Guide on bottom-up and top-down shell models for the determination of mobile and fixed-line wholesale voice call termination rates

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1 Introduction

Acacia Economics has been briefed to assist the Independent Communications Authority of South Africa (‘the Authority’) to update top-down and develop bottom-up cost models to determine suitable mobile and fixed-line termination rates.

ICASA is engaged in a review of the pro-competitive conditions imposed on licensees in terms of its Call Termination Regulations, 2014. A Findings Document was published on 28 March 2022 in which the Authority reviewed the market for wholesale voice call termination services as well as the effectiveness of competition in the telecommunications market.

The Authority made various determinations including the following:

- Licensees must charge cost-based pricing.
- Mobile termination rates will move to symmetry within a transitional period of twelve months.
- New licensees will qualify for asymmetry for a limited period of three years after entry into the market.
- South African licensees must charge reciprocal international termination rates for voice calls originating outside of South Africa.

We base our modelling approach on international best practices which aligns with the determinations above, while also considering South Africa’s market dynamics.

The remainder of this report is structured as follows. In section 2, we describe bottom-up long run incremental costing principles. In Section 3, we explain some key concepts in relation to our bottom-up models, and in Section 4 we explain our approach to top-down models.

2 Methodology: pure LRIC MTRs

In this section, we explain our methodology for Pure Long Run Incremental Costs (LRIC).

2.1 Cost modelling options

There are, broadly, three cost standards for setting voice call termination rates:

Bottom up long-run incremental costs (BU-LRIC). In 2009, the EC recommended member countries to move towards using LRIC as a basis for setting call termination rates.[1] This involves calculating the costs that are caused by the provision of a defined increment, in this case the wholesale call termination service provided to third parties. These can be defined as the costs which would be avoidable if the increment (call termination) was no longer produced (see Box 1).[2] Another way of putting this is “*the difference between the identified total long-run costs of an operator providing its full range of services and the identified total long-run costs of that operator providing its full range of services except for the wholesale call termination service supplied to third parties (i.e. stand-alone cost*

1 EC (2009). Commission Recommendation of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU. Available at: https://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2009/c_2009_3359_en.pdf .

2 EC (2009), cited above.

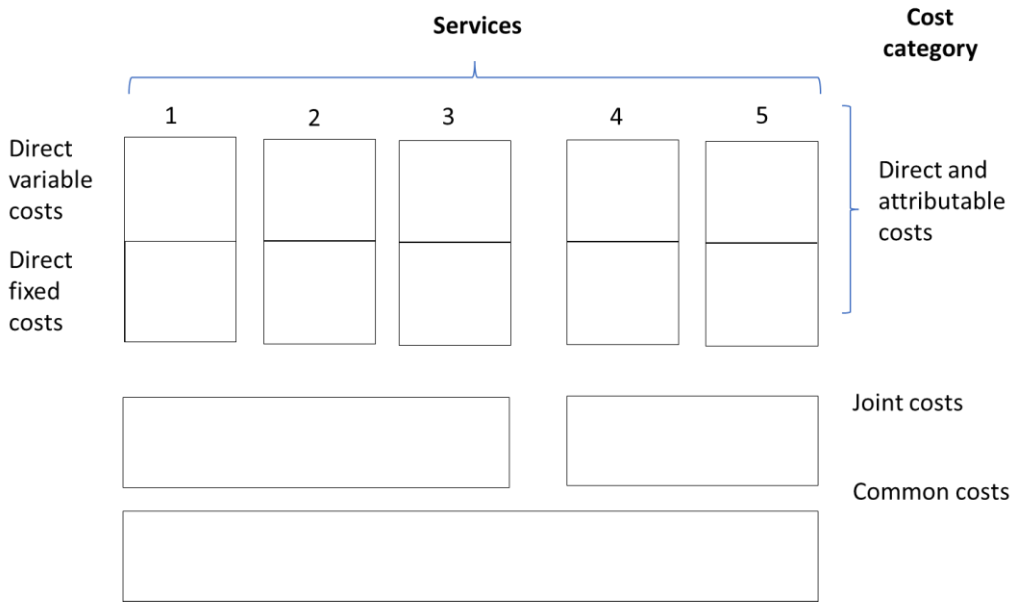
of an operator not offering termination to third parties)."[3] Included in the costs to be considered are the direct fixed and variable costs associated with call termination. This is referred to as pure bottom-up LRIC (BU-LRIC).

