Sustainable spectrum pricing

Fostering the deployment of 5G through appropriate spectrum pricing

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Stefan Zehle, MBA
CEO,
Coleago Consulting Ltd

Tel: +44 7974 356 258
stefan.zehle@coleago.com

Content

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1 Executive summary

5G mobile is an enabling platform for the 4th industrial revolution and essential to ensure the socio-economic development of nations.

5G mobile is an enabling technology for enhanced mobile broadband, delivering a fibre-like user experience at a price which is lower than 4G. 5G also facilitates the Internet of Things, making it an enabling platform for what has been described as the "4th industrial revolution". Recognising its immense transformational value, governments in developed and developing markets are keen to facilitate the deployment of 5G mobile services in their respective countries.

Average monthly data usage per SIM is growing by up to 50% per year. In some countries average data use per smartphone is now above 20Gbytes as people use their screens for all aspects of life. Fortunately mobile users do not pay more for ever larger data bundles and even lower income groups can benefit from the mobile broadband revolution. However, to make this happen, operators are continually investing in mobile broadband capacity in the form of 4G and now also 5G.

From a technical perspective, 5G makes better use of the scarce resource that is spectrum. Nevertheless 5G also requires a lot more spectrum in low, mid and high band frequency ranges. Operators have to acquire spectrum licences for these bands, but spectrum licences are only the starting point. To deploy 5G, mobile operators have to make very large investments particularly in 5G radios, more physical sites, and building Gbit capacity backhaul to cell sites.

While operators are required to make large investments, smartphone users do not pay more due to fierce competition between mobile operators. Hence in most countries mobile operator revenue has been flat or even declining. This means the business case for 5G is a challenging one.

Whether or not a 5G business case is workable depends in no small part on how much operators have to pay for spectrum licences.

Whether or not a 5G business case is workable depends in no small part on how much operators have to pay for spectrum licences. 5G requires more spectrum but generates little or no incremental revenue. Looking at mobile revenue per MHz of spectrum in use reveals a stark picture: Since the launch of 3G, mobile operator revenue per MHz of licenced spectrum has declined by around 50%. When up to 400MHz of C-band spectrum and other 5G related spectrum are licenced, mobile revenue per MHz will decline by a further 50%.

In several countries governments have pushed up spectrum licence fees. However, as we have seen there are no incremental revenues generated by deploying more spectrum. We are now at a point where in some countries spectrum licence fees have become unsustainable. Policy makers face a choice: Assign spectrum, notably 700MHz, the C-Band, and other band(s) at a price which fosters 5G deployment or risk being left behind in the 4th industrial revolution.

Looking at the annualised cost of spectrum against mobile operator revenue, regulators can ensure that spectrum licence fees are sustainable and do not block 5G development.

Looking at their spectrum roadmap, how can regulators set spectrum licence fees and be confident that spectrum will be acquired and deployed without delay? Given the large amount of additional spectrum required for 5G, using benchmarking to set spectrum prices no longer works because it is backward looking. Regulators need to assess the sustainability of spectrum licence fees by calculating how large the annualised cost of spectrum is in proportion to mobile operator revenue. The methodology is easy to apply and only relies on data internal to a particular market. As part of this paper Coleago provides worked examples and Excel calculation tools ready to be used by policy makers and regulators.

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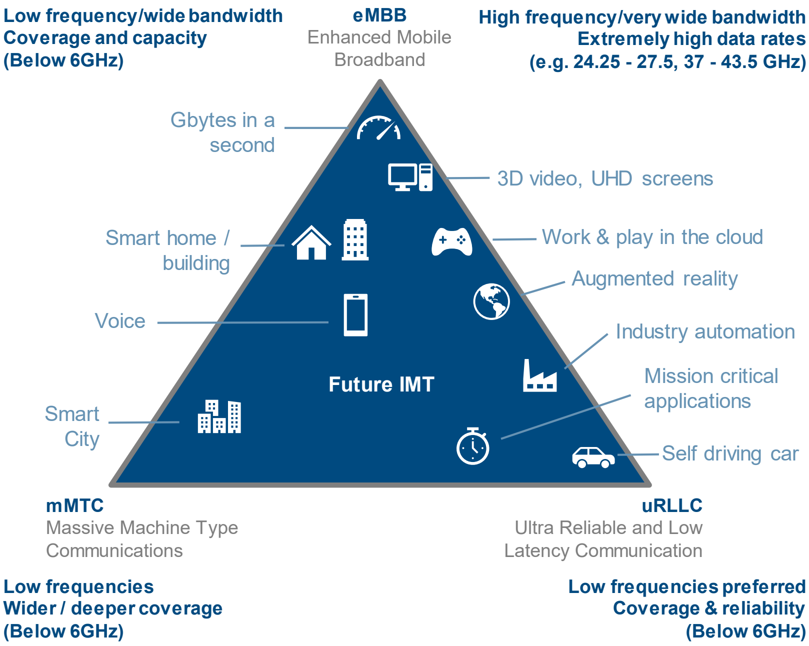
2 Evolution to 5G mobile

