the base year.

5.1.1 Forecasting for a countrywide adoption

The value of 'M', or the ultimate adoption value, is taken as 100% of the given population in the base year (2014). However this value can be changed by the operator and used for different scenarios of adoption. The initial base year adoption (36 million), and the cumulative adoption (60 million) are from the TRAI figures on annual Broadband subscription in India.

Table 1: Bass Model adoption forecasts for countrywide LTE Broadband scenario

Year	Adoption[15]	Cumulative Adoption[16]	Population[17] (Million)	Adoption Percentage
2014	3,62,16,000	6,00,00,000	1,260	4.8%
2015	4,02,83,806	10,02,83,806	1,276	7.9%
2016	6,11,77,252	16,14,61,058	1,293	12.5%
2017	8,99,50,743	25,14,11,801	1,310	19.2%

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[15] Calculated using Equation(1)

[16] Cumulative adoption(t) = adoption(t) + adoption(t-1)

[17] Source: Forecasted using 2010 India census data, and annual growth rate figures.

2018	12,57,82,356	37,71,94,157	1,327	28.4%
2019	16,29,62,683	54,01,56,840	1,345	40.2%
2020	18,87,20,916	72,88,77,756	1,362	53.5%
2021	18,69,38,239	91,58,15,995	1,362	67.2%
2022	15,17,23,932	1,06,75,39,927	1,378	77.5%
2023	9,86,69,088	1,16,62,09,015	1,409	82.8%
2024	5,23,98,881	1,21,86,07,896	1,457	83.7%
2025	2,40,56,455	1,24,26,64,351	1,523	81.6%
2026	1,01,68,338	1,25,28,32,689	1,610	77.8%
2027	41,32,261	1,25,69,64,950	1,721	73.0%
2028	16,51,142	1,25,86,16,092	1,861	67.6%
2029	6,55,205	1,25,92,71,297	2,035	61.9%
2030	2,59,278	1,25,95,30,575	2,249	56.0%
2031	1,02,489	1,25,96,33,063	2,514	50.1%
2032	40,495	1,25,96,73,558	2,842	44.3%
2033	15,997	1,25,96,89,555	3,248	38.8%
2034	6,319	1,25,96,95,874	3,754	33.6%

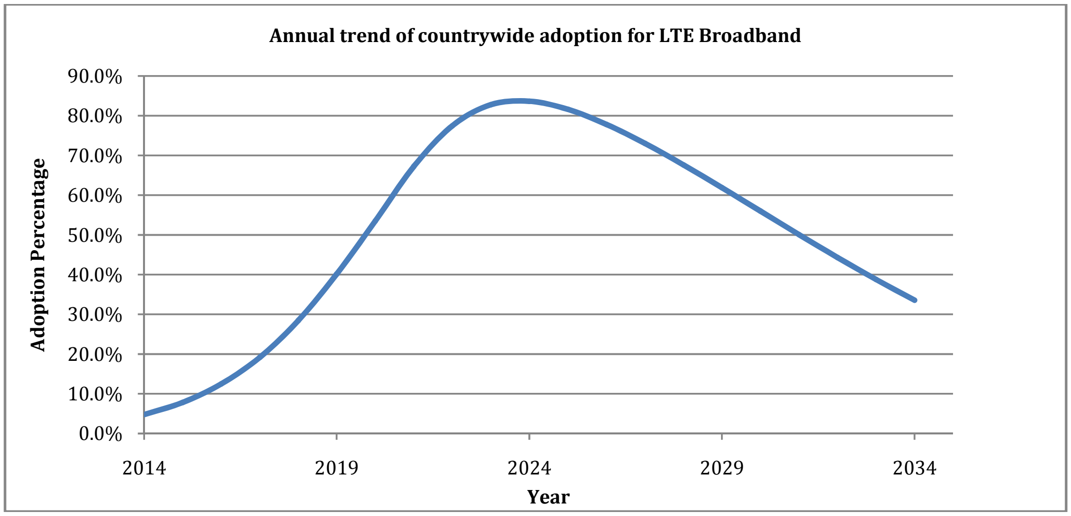

Figure 4: 2014-2034, countrywide adoption forecast of LTE Broadband using Bass-Model

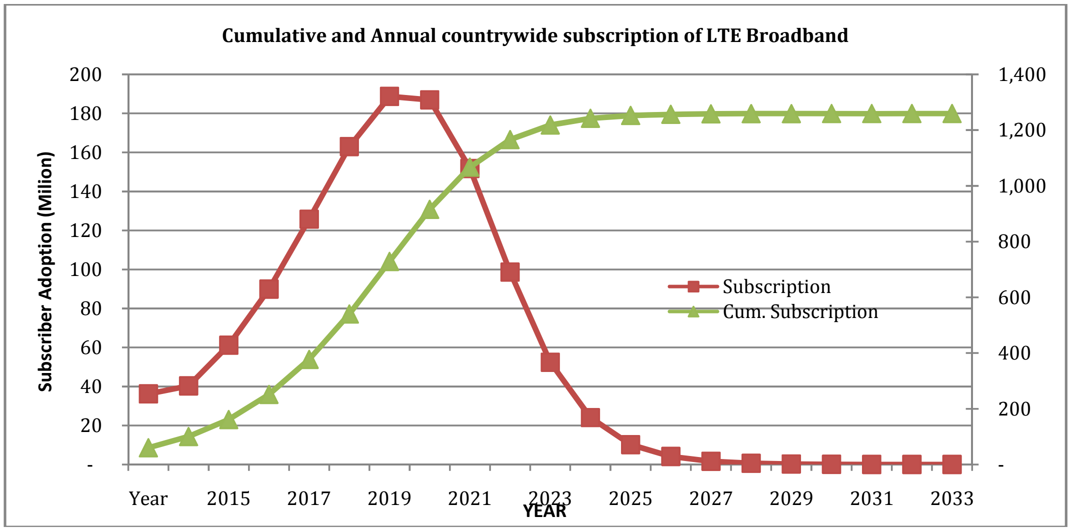

Figure 5: Annual and cumulative LTE Broadband subscription forecast using Bass-Model