Box 1: Avoidable costs for voice call termination rates
In order to determine which costs could be avoided, it is necessary to identify the costs which vary with traffic levels, as these are the costs which could be avoided if termination was no longer offered. The EC considers that the default demarcation-point between costs which vary with traffic costs which vary with traffic and those which do not is typically at the first point where traffic concentration occurs[4]. However, the demarcation point will be determined by the point at which dedicated capacity is first allocated to the voice call termination service. Where applicable, this includes any additional network capacity needed to transport additional wholesale termination traffic and any additional commercial costs directly related to the provision of termination services to third parties. The EC recommends that the evaluation of efficient costs be based on current cost and the use of a bottom-up modelling approach.[5] The cost model should be based on efficient technologies available in the timeframe considered by the model which may be Next-Generation-Network-based. This is to ensure that efficient investment is incentivized.

BU-LRIC+: This approach considers the fixed and variable costs avoided without termination (BU-LRIC) and adds an additional margin to cover joint and common costs that are shared between different services (Figure 1).

Fully allocated costs: This approach adds the fixed and variable costs of call termination and apportions joint and common costs to call termination activities, arriving at a fully allocated cost (Figure 1).

Figure 1: Allocating costs in a multi-service network operator (ITU)



Source: ITU. 2009. Regulatory Accounting Guide. Available at: : https://www.itu.int/ITU-D/finance/Studies/Regulatory_accounting_guide-final1.1.pdf

3 EC (2009), cited above.

4 EC (2009), cited above.

5 EC (2009), cited above.

2.2 Pure LRIC versus LRIC+

South Africa's termination rates were previously based on the LRIC+ cost-based pricing methodology which allows operators to recoup joint and common costs that are not solely attributable to call termination. As explained above, pure LRIC on the other hand includes only costs associated with terminating traffic from a third party and excludes joint and common costs. To assess the merits of these two approaches we consider the framework developed by Ofcom in their May 2009 consultation document.[6] Their analysis makes use of four broad criteria: (i) economic efficiency, (ii) distributional effects, (iii) competitive effects, and (iv) commercial and regulatory consequences.

2.2.1 Economic efficiency

Economic efficiency in the present context includes allocative efficiency, which concerns the efficient allocation of resources, and dynamic efficiency, which refers to the incentives of mobile operators to invest and innovate over time. Pure LRIC is likely to lead to the efficient allocation of resources in South Africa, since bringing the costs of wholesale termination services close to their marginal cost is likely to lead to the optimal consumption of voice calls.

The transition to pure LRIC should not distort investment incentives (dynamic efficiency) as South Africa has a mature mobile market which means investments are linked to the expansion of data services and not traditional voice. In a 2015 MCT Market Review Statement, Ofcom found no evidence of reduced investment when transitioning to Pure LRIC in 2011.[7] The industry did experience investment growth in both network and services since 2011.

The adoption of pure LRIC is therefore supportive of economic efficiency.

2.2.2 Distributional effects

Assessing the distributional effects on consumers involves analysing how the switch to pure LRIC would impact different consumer segments in the market**.** The lowering of termination rates is likely to benefit especially low-income consumers, as lower termination rates are likely to be carried over to lower retail prices.[8] This suggests that the distributional effects of pure LRIC will be positive.

2.2.3 Competitive effects

Switching to pure LRIC would reduce on-net/off-net differentiation among MNOs, and this would reduce the ability for large operators to use low on-net prices relative to high termination rates to generate tariff-mediated network effects.[9] Tariff-mediated network effects increase the barriers to entry and expansion for new entrants and smaller rivals. Ofcom reported that after it implemented pure LRIC the market shares of smaller operators increased in addition to a reduction in the overall

[6] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0025/58075/mobile_call_term.pdf. A detailed assessment of the UK market using these criteria can be found at: https://www.ofcom.org.uk/__data/assets/pdf_file/0020/42662/wmvct_annexes.pdf

[7] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0029/76385/mct_final_statement.pdf

[8] Hawthorne, R. (2018). The effects of lower mobile termination rates in South Africa. *Telecommunications Policy*, 42(5), 374-385.

[9] Laffont, J. J., Rey, P., & Tirole, J. (1998). *Network competition: II. Price discrimination*. The RAND Journal of Economics, 38-56.

concentration levels in the market.[10] The Irish Commission for Communications Regulation explains in relation to MTRs for mobile service providers (MSPs):

> *"Pure LRIC MTRs enable smaller MSPs to compete more easily with larger MSPs whereas MTRs that exceed incremental cost i.e. LRAIC+ can lead to more pronounced tariff-mediated network externalities, which may cause inertia in the retail market, and make it difficult for smaller MSPs to win customers from large MSPs. Pure LRIC MTRs lower the floor for the retail pricing of off-net calls which strengthens the ability of smaller MSPs to construct competitive packages. This easing of barriers to entry/expansion (associated with large financial transfers at wholesale level and tariff-mediated network externalities at retail level) therefore facilitates a more competitively neutral framework."*[11]

Pure LRIC is therefore pro-competitive.