2.1 What to expect from 5G?

The socio-economic benefits of 5G are well documented, notably better broadband connectivity results in accelerated GDP growth.

5G will deliver significant enhancements compared to 4G (LTE). Mobile broadband users will experience enhanced Mobile Broadband (eMBB) with low prices for monthly data volumes approaching fixed broadband usage, higher speeds and lower latency. The socio-economic benefits are well documented, notably better broadband connectivity results in accelerated GDP growth. A study by Chalmers University of Technology showed that higher broadband speeds have a positive impact on GDP: "*The study found that the estimated coefficient of broadband speed is statistically significant. Doubling the broadband speed will contribute to 0.3% growth compared with the growth rate in the base year*"[1].

Exhibit 1: IMT 2020 (5G) Vision



Source: : Recommendation ITU-R M.2083-0, 09 2015

Furthermore, 5G enables the Internet of Things (IoT) with Massive Machine Type Communications (mMTC) and Ultra Reliable and Low Latency Communications (uRLLC). With this capability 5G is an enabling platform for what has been described as the "4th industrial revolution"[2]. Recognising its immense transformational value, governments in developed and developing markets are keen to facilitate the deployment of 5G mobile services in their respective countries.

From a technical perspective, 5G makes better use of the scarce resource that is spectrum.

From a technical perspective, 5G makes better use of the scarce resource that is spectrum. 5G New Radio combined with massive mimo results in higher spectral efficiency of 5G compared to 4G. However, due to the need to cater for very high traffic volumes at fibre-like speeds to deploy 5G, mobile operators also require more spectrum in mid bands. Importantly, 5G also allows the use of higher frequency bands. 5G New Radio has been standardised in 24-28GHz which were not previously used to deliver broadband services.

[1] "Does broadband speed really matter for driving economic growth?", Rohman et al, Division of Technology and Society, Department of Technology Management and Economics Chalmers University of Technology, Gothenburg, Sweden, 2012
[2] Klaus Schwab, The Fourth Industrial Revolution, Magazine of Foreign Affairs, 12 Dec 2015

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2.2 Spectrum for 5G

The introduction of 5G is inseparable from making large amounts of new spectrum available for mobile. 5G will be introduced in low (sub-1 GHz), mid (1.8 to 6GHz) and high frequency (24GHz and above) bands. Other bands are already in use for mobile but in time will be refarmed to 5G.

Exhibit 2: Low, mid and high frequency bands for 5G

Category	Frequency	Comment
Low-bands	< 1 GHz	Coverage layer (eMBB, indoor, massive IoT) Original GSM bands, 1st & 2nd digital dividend 700MHz / 600MHz first 5G coverage layer Suitable for use cases requiring wide area coverage, deep indoor & mobility, IoT Low throughput / capacity due to narrow bandwidth, <20 MHz DL per operator NR to provide shorter latency than in LTE-A
Mid-bands	1.8 GHz to 6 GHz	Urban coverage layer (eMBB, indoor, massive IoT) Existing mobile bands used 2G, 3G, 4G Suitable for use cases requiring indoor coverage and mobility, massive IoT 2600MHz TDD (n41) consists of 190MHz and a 100MHz wide channel can be deployed C-Band 3.3-4.2GHz is the key capacity band for 5G Flexible for many use cases with higher throughput, wider spectrum Target 100MHz wide per operator assignments, 100MHz wide channel Latency: <3ms RTT at 3.5GHz
High bands	> 24 GHz	Extreme capacity layer (eMBB, FWA, URLLC, backhaul) Potential large band availability, highest throughput, target 800MHz wide per operator assignment, 400MHz wide channel Limited coverage, but compensated with Massive MIMO Latency <1ms RTT at 26GHz