The maximum adoption likely, as predicted by the Bass model, for the assumed parameter values and maximum number of subscriber potential, is 83.7%, occurring in the year 2023. The adoption remains higher than 67% between 2020-28. If the rural to urban migration effects are not considered, the maximum population likely to subscribe to the service is 1260 million.

5.1.2 Rural and Urban share in the aggregate adoption:

First we divide the total population into rural and urban categories, based on their individual proportion in the total population (5:1)[18]. For simplicity, this fraction is kept the same for the entire time frame, and effects due to migration to cities are not considered. We divide the aggregate number of subscriber population into rural and urban sections, using their individual Broadband adoption trend[19]. The annual subscriber growth rate for the rural area and urban area is assumed to be similar to that of the 3G-service penetration pattern[20].

Table 2: Rural and Urban Adoption Forecasts for LTE Broadband

	Rural			Urban		
Year	**Subscribers**	**Cumulative Subscribers**	**Adoption[21]**	**Subscribers**	**Cumulative Subscribers**	**Adoption**
2014	8691840.0	14400000.0	1.14%	27524160.0	45600000	3.62%
2015	10070951.5	25070951.5	1.96%	30212854.5	75212854.52	5.89%
2016	15906085.5	41979875.0	3.25%	45271166.3	119481182.8	9.24%
2017	24286700.6	67881186.2	5.18%	65664042.3	183530614.5	14.01%
2018	35219059.8	105614364.0	7.96%	90563296.6	271579793.1	20.46%
2019	47259178.0	156645483.6	11.65%	115703504.8	383511356.3	28.52%
2020	56616274.9	218663326.9	16.05%	132104641.4	510214429.4	37.45%
2021	57950854.0	283902958.5	20.84%	128987384.8	631913036.6	46.38%
2022	48551658.1	341612776.6	24.80%	103172273.5	725927150.2	52.69%
2023	32560799.1	384848975.0	27.32%	66108289.2	781360040.1	55.46%
2024	17815619.6	414326684.7	28.44%	34583261.6	804281211.5	55.22%
2025	8419759.1	434932522.8	28.56%	15636695.5	807731828.1	53.04%
2026	3660601.7	451019768.0	28.01%	6507736.3	801812920.9	49.80%
2027	1528936.5	465077031.4	27.02%	2603324.3	791887918.3	46.00%
2028	627434.1	478274115.0	25.70%	1023708.3	780341977.1	41.93%
2029	255529.8	491115805.7	24.14%	399674.9	768155491	37.76%
2030	103711.2	503812229.9	22.40%	155566.7	755718344.8	33.60%
2031	42020.3	516449556.0	20.54%	60468.3	743183507.4	29.56%
2032	17007.7	529062894.3	18.62%	23486.8	730610663.6	25.71%
2033	6878.8	541666508.7	16.68%	9118.4	718023046.4	22.11%
2034	2780.4	554266184.6	14.76%	3538.7	705429689.5	18.79%

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[18] Source: Report on Indian Rural Urban divide

[19] Source: TRAI annual reports, 2012-13, 2013-14; DoT report on Telecom Statistics in India, 2014

[20] Source:PwC Report on Mobile Broadband Outlook, 2015

[21] Adoption percentage value for rural/urban case, is the number of rural/urban subscribers divided by the total rural/urban population

The peak adoption in the rural case is around 29% while in the urban case it is 55%. Between 2012-29 the adoption is higher than 40%. The adoption in the rural areas are relatively slower as compared to the adoption in the urban areas, indicating a slower rate of growth in the digital-literacy and awareness about the benefits of Broadband adoption.