2.2.4 Commercial and regulatory consequences

The transition to pure LRIC is not expected to be an overly burdensome undertaking as the market is already familiar with regulated cost-based pricing (i.e. LRIC+). Although this method will be new to the market it is important to note that the trend in respect of the regulation of termination rates (TRs) is towards pure LRIC. For example, in 2008, the East Africa Regulatory, Postal and Telecommunications Organization issued guidelines to East African community members to adopt the Pure LRIC method when setting MTRs. In fact, the trend in the level of voice termination rates is towards zero, particularly with the implementation of BU-LRIC in many countries and the use of low-cost internet protocol for voice services. A number of countries already have zero termination rates, including Canada, Colombia, Costa Rica, Hong Kong, India, Mexico, Singapore, and the United States. In Rwanda, the termination rates declined by 30% between 2017 and 2019. Tanzania termination rates declined by over 85% over the period 2018-2022, and the termination rate in South Africa declined by nearly 90% between 2010 and 2021. shows the decline in mobile termination rates (MTR) in Europe, from a weighted average of 14.47 euro-cents/min in 2004 to 0.70 euro-cents/min in June 2021, representing a cumulative decline of 95.2% over the period. More recently, the European Commission has implemented the 'Eurorate' for call termination rates, to be set no higher than 0.2 euro-cents per minute (0.2 US-cents) by 2024, in respect of mobile calls. This suggests that average termination rates will likely decline further in the EU.

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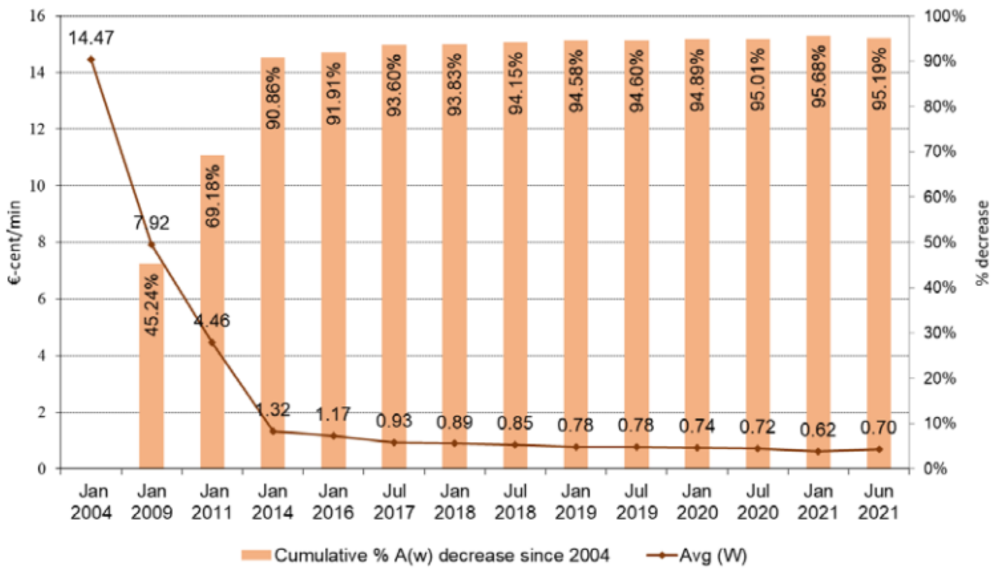
[10] https://www.ofcom.org.uk/__data/assets/pdf_file/0029/76385/mct_final_statement.pdf

[11] Irish Commission for Communications Regulation (2018). Price Consultation Further Specification of Proposed Price Control Obligations for Fixed and Mobile Call Termination Rates. Available at: https://www.comreg.ie/media/2018/03/ComReg1819.pdf

Figure 2: European MTRs weighted average and cumulative decline.



Source: BEREC. 2021. 'Termination rates at European level'. Available at : [*https://www.berec.europa.eu/sites/default/files/files/document_register_store/2021/12/BoR_%2821%29_159_Termination_Rates_Report_-_30_June_2021_P4_2021_clean.pdf*](https://www.berec.europa.eu/sites/default/files/files/document_register_store/2021/12/BoR_%2821%29_159_Termination_Rates_Report_-_30_June_2021_P4_2021_clean.pdf)

Countries applying BU-LRIC, such as Tanzania, typically set very low termination rates. Figure 3 compares mobile termination rates among African and non-African countries with Tanzania having the lowest at US 0.09 cents per minute. The average termination rate for the 18 African countries in Figure 3 is 0.66 US cents per minute. In South Africa, rates stand at around US 0.52 cents per minute which is below the average. Note that Namibia's interconnection rate, at US 0.67 cents, was based on international benchmarks using countries that implemented BU-LRIC. In Europe, BU-LRIC is currently used by 25 out of 37 countries. This is followed by the Benchmark BU-LRIC methodology (6 out of 37 countries).[12] More recently, based on a region-wide study, the European Commission decided on a maximum termination rate of EUR-cents 0.2, which falls closer to the lower-priced African economies.[13]