Source: Coleago

New frequency bands that typically have not been previously used for mobile broadband include 3.3 to 4.2 GHz and mm wave bands at global level, and 2300 MHz and 2600 MHz in some countries e.g. Region 3. In the mm wave 5G-New Radio has been standardised in 24-28GHz and will become available in even higher frequencies 40GHz and 66-71 GHz in the future. Below 1 GHz 5G will first appear in 600MHz (North America) and 700 MHz.

With new spectrum for 5G, the amount of spectrum used by mobile operators to satisfy the growth in mobile data will double from current levels.

In Region 3 (Asia Pacific) depending on the country, in 2019 mobile operators use around 525 MHz of spectrum. By 2021, once spectrum in C-band , 2300 MHz and 2600 MHz frequency bands is assigned, the spectrum used by mobile operators will have increased to 1,155MHz i.e. more than double the amount used in 2019, see Exhibit 3 below.

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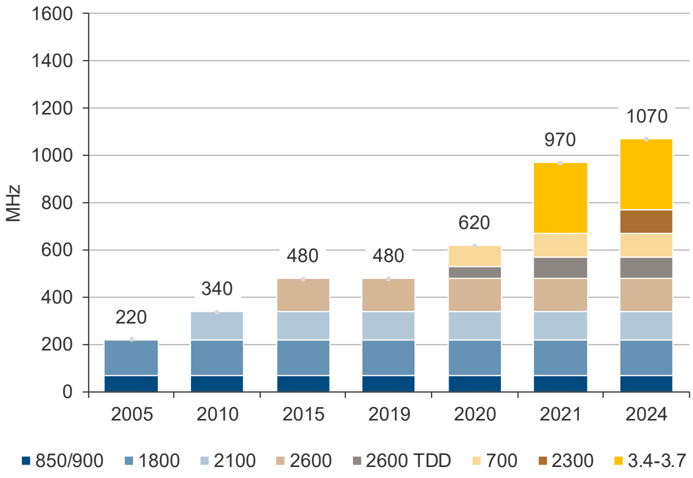
Exhibit 3: Typical spectrum allocated to mobile in Asia



Source: Coleago

One of the most important bands in the context of deploying 5G is the C-Band (3.3-4.2GHz).

One of the most important bands in the context of deploying 5G is the C-Band (3.3-4.2GHz) and there are already 3GPP standardised radios and terminals available. Band N77 is specified as a TDD band and covers 3.3 to 4.2 GHz and N78 covers 3.3 to 3.8GHz. The width of the band - 400 MHz in Europe - means that this is the first mid-band in which a channel width of 100MHz – a 5G innovation - can be used. The importance of the 3.4-3.8 GHz band for 5G is recognised by the European Commission (Commission Implementing Decision (EU) 2019/235 of 24 January 2019). Rolling out 5G in the C-Band is an overriding policy objective.

2600MHz and 2300MHz have also emerged as 5G candidate bands in some countries. The 2600MHz band has been assigned in several markets as FDD (Band 7) and separately the centre gap as TDD (Band 38). Regulators are now looking at licencing the band as TDD (Band n41) because it would provide a 190MHz wide band and 3GPP 5G-NR specification include a 100MHz wide channel, which matches that of Band n77. China, USA, Philippines and Saudi Arabia have committed to this and regulators in Thailand, Myanmar, Sri Lanka, India, Nepal are looking at this option. 2300MHz TDD (Band n40) is 100MHz and the 3GPP specification includes an 80MHz wide channel.

700MHz has been labelled a 5G candidate band in the sense that in ITU Region 1 (Europe and Africa) it is likely to be used as the first 5G coverage layer. However, 700MHz (3GPP band 28) is already widely deployed in Asia, Australia, New Zealand, and Latin America as a 4G (LTE) coverage layer. In time, the 700MHz band will be refarmed to 5G. In the US and Canada the 600MHz band is the equivalent to 700MHz in Region 1.