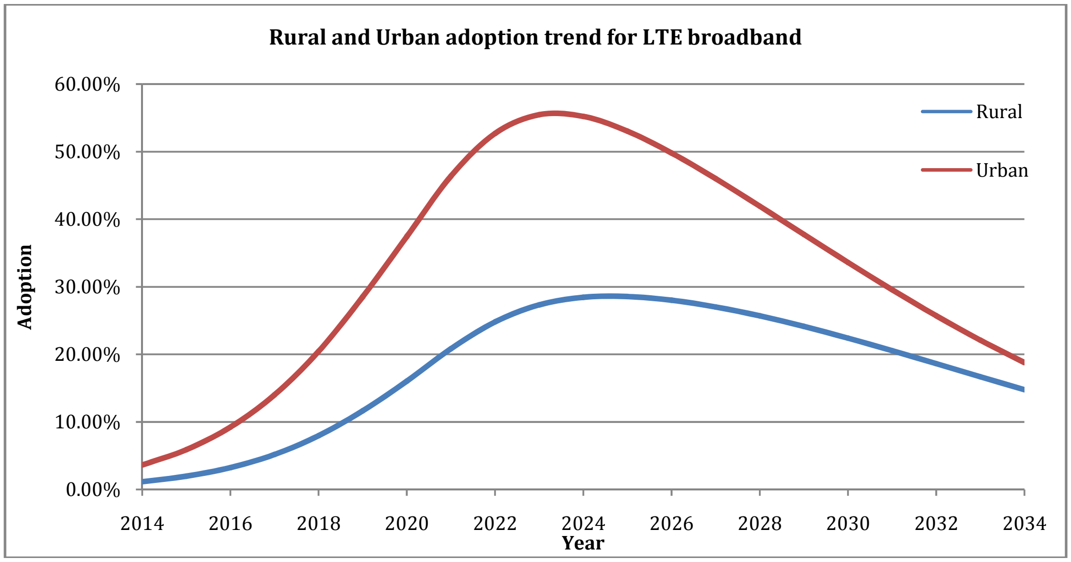

Figure 6: 2014-2034 rural and urban adoption forecast of LTE Broadband

5.2 MAPL value calculations using the LTE link budget model

The input assumptions for the MAPL calculations are for a typical LTE transceiver with specifications to match the desired cell throughput. The MAPL value is obtained for both the uplink and the downlink case using equation (2), (3), and (4). The standard values for LTE link budget input parameters have also been explained in [27].

Table 3: LTE Link budget inputs and outputs

Transmitter - UE		
Maximum Transmitter Power (dBm)	P_{Tx}	46
Transmitter Antenna Gain (dBi)	G_{Tx}	18
Body Loss (dB)	Lb	2
EIRP (dBm)	$EIRP_{Tx}$	62
Receiver - Node B		
Node B noise figure (dB)	NB_{noise}	7
Thermal Noise (dB)	Th_{noise}	-104.45
SINR (dB)	SINR	-9
Receiver Sensitivity	R_{SENS}	-106.45
Interference margin (dB)	IM	3
Cable loss (dB)	L_{cable}	20
Receiver antenna gain (dBi)	G_{Rx}	0
Fast fade margin (dB)	M	0
Soft handover gain (dB)	G_{soft}	0
Maximum Allowable Path Loss (dB)	MAPL	145.45(Uplink) 144.45(Downlink)

5.3 Cell radius and coverage calculations using Okumara-Hata model

The frequency in our case is 800 MHz and the antenna height for the base-station, and the mobile-station is kept at 30 meters and 1.5 meters respectively. Using equations (6) and (7) we derive the values for different common parameters, while the different gain functions and C values, for both the rural and the urban case, results in their respective cell radius' using equation (5). Equation (8) is used for calculating the coverage area.

Table 4: Input parameters for Okumara-Hata model

Carrier frequency, f_c	800 MHz
BS antenna height, h_b	30 m
MS antenna height, h_m	1.5 m

Table 5: Output parameters of the Okumara-Hata model

	A[22]	B[23]	C	Cell radius (km)[24]	Coverage (sq. km)[25]
Rural	125.053	35.225	-28.012	20.841	846.36
Sub-Urban	125.053	35.225	-9.639	11.091	239.67
Urban	125.065	35.225	0.000	3.337	21.7

5.4 Data rate based cell dimensioning, and number of base-station calculations

We have considered three different product types namely, Gold, Silver and Platinum, with different data volumes. Reasonable assumptions are made for the respective product demands in rural, urban and suburban settings, with a futuristic view. With the help of Table 1 and 2 and applying equation (9), the total data demand for a month is calculated for different percentages of adoption. Dividing the aggregate monthly data demand with the cell capacity gives the total number of base stations required to meet the user data demands.

Table 6: Monthly data volume cell capacity calculations and results

Spectrum bandwidth (MHz)	2 x 5 MHz FDD LTE
Average downlink rate	30 Mbps
LTE downlink spectral capacity	5 bps/Hz
Average loading	50%
Busy hour % daily traffic	20%
Total data volume capacity per cell per month	9887.7 GB

Table 7: Input assumptions for user data demand and product types

Product Type	Gold	Silver	Platinum
Data Volume	30 GB	20 GB	10 GB
Rural Demand	30%	10%	60%
Urban + Suburban Demand	60%	30%	10%

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[22] Using equation (6)
[23] Using equation (7)
[24] Using equation (5)
[25] Using equation (8)

Table 8: Results for the number of Base Stations needed to meet the user demand

Monthly data demand in Petabyte (PB)[26]				Number of Base stations		
Year	Countrywide	Rural	Urban & Suburban	Aggregate	Rural	Urban & Suburban
2014	1219	216	1003	123305	21845	101459
2015	2132	395	1737	215650	39935	175715
2016	3592	694	2898	363306	70213	293093
2017	5853	1179	4674	591930	119210	472720
2018	9188	1926	7262	929233	194750	734484
2019	13767	2999	10768	1392353	303292	1089061
2020	19438	4395	15042	1965841	444537	1521304
2021	25554	5992	19562	2584407	606026	1978381
2022	31166	7571	23596	3152030	765675	2386355
2023	35623	8955	26667	3602722	905712	2697010
2024	38945	10123	28822	3938773	1023840	2914933
2025	41551	11158	30393	4202307	1128497	3073811
2026	43828	12150	31679	4432600	1228749	3203851
2027	46005	13155	32851	4652801	1330399	3322402
2028	48195	14204	33991	4874217	1436558	3437659
2029	50448	15315	35133	5102058	1548886	3553172
2030	52788	16496	36292	5338800	1668375	3670425
2031	55230	17756	37475	5585757	1795735	3790022
2032	57781	19099	38683	5843771	1931572	3912200
2033	60448	20531	39917	6113503	2076466	4037036
2034	63237	22059	41178	6395548	2231005	4164543