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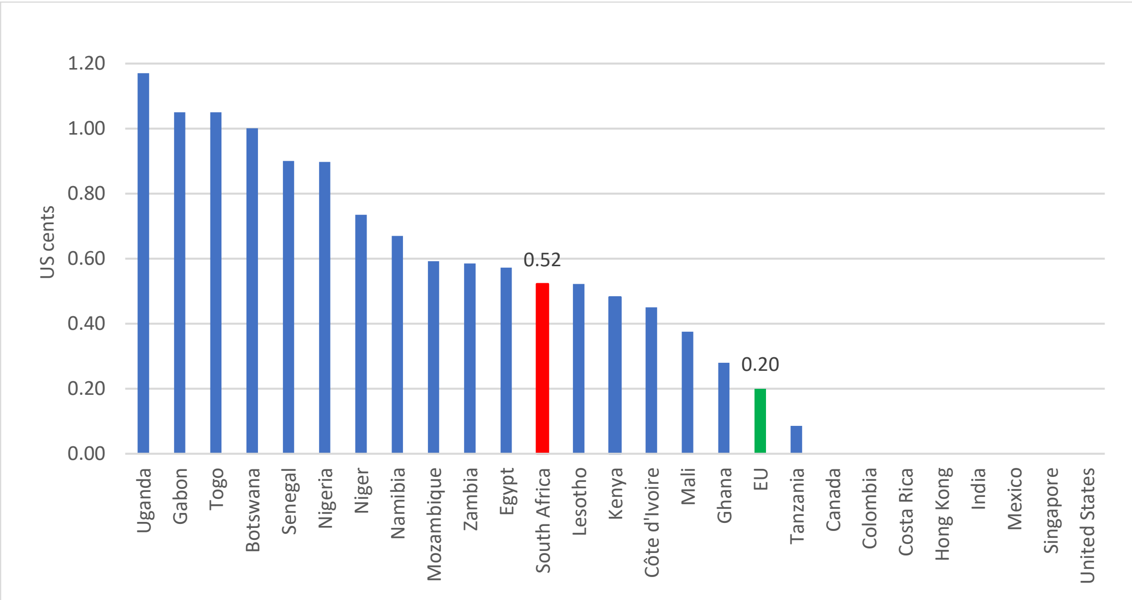
[12] See: https://www.berec.europa.eu/sites/default/files/files/document_register_store/2021/12/BoR_%2821%29_159_Termination_Rates_Report_-_30_June_2021_P4_2021_clean.pdf

[13] See: https://digital-strategy.ec.europa.eu/en/news/eu-wide-voice-call-termination-rates-become-applicable-today

Figure 3: Voice call termination rates



Note: Spot Exchange Rate as at 5 September 2022. 2021 MTRs except: Uganda (2020), Botswana (2018), Senegal (2018), Namibia (2017), Zambia (2022), Kenya (2022), Côte d'Ivoire (2022) and Tanzania (2022).[14]

This suggests that adopting a pure LRIC approach will result in significant reductions in termination rates in South Africa. This need not, however, have a substantial impact on the regulator since the Authority already collects detailed bottom up cost information for setting termination rates.

Furthermore, the commercial impact on individual licensees will depend on the calling patterns: licensees with balanced calling patterns will experience reductions in revenues as well as costs, and so reducing termination rates will have a neutral impact on overall profitability in this case. In any event, pure LRIC has been successfully implemented in a number of countries and indeed a growing number of countries have set termination rates at zero (imposed bill and keep), suggesting there will be only a limited commercial impact, if any, from implementing pure LRIC.