Several countries in South East Asia and Latin America have yet to assign the 700MHz spectrum to mobile operators. Once it is assigned in these countries, the mobile operators there will install the latest technology. The most recent radios are multi-mode and allow for Dynamic Spectrum Sharing, i.e., they support 4G and 5G. For example, an operator who obtains 2x10MHz of 700MHz spectrum might initially use the full 2x10 for 4G and gradually switch the spectrum to 5G. If the 700MHz assignment is delayed, then operators might go straight to 5G. The timing of this decision depends on technology diffusion among the customer base i.e. the market.

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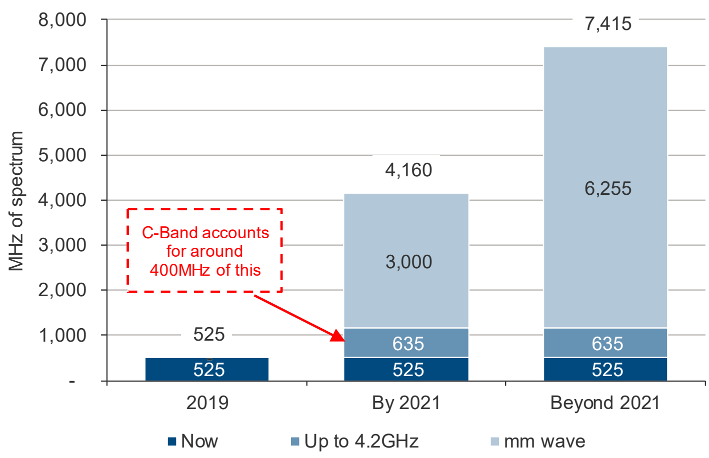
One of the benefits of 5G is that the 3GPP standards extend into much higher frequency ranges i.e. the mm wave range, including 26GHz, 28GHz and 39GHz with a channel bandwidth of up to 400MHz. There are no 4G standards for these bands and therefore default mobile deployment will be 5G. Adding mm wave spectrum will increase the spectrum used by mobile operators by up to 6000MHz, i.e. dwarfing the amount of spectrum deployed by mobile operators as of 2019.

In order to deliver 5G, mobile operators must have access to all three categories of spectrum - low, mid and high band - because each category has particular characteristics.

In order to deliver 5G, mobile operators must have access to all three categories of spectrum - low, mid and high band - because each category has particular characteristics as shown in Exhibit 2 above. Regulators must adopt policies which make it possible for mobile operators to acquire new spectrum at a price which does not destroy the business case for 5G. In other words, spectrum pricing must be sustainable in the context of the reality of the market.

Exhibit 4: Growth in mobile spectrum use associated with 5G



Source: Coleago

Existing frequency bands below 3 GHz will be gradually refarmed. Ultimately this will include all existing bands but refarming will start earlier in some bands and later in others. Not only will different bands be refarmed at different times, but even within a particular frequency band refarming will be gradual. This was the case when 4G was introduced in 1800MHz: Initially MNOs refarmed 2x5MHz to LTE while running 2G in the remainder of their 1800MHz spectrum holdings.

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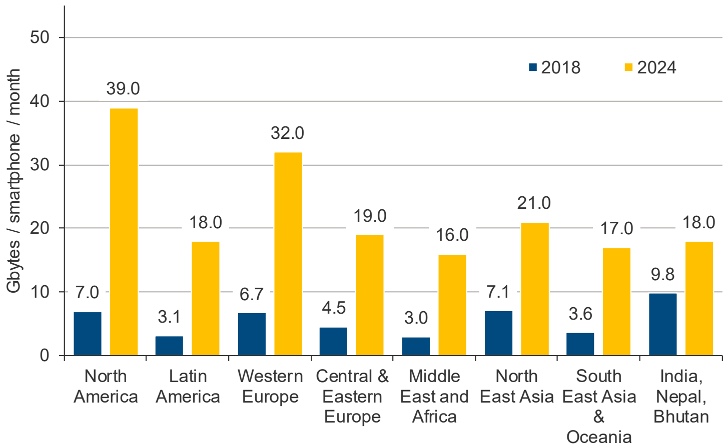
3 The business case for 5G

3.1 Investment in mobile broadband and 5G

Depending on the country, monthly usage per smartphone will increase by 3 to 6 times, provided more spectrum and 5G is deployed.