5.5 CAPEX and OPEX calculations for the 20-year period

The CAPEX comprises of investments in network and site infrastructure, and the spectrum auction fee (fixed), license costs, and the annual usage charges. For the recently concluded 800 MHz spectrum auction in March, 2015, the spectrum usage charges are fixed at 5% of the Adjusted Gross Revenue value per circle, for an operator[27]. A total amount of Rs.17158.79 crore resulted from an auction of 86.25 MHz (1.25 x 69 blocks) of spectrum. 25% of the total bid amount was to be paid upfront, while the rest was supposed to be paid through annual installments (if opting for it).

We have calculated the spectrum license charges for a paired block of 5MHz (2x5MHz) using the unit license costs per MHz. This amount is paid partly as the upfront charges (25%), and the rest as annual installments over the required period. The annual spectrum usage charges (SUC) comprise of 5% of the operator's revenue, resulting from the revenue model calculations.

Table 9: Spectrum Costs for the 800 MHz band[28]

CAPEX (year 0)	Upfront license charges + Auction Fee	4975 (Million Rs.)
CAPEX (year 1 to 20)	Annual license charge Installment	2938 (Million Rs.)

For the network infrastructure and site related expenses, we have taken the aggregate values based on standard industry sources.

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[26] The data demand values remain the same for a given year, growing at the rate of 5% annually.

[27] Source: Order dated February 5th, 2015. Ministry of Communications and IT –(DoT)
See: http://www.wpc.gov.in/WriteReadData/Orders/Spectrum%20Usage%20Charges%20Order.pdf

[28] Source: DoT report on spectrum auctions, 2014

Table 10: Aggregate CAPEX and OPEX for network infrastructure and site

CAPEX	Aggregate physical network	1.5 (Million Rs per BS)
OPEX (year 0 to 20)	Site rental and maintenance costs	2.4 (Million Rs per BS)

Table 11: Countrywide aggregate operator cost calculations and breakeven ARPU

Year	CAPEX (million Rs)	OPEX (million Rs)	Total (million Rs)	ARPU for breakeven (Rs)
2014	189932	295931	485863	8098
2015	141456	221629	363086	3621
2016	224422	354374	578795	3585
2017	345875	548698	894573	3558
2018	508893	809527	1318420	3495
2019	697618	1111487	1809105	3349
2020	863171	1376372	2239543	3073
2021	930787	1484558	2415345	2637
2022	854373	1362295	2216668	2076
2023	678975	1081660	1760635	1510
2024	507014	806522	1313536	1078
2025	398240	632484	1030724	829
2026	348377	552702	901079	719
2027	333240	528483	861724	686
2028	335062	531397	866459	688
2029	344700	546819	891520	708
2030	358050	568180	926230	735
2031	373373	592697	966070	767
2032	389960	619235	1009195	801
2033	407535	647355	1054890	837
2034	426006	676908	1102914	876

Table 12: Rural cumulative annual cost (CAPEX + OPEX) and breakeven ARPU calculations for LTE

Year	CAPEX (million Rs)	OPEX (million Rs)	Total (million Rs)	ARPU for breakeven (Rs)
2014	37743	52429	90171	6262
2015	32109	43416	75525	3012
2016	50391	72666	123057	2931
2017	78471	117594	196065	2888
2018	118283	181294	299578	2837
2019	167788	260501	428289	2734
2020	216842	338989	555831	2542
2021	247208	387573	634781	2236
2022	244449	383159	627607	1837
2023	215030	336088	551118	1432
2024	182166	283507	465673	1124
2025	161960	251177	413136	950
2026	155353	240606	395960	878
2027	157449	243959	401408	863
2028	164213	254782	418995	876
2029	173467	269588	443054	902
2030	184207	286773	470980	935
2031	196014	305663	501677	971
2032	208730	326009	534739	1011
2033	222316	347746	570062	1052
2034	236783	370893	607676	1096

Table 13: Urban and Sub-urban cumulative annual cost (CAPEX + OPEX) and breakeven ARPU calculations for LTE

Year	CAPEX (million Rs)	OPEX (million Rs)	Total (million Rs)	ARPU for breakeven (Rs)
2014	157164	243503	400666	8787
2015	116358	178213	294571	3917
2016	181042	281708	462749	3873
2017	274415	431104	705519	3844
2018	397620	628233	1025853	3777
2019	536841	850986	1387827	3619
2020	653339	1037384	1690723	3314
2021	690590	1096985	1787575	2829
2022	616935	979137	1596071	2199
2023	470957	745571	1216528	1557
2024	331859	523015	854874	1063
2025	243291	381307	624598	773
2026	200035	312096	512131	639
2027	182802	284524	467326	590
2028	177859	276616	454475	582
2029	178244	277232	455476	593
2030	180854	281407	462261	612
2031	184370	287033	471404	634
2032	188241	293226	481466	659
2033	192230	299609	491839	685
2034	196234	306015	502249	712

As we can see from Figure 7, the individual break-even ARPU for a year varies depending on the amount of investment, with the highest ARPU in the first year, due to heavy infrastructure and spectrum license costs. However, the average annual ARPU over the total study period is below Rs.2000 for both the rural and the urban case.