[14] See: https://uccinfo.blog/2019/07/08/mobile-termination-rates-dropping/ (Uganda), https://www.ncc.gov.ng/media-centre/news-headlines/1142-press-statement-ncc-sets-new-mobile-international-termination-rate-for-voice-services#:~:text=%2D%20New%20rate%20takes%20effect%20from,networks%20in%20Nigeria%20at%20%240.045. (Nigeria), https://www.commsupdate.com/articles/2022/08/09/ca-operators-agree-on-interim-termination-rates-following-challenge/ (Kenya), https://www.cran.na/yglilidy/2019/12/6141-Gen_N393-402.pdf (Namibia), https://www.icasa.org.za/news/2018/icasa-to-publish-final-call-termination-regulations#:~:text=glide%20path%20period%E2%80%93-,where%20a%20charge%20for%20terminating%20a%20call%20at%20a%20mobile,c%20from%20October%202020%20onwards. (South Africa), https://investors.vodafone.com/sites/vodafone-ir/files/2021-05/vodafone-annual-report-2021.pdf (Mozambique), https://www.zicta.zm/storage/posts/attachments/oiBT4oMnpJoN3dgHKpvByoDmNXq5ZDYtp3sxVYM3.pdf (Zambia), https://www.tcra.go.tz/uploads/text-editor/files/Interconnection%20Determination%20No.%205%20Issued%20in%20December,%202017_1622553922.pdf (Tanzania), https://sonatel.sn/wp-content/uploads/2019/10/Sonatel-2018-Annual-report-2018.pdf (Senegal), https://www.bocra.org.bw/sites/default/files/documents/Directive%20No.%201%202017.pdf (Botswana), https://investors.vodafone.com/sites/vodafone-ir/files/2021-05/vodafone-annual-report-2021.pdf (Ghana), http://www.iam.ma/Lists/TelechargementFinance/Attachments/1364/Maroc_Telecom_2021_half_year_Financial_Report.pdf (Gabon, Togo, Niger and Mali), https://www.artci.ci/index.php/publications/newsletters/522-newsletter-de-l-artci-02-mars-2022.html (Côte d'Ivoire), https://investors.vodafone.com/sites/vodafone-ir/files/2021-05/vodafone-annual-report-2021.pdf (Lesotho, Egypt). https://www.itu.int/net/itunews/issues/2010/03/20.aspx (Canada, Colombia, Costa Rica, Hong Kong, India, Mexico, Singapore, and the United States), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0654&from=EN (EU)

2.2.5 Summary

Our analysis of economic efficiency, distributional effects, competitive effects, and commercial and regulatory consequences, all support the introduction of pure LRIC. We therefore suggest that the Authority adopts this approach.

3 Modelling approach

There are several costing approaches to BU-LRIC models:

- Scorched earth: a model is built from the ground up (i.e. no existing network topologies are taken into account);
- Scorched node: existing network topologies are used, and network elements not related to voice traffic are removed;
- Modified scorched node: an efficient network is constructed, based on existing network topologies.

The modified scorched node approach, which takes into account existing networks and allows for efficiencies to be introduced in the network model, is often applied in practice. The main idea in respect of developing the BU-LRIC model for termination is to use network traffic demand to dimension a reasonable, representative network for South Africa, typically based on the number of operators.

In the sections that follow, first we explain our approach to the weighted average cost of capital (WACC) and economic depreciation. Next, we explain our approach to modelling fixed and mobile call volumes. We then explain some more details on our modelling approach for mobile call termination and fixed call termination.

3.1 Weighted average costs of capital and economic depreciation

In this section, we explain our approach to weighted average costs of capital and depreciation.

3.1.1 Weighted average costs of capital

In order to develop annualised capital costs, we apply depreciation rates used by licensees or alternatively those available from international best practice where information from licensees is not available.

We develop a weighted average cost of capital (WACC) for telecommunications networks in South Africa in order to apply a reasonable return to the regulatory asset base, so as to identify the annualised costs of capital (sometimes referred to as CAPEX), as follows:[15]

$$CAPEX = (Gross\ value - cumulated\ depreciation) * WACC$$

The WACC, in turn, can be represented as follows:

$$WACC = \left[Ke \times \frac{E}{D+E}\right] + \left[Kd \times (1-t) \times \frac{D}{D+E}\right]$$

[15] See, in this regard, the International Telecommunications Union (ITU), 2009, Regulatory Accounting Guide, available at: https://www.itu.int/ITU-D/finance/Studies/Regulatory_accounting_guide-final1.1.pdf

where:

Ke is the cost of equity, typically determined using the Capital Asset Pricing Method (CAPM) model, explained below

Kd is the cost of debt, which sometimes uses the firms' actual cost of debt, which includes a premium over the risk-free rate applied to debt (often government treasury bonds)

E is the proportion of equity in the firms' capital structure (or the market value of equity)

D is the proportion of debt in the firms' capital structure (or the market value of debt)

t is the rate of tax

The CAPM model, in turn, defined as follows:

$$\mathrm{Ke} = \mathrm{rf} + \beta \times (\mathrm{Em} - \mathrm{rf})$$

where:

rf is the risk-free rate applied to debt (often government treasury bonds)

β is the risk of the company relative to the market

$\mathrm{Em} - \mathrm{rf}$ is the market risk premium (the premium over risk-free returns)

Historical WACC figures applied to the mobile sector in Europe ranged between 11.64% for Telefonica Moviles in Spain to 12.4% in Italy in around 2008.[16] There can be risk premia applied where investments in new technologies are uncertain, such as in respect of next generation access fixed line (fibre) networks compared to copper. In 2019, these risk premia varied for instance between 0.1% in Estonia (copper WACC: 10.3%; fibre WACC 10.4%), and 3.31% in the Czech Republic (copper WACC: 7.89%; fibre WACC: 11.2%).[17] In the present matter, however, the Authority is developing cost models that do not concern risky investments in new technologies but rather rates applying to 2G, 3G and 4G services, which have long-established business models and do not involve substantial risks. We understand that the Authority has previously used a pre-tax nominal value of 18.25%, which is what is currently applied in our model as a starting point.