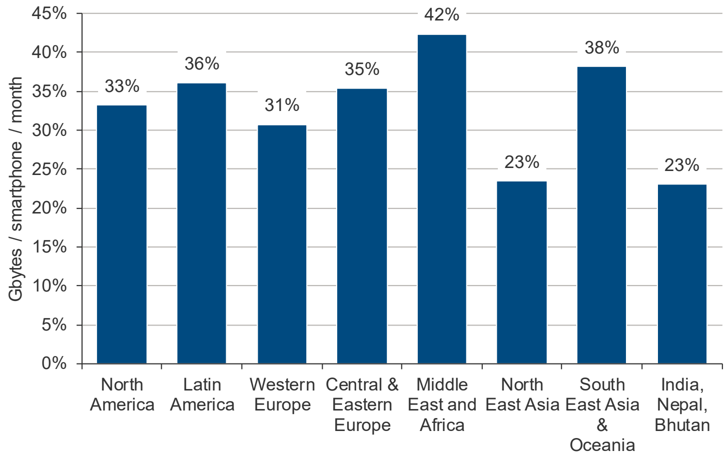
Mobile broadband traffic grew close to 88% between Q4 2017 and Q4 2018[3]. The trend points to an even steeper increase driven by the adoption of 4G and soon 5G smartphones as well as the increasing data usage per smartphone. Exhibit 5 shows the forecast average monthly traffic per smartphone between 2018 and 2024. Depending on the country, monthly usage per smartphone will increase by 3 to 6 times, provided more spectrum and 5G is deployed. At the same time smartphone adoption will increase, particularly in emerging markets leading to large mobile broadband traffic increase in all mobile networks. Exhibit 6 shows a Compound Annual Growth Rate of 23 to 42% over the next 6 years.

Exhibit 5: Monthly data traffic per smartphone



Source: Ericsson Mobility Report, June 2019

Exhibit 6: Total mobile data traffic compound annual growth rate 2018-2024



Source: Ericsson Mobility Report, June 2019

[3] Ericsson Mobility Report, Q4 2018

Over the next 10 years per user traffic could grow to 100Gbytes per month i.e. 40 times more than the per user traffic in most markets. This is based on evidence from Finland where already over 35% of households are mobile broadband only. In 2018 average monthly consumption per smartphone user amounted to around 21 Gbytes. Monthly data volumes for substitutional users are approaching DSL / fibre broadband consumption.

Mobile operators are ramping up investment to cater for the surge in mobile broadband traffic.

To cater for this growth, operators are continuing to invest large sums in 4G and 5G radio access networks and backhaul infrastructure. Between 2018 and 2020 mobile network operators world-wide are investing US$ 480 billion in their 4G and 5G networks, i.e. around US$ 160 billion per year[4]. The vast majority of this investment is in the radio access network (RAN), notably cell sites, 4G / 5G radios, and backhaul. Investment in 5G is already under way, even in markets where the launch of 5G will take place a little later. Most 4G RAN investment currently taking place is software upgradable to 5G. Preparing for the launch of 5G, several operators started to deploy Massive MIMO in combination with three-carrier aggregation thus delivering Gbit/s speeds.

2019 saw the first launches of standards based 5G. However, the transition to 5G requires further significant infrastructure investment. Deutsche Telekom CEO Timotheus Hoettges estimated the cost of providing 5G networks in Europe at € 300-500 billion (US$487.2 - US$811.9 billion) and Sprint's CEO Marcelo Claure stated at this year's Mobile World Congress that in the US operators will invest US$275 billion in their networks. On top of the huge network capital expenditure operators need to acquire new spectrum below 1 GHz, in 2GHz to 4GHz and in mm wave bands.

A 5G mobile network is different from a traditional mobile network which has relatively large cell sites. A 5G network will have many more small cell sites because of 5G carried on higher frequencies. Estimates as to the number of 5G cells required vary greatly, but over the next ten years the number of outdoor cell sites in networks in advanced markets may increase by a factor of three - and more if indoor solutions are included.