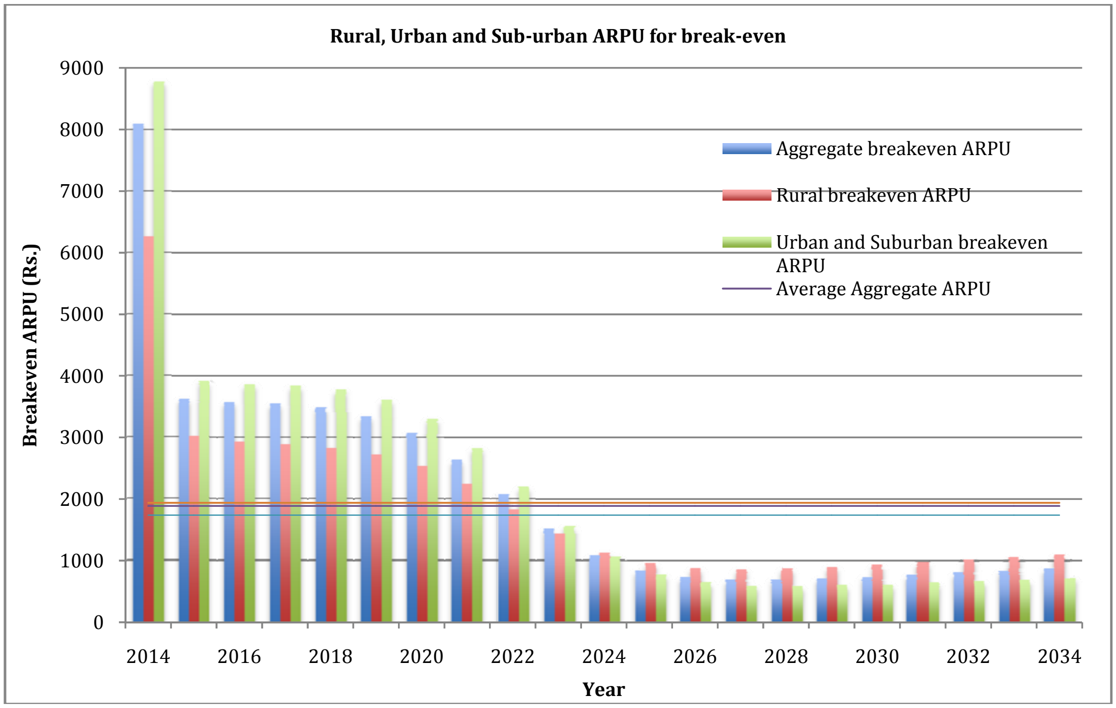

Figure 7: Break-even ARPU for rural and urban cases

For the three product types having different volumes of data, the Silver category has the highest CAPEX and OPEX values, due to the maximum demand. While, the Gold product has the least CAPEX and OPEX due to minimum demand, even though it has the maximum data volume (Figure 8). We observe the detailed impacts of a range of data volume packages on the profitability (NPV/MIRR), for five different demand scenarios, in Figure 15.