3.1.2 Economic depreciation

We follow the approach to economic depreciation that results in outcomes we would observe in a competitive market, applying modern equivalent asset values, and considering the lifetime of a business rather than a narrow timeframe. To do so, we apply a levelised cost of incoming voice minutes, including a time trend for inflation. This is the approach proposed by the GSMA[18], for example, and applied by regulators such as Comreg[19].

Applying this approach, each asset is purchased in the year in which it is needed, applying a cost for the asset based on a specific price trend for it. All of the capital expenditure is added in each year,

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[16] See ITU regulatory accounting guide, cited above. It is not clear whether these WACC rates are pre-tax or post-tax, and they are provided here for illustrative purposes rather than as figures to be used in the cost models.

[17] ITU, 2021, 'Economic policies and methods of determining the costs of services related to national telecommunication/ICT networks: Output Report on ITU-D Question 4/1 for the study period 2018-2021', available at: https://www.itu.int/pub/D-STG-SG01.04.2 .

[18] See: https://www.gsma.com/mobilefordevelopment/resources/the-setting-of-mobile-termination-rates-best-practice-in-cost-modelling/

[19] See: https://www.comreg.ie/media/dlm_uploads/2019/05/ComReg-1948b.pdf

together with operating expenditure, and discounted to the beginning of the period using the WACC. The total costs with no call termination volumes are then deducted from the total costs incurred for all volumes including termination to arrive at termination costs.

The termination volumes, multiplied by an inflation price index in each year, are also discounted to the present day using the WACC. The total costs of termination are then divided by the total discounted termination volumes to arrive at a unit price. The latter is then inflated using the price index in each year to arrive at a price we would observe in a competitive market.

We consider a business period of 2013 – 2048, which balances the need to have realistic values of assets, costs and volumes, with the need to have a long enough life of business.

3.2 Volume calculations

The volume calculations in our model determine the dimension of the network for the modelled operator (Table 1). It determines, from the whole market and the market share of this modelled operator what the peak traffic load will be that the network needs to be able to handle. This is calculated by taking the share of traffic in the busy hour, the average duration of voice calls in respect of fixed calls and the proportion of data traffic in the busiest data path, the downlink, in respect of mobile networks.

We have captured data from the ITU Datahub[20] and utilised traffic splits present in network cost study data for Kenya[21] between FY2015/16 until FY2021/22 in cases where we were unable to determine the split for South Africa.

We determined the medium growth scenario as a compound average growth rate for each variable over the abovementioned time period. For example, the CAGR for FY 2021/22, using FY 2015/16 as a base year would be:

$$CAGR_{(2015-2021)} = \left(\left(\frac{FY2021}{FY2015}\right)^{1/6} - 1\right)$$

This approach differs in various instances depending on the volumes associated with each traffic type.

Table 1: Worksheets on volumes details

Projections	• This sheet trended the figures of population numbers and the mobile penetration rate forward to 2048. • It provides the basic understanding for the growth scenarios applied.
Forecasts	• This sheet provides an overall view of the data captured from 2013- 2021, and trended forward to 2048 for each type of voice, data and SMS traffic specified. • It provides a visualisation of the historical data captured and the results for each growth scenario according to each specified variable for voice, data and SMS traffic.
Data Only	• This sheet captures the original data that is fed through to the *projections* and *forecasts* tabs, as well as other sections.

[20] ITU. 2022. Connectivity, Traffic. Available at: https://datahub.itu.int/data/?id=2&e=ZAF&i=54

[21] CAK. 2015 – 2022. Statistics. Available here: https://www.ca.go.ke/consumers/industry-research-statistics/statistics/

	• It collates and presents the different growth scenarios for each type of traffic variable specified according to the growth scenario.
ITU	• This sheet captures the data provided by the ITU as mentioned above and provided assumptions on the splits used to account for traffic on variables undisclosed in this dataset.
State of ICT Sector	• This sheet captures the data provided in the State of the ICT Sector reports released annually by ICASA on several different variables.