The deployment of many thousands of 5G cells, for example on street furniture, requires an unprecedented investment in fibre and will push up network operating costs. A calculation by The Fiber Broadband Association of the US illustrates the size of the required investment: In an urban environment it will take eight miles of fibre cable per square mile to connect small cells. The largest 25 metro areas in the US cover 173,852 square miles which means that to provide 5G coverage will require around 1.4 million miles of fibre cable. Validating this analysis, Verizon stated in a press release in April 2017 that it will purchase from Corning up to 20 million kilometres (12.4 million miles) of optical fibre each year from 2018 through 2020, with a minimum purchase commitment of $1.05 billion. .

On the positive side, operators will find some savings as they move to virtualised networks and increase infrastructure sharing. However, operating a mobile network with a factor increase in the number of cell sites presents a network operating cost challenge

3.2 Flat revenues

The investment in the new technology comes at a stage of the mobile industry lifecycle when revenues are declining.

The investment in the new technology comes at a stage of the mobile industry lifecycle when revenues are declining in many markets. In markets where there is revenue growth, this tends to be below inflation, i.e. revenue is declining, as evidenced by research from Bank of America Merrill Lynch: *Globally, average mobile service revenue contracted 1.0% from a year ago as Emerging Markets and Developed Markets service revenue both declined. Revenue in developed markets declined -1.3% overall, with Asia-Pacific down 1.9%, Developed EMEA down 1.9% and North America*

[4] The Mobile Economy in 2019, GSMA

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down 0.7%. Emerging markets service revenue declined 0.7% in 4Q18 vs. last year's growth of 3.1% with Emerging Asia declining 2.5%, Emerging EMEA growing +3.0%, and Latin America expanding +1.6%.[5]. In some markets revenues declined substantially, driven by competition. India is an extreme example of this where revenues declined by 14% in 2017.

But are there additional revenues to be had from 5G mobile broadband? Mark Allera, CEO Consumer, BT Group commented in March 2018: "*We will have to assume that consumers and businesses will be prepared to pay a little bit more for faster, higher quality access to the internet …… getting some sort premium out of 5G as we did for 4G.*" In other words there is little or no revenue upside from enhanced mobile broadband (eMBB) which will account for the vast majority of 5G traffic.

However, most operators did not gain additional revenue from 4G compared to 3G. For example, when Vodafone India launched 4G, customers with 4G devices and a 4G SIM received 2 GB of data for the same price that 3G customers pay for only 1 GB of data. Vodafone's revenue did not increase but as a result of Vodafone's investment in 4G customers see a 50% reduction in the price per GB of mobile data.

The evidence from 5G tariff plans shows that not only will consumers not pay more but they will also get larger data buckets and faster speeds.

A similar trend can be observed for 5G vs. 4G tariff plans. The evidence available so far shows that some operators attempted to launch 5G at premium price, but quickly abandoned this. Prices for 5G packages are not only not higher than for 4G, but also offer larger data volumes and of course high download speeds. In April 2019, mobile operators in Korea announced tariffs for 5G mobile. Depending on the tariff plan, in some instances 5G plans are cheaper than 4G plans. In early 2019 AT&T in the USA announced a 5G plan at rate of US$ 4.67 per GB compared to US$ 5 per GB for 4G.

Exhibit 7: 5G vs. 4G data pricing in Korea

	Package Type	5G			4G		
		Tariff KRW	Data pack	Limit after out of pack	Tariff KRW	Data pack	Limit after out of pack
LGU+	Entrance	55,000	9GB	1Mbps	55,900	6.6GB	3Mbps
	Middle	75,000	150GB	5Mbps	74,800	16GB	3Mbps
	High	85,000	Unlimited	Unlimited	88,000	30GB	3Mbps
	Premium	95,000	Unlimited	Unlimited	110,000	40GB	3Mbps
SKT	Entrance	55,000	8GB	1Mbps	50,000	4GB	5Mbps
	Middle	75,000	150GB	5Mbps	69,000	100GB	5Mbps
	High	95,000	Unlimited	Unlimited	79,000	150GB	5Mbps
	Premium	125,000	Unlimited	Unlimited	100,000	Unlimit.	n/a
KT	Entrance	55,000	8GB	1Mbps	49,000	3GB	1Mbps
	Middle	80,000	Unlimited	Unlimited	69,000	100GB	5Mbps
	High	100,000	Unlimited	Unlimited	89,900	Unlimit.	5Mbps
	Premium	130,000	Unlimited	Unlimited	n/a	n/a	n/a