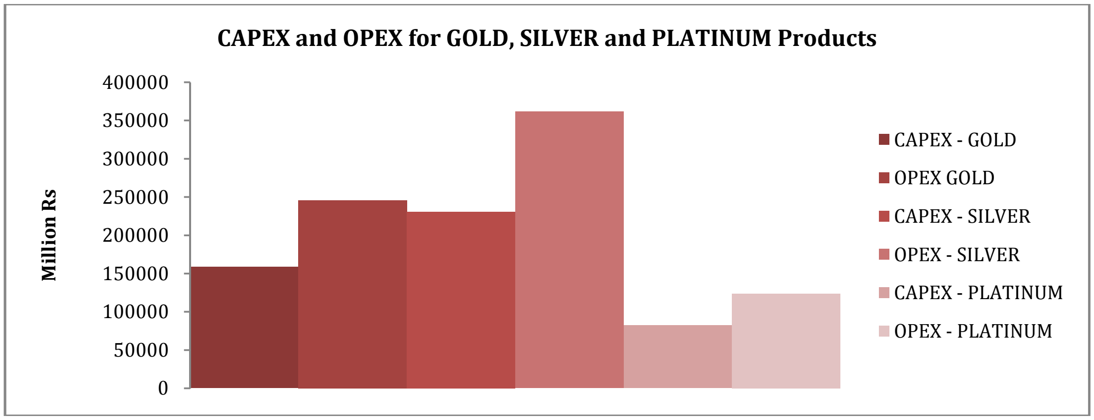

Figure 8: Average CAPEX and OPEX for Gold, Silver and Platinum Product types

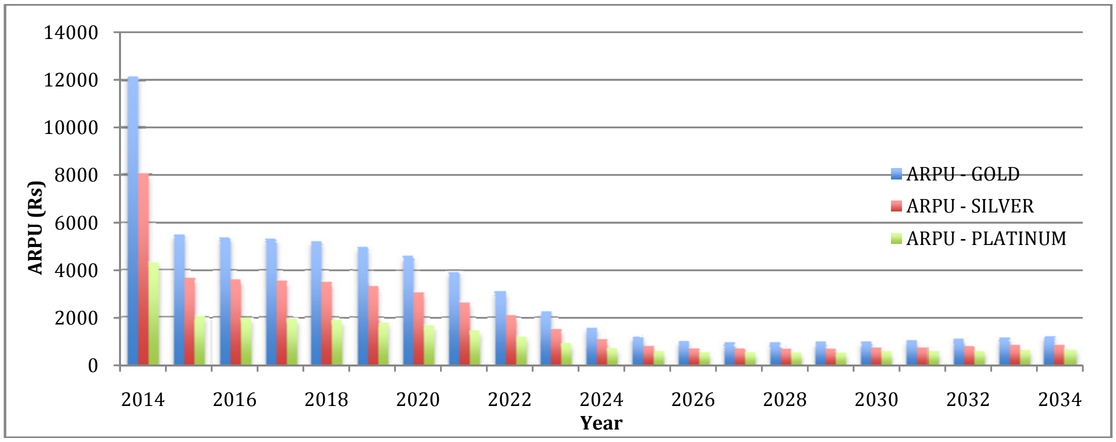

Figure 9: Breakeven ARPU for different product types

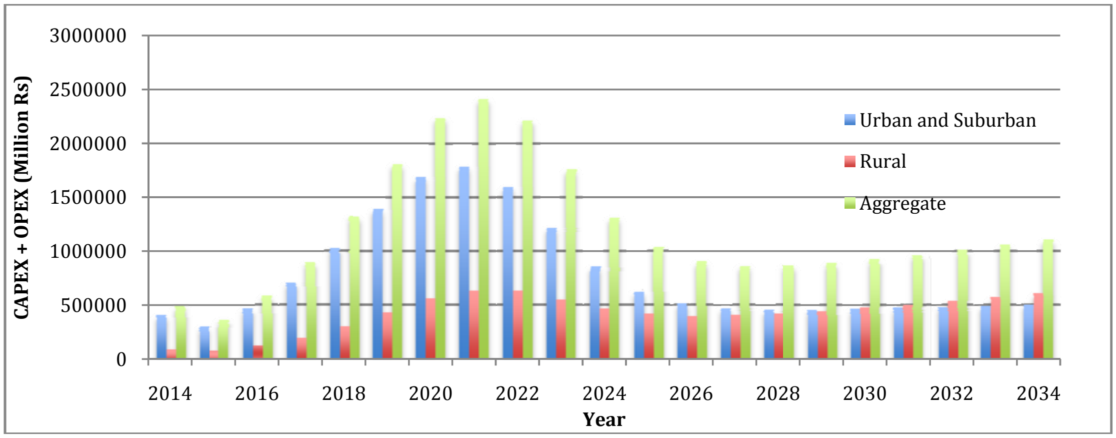

Figure 10: Countrywide operator cost calculation for LTE

For the break-even ARPU of different product types, Gold category has the lowest break-even ARPU and the Platinum the highest ARPU. The Silver category results in a moderate break-even ARPU in spite of the highest total investment costs.

5.6 Discounted Cash-Flow analysis for rural, urban and sub-urban case

We have calculated the net present value (NPV) and modified internal rate of return (MIRR) for a range of annual ARPU values, using scenario analysis. As is visible from Figure 11 and 12, in the rural case, the positive rate of MIRR is for annualARPU values above Rs.2500, and the positive NPV case has ARPU above Rs.6000. The case when the MIRR is greater than WACC, or the NPV>0, the investment would be profitable. We find that the annual ARPU value above which the investment would be profitable to be around Rs.6500 for the rural case.