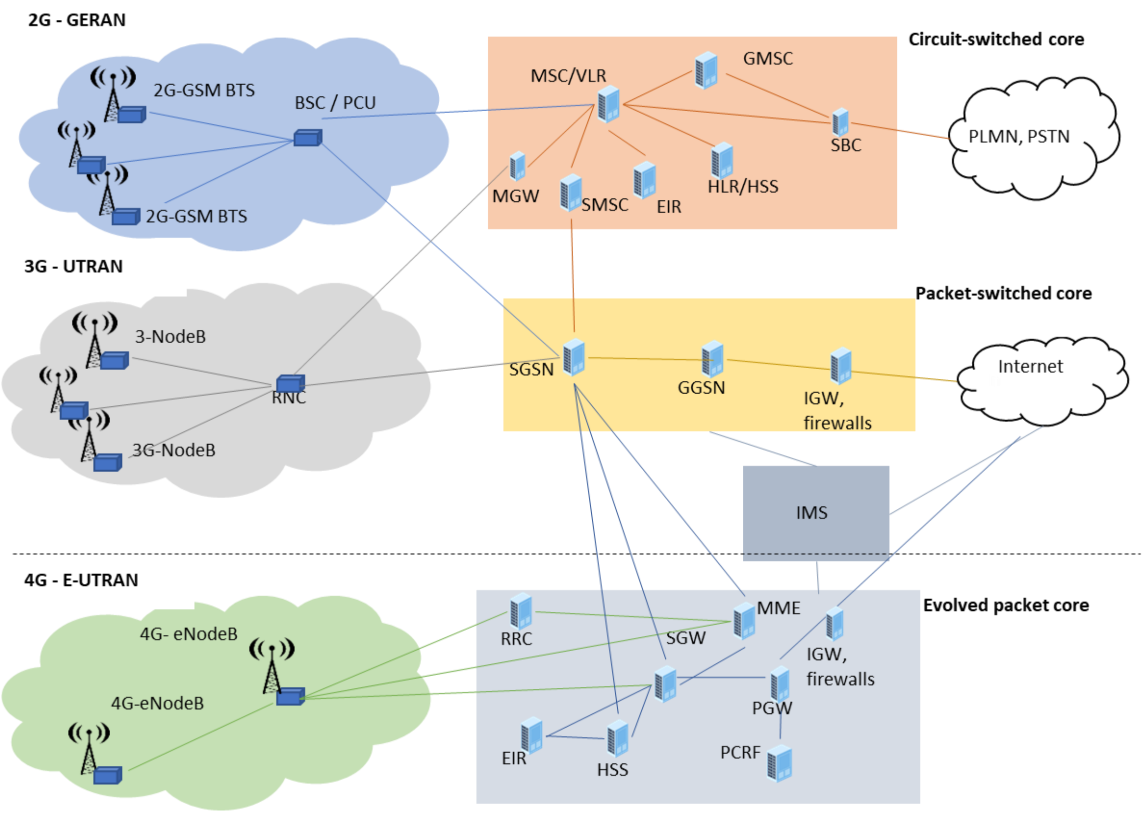
3.3 Mobile network

The starting point for modelling the bottom-up model for the mobile network is site coverage radii and the geography of South Africa. We first build a coverage network to a specified population coverage, and this coverage network provides for a basic layer of network capacity using coverage spectrum. We then use traffic demand to assess the total capacity requirements, and first apportion traffic demand to coverage sites. Once coverage sites are full, we add capacity sites, using capacity spectrum. It is important that the number of sites emanating from the model approximates the number of sites that operators actually use in South Africa.

3.3.1 High level network topology

We consider a generic network topology, shown on Figure 4 (see list of acronyms in Appendix A).

Figure 4: Network topology



Sources: Acacia analysis adapted from: https://telecominfraproject.com/naas-playbook-post-launch/ and Haryadi, S. (2018). The Concept of Telecommunication Network Performance and Quality of Service., available at: https://osf.io/mukgb/

3.3.2 Coverage and capacity networks

In order to model the costs of an efficient network, we need to consider an efficient network of high sites, and corresponding radio access network infrastructure including base station controllers and radio network controllers, and backhaul links.

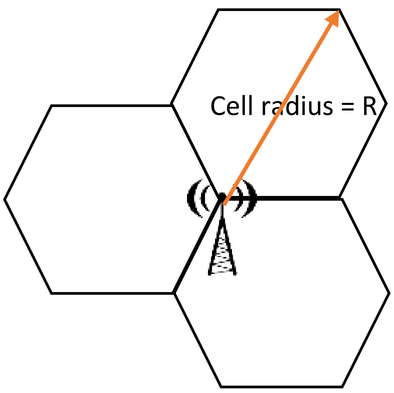
We assume, in respect of spectrum, that our modelled operator has:

- 2G: 2 x 5MHz in the sub-1GHz band, 2 x 12MHz in above 1GHz band.
- 3G: 2 x 5MHz in the sub-1GHz band, 2 x 15MHz in above 1GHz band.
- 4G: 2 x 10MHz in the sub-1GHz band, 1 x 80MHz in above 1GHz band.

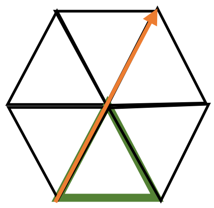
We dimension the network based on cell radii and a standard model of cell coverage, assuming a mobile site that has three sectors (described on Figure 5).