Table 14: Input assumptions for NPV and MIRR analysis

Savings rate of Interest[29]	8%
WACC[30]	15%

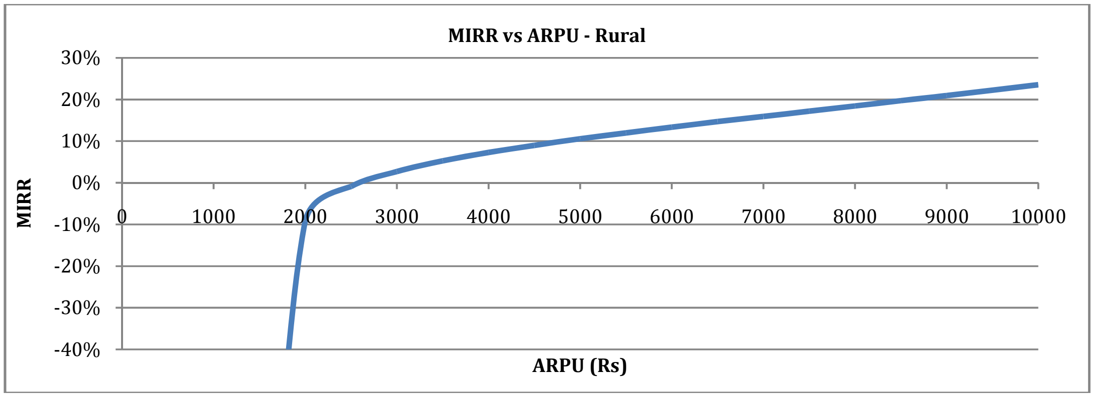

Figure 11: MIRR outputs over a range of ARPU for rural case

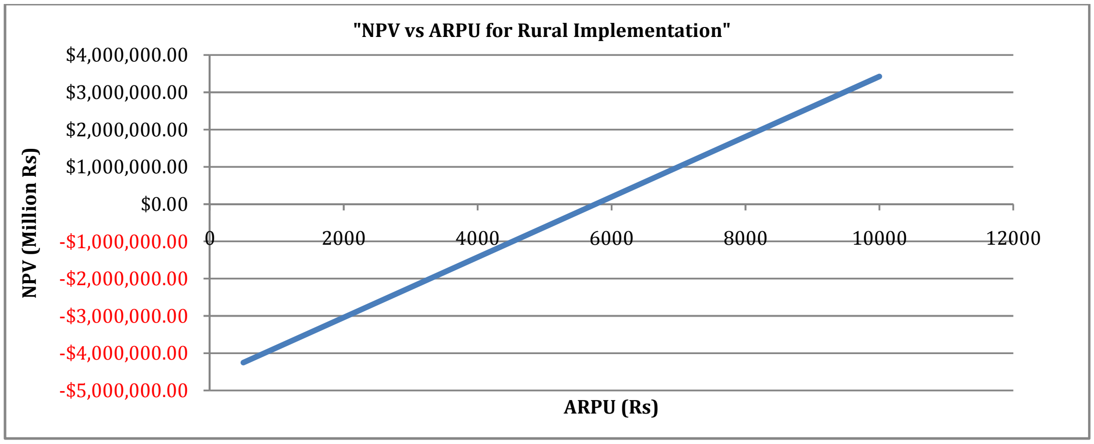

Figure 12: NPV outputs over a range of ARPU values – Rural

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[29] Source: Reserve Bank of India, Savings Interest rates

[30] 15% is the standard weighted average cost of capital

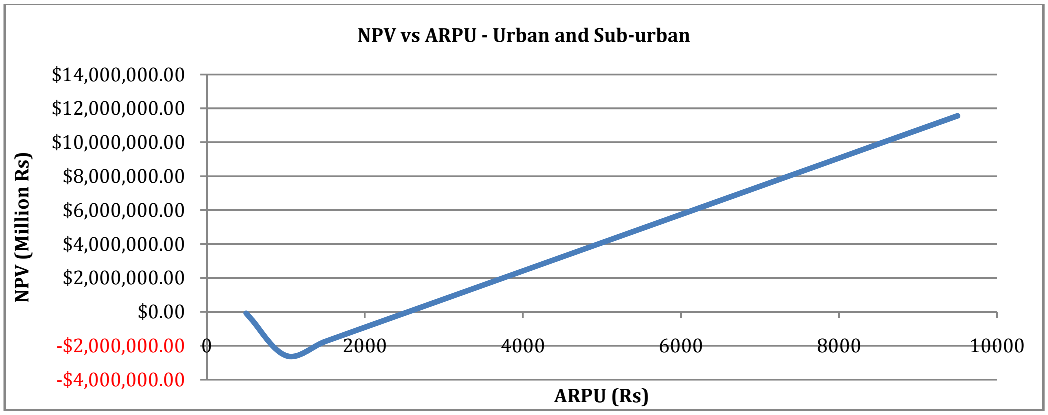

Figure 13: NPV outputs over a range of ARPU for Urban and Sub-urban implementation

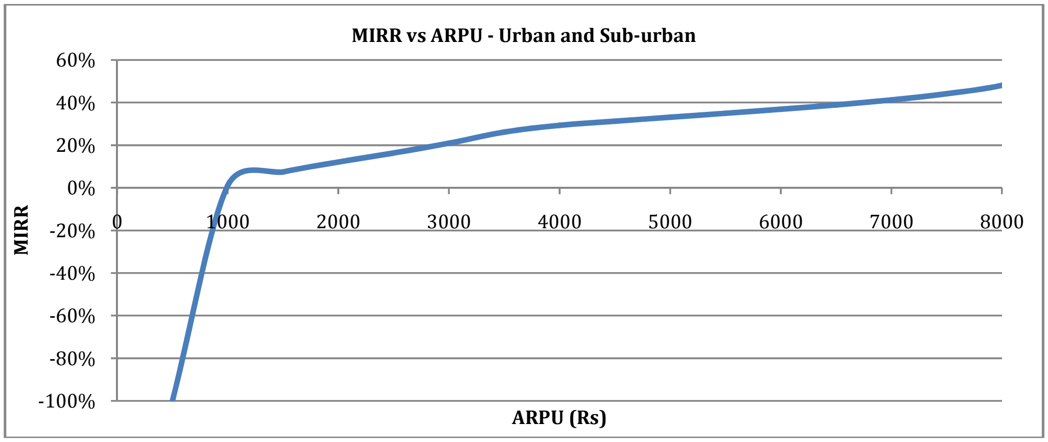

Figure 14: MIRR outputs over a range of ARPU for Urban and Sub-urban implementation

5.7 Demand Scenario Analysis

The previous results were for the case of a high-speed (30 Mbps) connectivity and high data volume demand for three product types. To analyze the effects of different data demand patterns on the average annual break-even ARPU, we have done a scenario-analysis with varying data-cap value for the three different products. There are five scenarios, namely, very-low demand, low demand, moderate demand, high demand and very high demand. The input data-cap combinations and the resulting average annual ARPU values are shown below.

Table 15: Break-even ARPU values for scenario analysis for different demand situations

Demand scenario	Annual Average ARPU (Rs.)		Gold (GB)	Silver (GB)	Platinum (GB)
	Rural	Urban			
Very High Demand	3093	3126	40	30	20
High Demand	1875	2155	30	20	10
Moderate Demand	1022	1232	20	10	5
Low Demand	498	620	10	5	2
Very Low Demand	291	348	5	2	1

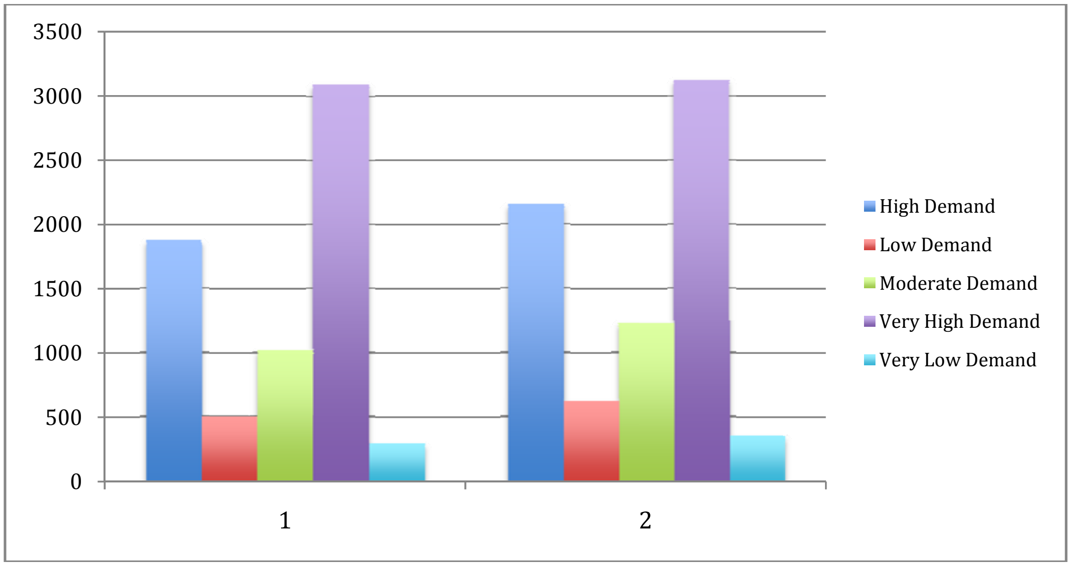

Figure 15: Average Annual ARPU for different demand scenarios. Description: 1 and 2 are for rural and urban cases respectively, while the Y-axis is the annual average ARPU required for break-even

As can be observed from Figure15, as the data volume demands fall, the ARPU required for break-even becomes lower and reasonable enough for service provisioning in the rural case, also in case of very high demand scenario, the ARPU required to break-even does not vary much between rural and the urban situations. This indicates that, for an optimum combination of product data volume, there is lower recovery period and lesser annual ARPU required.

6. Conclusion

The Broadband adoption in the urban part of India is growing very rapidly (TRAI, 2014). There is a growing demand for higher data volume and downlink speed, which makes the urban section an attractive investment destination for telecom service providers. However, limited spectrum availability, and dense urban planning, limits the capacity of the telecom network. The case of rural India is opposite, with very poor Broadband coverage and adoption rates. Due to sparsely populated areas, ensuring the last mile coverage becomes a challenge. Varying user demand, absence of competition, and a lack of digital literacy lead to apprehensions over the possibility of recovering operator investment in infrastructure deployment and service provisioning.

This work is an evaluation of the feasibility of deploying LTE networks for providing high-speed Broadband (30Mbps), to ensure the last mile coverage for the case of rural India. We have considered the 800 MHz frequency band for our analysis, due to its LTE suitability, and the recent interests shown by various operators considering LTE deployment in this band. Considering the upper limit for the spectrum block allocated per operator by the authorities, a 5 MHz paired spectrum block (2 x 5MHz FDD LTE) is taken for evaluating the parameters.

The Bass-Model forecasts for the adoption of Broadband services in rural India predict, adoption rate varying from 1.4% (14.4 million subscribers) in 2014, to the maximum of 28.56% (445 million subscribers) in 2025. For the assumed data volume demand and usage patterns for the rural case, the monthly data demand is 216 Petabytes (PB) in 2014, which goes up to 22059 Petabytes (PB) in 2034. The required number of base stations to meet this demand varies from 21845 in the year 2014, to 2231005 in the year 2034. The combined operator investment (CAPEX+OPEX) for meeting the user data and quality demands is Rs.90171 million in 2014, to Rs.607676 million in 2034. While the annual ARPU required, to cover the operator cost in the initial years, is high, the average annual ARPU value over the entire period of study is not very high (Rs.1739). Moreover, for a right mix of data-volume offering in a product, an optimal average annual ARPU ensuring maximum returns can be found.

Since the output is very sensitive to adoption and user demands, with the right amount of government stimulus, and demand inducing initiatives, investment in the rural areas can be as profitable, and attractive an option as that of the urban case. Affirming the same is the fact that average annual ARPUs do not differ significantly for the rural and the urban case.

While the government can initiate such programs as e-literacy, making low cost compatible computing devices available to the rural population, and providing subsidies in OPEX for operators wiling to invest in rural areas. The operators should explore techniques of cost reduction like active and passive sharing of network and infrastructure resources, and cognitive femtocell deployment for maximum spectrum utilization. Such initiatives and futuristic planning would help maximize the operator utility, as well as bring about welfare for a large segment of the population.

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