Figure 5: Cell coverage area

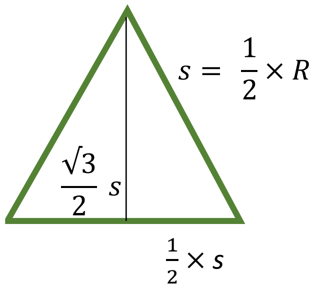
Step 1: Assume a 3-sector cell with cell radius R



Step 2: Divide one hexagon into 6 equi-lateral triangles



Step 3: Each triangle has a 30 degree, 60 degree, 90 degree angle, ratio of lengths is 1 : 2 : $\sqrt{3}$



Step 4: Area of triangle is (1/2 x base x height):

$\frac{1}{2} \times \frac{\sqrt{3}}{2} s \times \frac{1}{2} s = \frac{\sqrt{3}}{8} s^2$

Step 5: There are two right-angled triangles in our equilateral triangle, and 6 of the latter in hexagon:

$6 \times 2 \times \frac{\sqrt{3}}{8} s^2 = 2{,}6\, s^2 = \mathbf{2{,}6\left(\frac{1}{2}R\right)^2}$

We can then construct a coverage network reaching, for example, 99% of the population in South Africa using low frequency spectrum, e.g. the 900MHz band for 2G and 3G and the 800MHz band for 4G. In order to do so, first we use a dataset from Statistics South Africa's Census 2011 on populations and geographic areas in the 13 876 main places within South Africa sorted by population density, and add up the geographic area, by sub-location type (using the World Bank definition, that there are three degrees of urbanisation:[22]

[22] See: https://blogs.worldbank.org/sustainablecities/how-do-we-define-cities-towns-and-rural-areas

"1. Cities, which have a population of at least 50,000 inhabitants in contiguous dense grid cells (>1,500 inhabitants per km^2);

2. Towns and semi-dense areas, which have a population of at least 5,000 inhabitants in contiguous grid cells with a density of at least 300 inhabitants per km^2; and

3. Rural areas, which consist mostly of low-density grid cells.") until 99% of the population is covered (Table 2).

We apply the population density and not the minimum populations for main places in South Africa when computing data for the geotypes.

Table 2: Population coverage

	Area (square kms)	Population (2020)	Percentage of total
Cities	8 555	33 485 886	56,2%
Towns and semi-dense	25 392	18 545 238	31,1%
Rural	328 934	6 964 187	11,7%
Total	**362 880**	**58 995 311**	**99,0%**

3.3.3 Capex and opex costs

We then use the above approach to dimension a mobile network with and without termination traffic volumes, adding up all of the costs (capex and opex) associated with those network elements. We apply the economic depreciation method above to arrive at a termination cost per minute.

3.4 Fixed network

We consider, for fixed voice termination, that only core network elements are relevant from a dimensioning perspective. This is because access network elements in a modern fixed line network do not vary with call termination. We follow a similar approach to volumes, WACC and economic depreciation described above in respect of capex and opex.

3.5 Top down vs bottom-up

Our approach to top-down modelling is to apply a 'sense-check' to the bottom-up pure-LRIC model. The top down model will be used to compare high level capital expenditure, operating expenditure, network element numbers and the like with the numbers emanating from our models.

4 Annexure A - Acronyms

BSC	Base-station controller
DPI	Deep packet inspection
EDGE	Enhanced Data for GSM Evolution
EIR	Equipment Identity Register
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
GB	Gigabyte
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Centre
GN	Gateway Node
GPRS	General Packet Radio System
GSM	Global System for Mobile communications
GWCN	Gateway Core Network
HLR	Home Location Register
HSS	Home Subscriber Server
ICT	Information and Communications Technology
IGW	Internet Gateway
IMS	IP Multimedia Subsystem
IP	Internet Protocol
LTE	Long-Term Evolution
MB	Megabyte
Mbps	Megabits per second
MME	Mobility Management Entity
MNO	Mobile Network Operators
MOCN	Multi-Operator Core Network
MORAN	Multi-Operator Radio Access Network
MSP	Mobile service providers
MTR	Mobile Termination Rate
MVNO	Mobile Virtual Network Operators
NFV	Network Functions Virtualization
NNI	Network to Network Interface
OCS	Online Charging System
PCEF	Policy and Charging Enforcement Function
PCRF	Policy and Charging Rules Function
PCU	Packet Control Unit
PDN	Packet Data Network
PGW	Packet data Gateway
RAN	Radio Access Network
RNC	Radio Network Controller
RRC	Radio Resource Controller function of the MME
SBC	Session Border Controller
SDN	Software Defined Network
SGSN	Serving GPRS Support Node
SGW	Serving Gateway

SMSC	Short Message Service Centre
UMTS	Universal Mobile Telecommunications Service
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WACC	Weighted Average Cost of Capital