Source: Operator websites

Will mobile operator gain additional revenue from the Internet of Things (IoT)? The IoT market is projected to grow significantly, but more than 80% of the IoT market are services other than connectivity. These services, which by and large are not provided by mobile operators, include applications, platforms and services such as cloud data analytics and security, as well as professional services such as systems integration, consulting and managed services. Connectivity, i.e. mobile data, accounts for only a small part of the IoT revenue stack.

[5] Bank of America Merrill Lynch, Global Wireless Matrix, 30 April 2019

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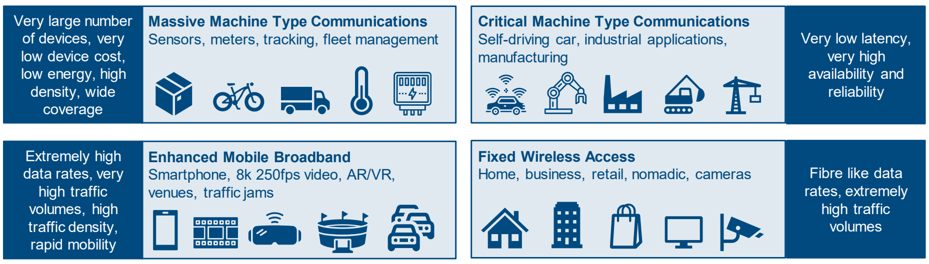
While the IoT market is promising, connectivity revenue may only add around 5% to revenue. This view is supported by the excellent statistics gathered by the French regulator shows that in 2011 IoT (M2M) SIMs accounted for 4.9% of all SIMs and 0.4% of revenue. By the end of 2018 IoT SIMs had grown to 19.5% of all SIMs but IoT revenue was a tiny 1% of total mobile service revenue. Furthermore, this small revenue slice also has to pay for investment in IoT optimised networks such as LTE-M and NB-IoT. Because future cash flows from IoT will be small, they cannot support the business case for high spectrum fees.

While the IoT market is promising, connectivity revenue may only add around 5% to revenue.

Of course 5G is a technology platform which opens up opportunities beyond enhanced mobile broadband, including serving the so called “verticals”, smart cities, autonomous vehicles and robotics. Connectivity is the glue of the 4th industrial revolution. The amount of data generated by millions of sensors and other devices opens up opportunities in the application of AI services. However, this is where the business case becomes rather uncertain and mobile operators are unlikely to be the main beneficiaries from this. Big investment bets, including investment in spectrum, will not be driven by business cases with a highly uncertain revenue potential.

The evidence is clear: With no growth in revenue, continuing high levels of capital expenditure and growing network operation expenditure the business case for 5G is finely balanced. For operators the introduction of 5G is not primarily about new revenue but it is necessary to bring down the cost per bit, given the massive growth in data traffic.

Exhibit 8: 5G use cases



Source: ITU, Huawei, Ericsson, Coleago

3.3 Mobile operator revenue per MHz of spectrum is declining

Some regulators believe that more spectrum results in increased revenue. While this was true during the growth stage of the mobile industry life cycle, it is no longer the case. In most markets around the world, revenue generated per MHz of spectrum deployed has declined over the period 2007 to 2019. For example:

In most markets around the world, revenue generated per MHz of spectrum deployed has declined over the course of the previous 10 -12 years.

- In Canada mobile market revenue per MHz declined from CN$81 million in 2007 to CN$33 million in 2019 – a 60% decline.
- In France over the same period revenue per MHz dropped from €52 million to €21 million – a 59% decline.
- In Germany between 2007 and 2018 revenue per MHz declined from €63 million to €25 million, a 60% decrease. Once the c-band spectrum auction currently under way concludes, revenue per MHz of spectrum will be down to €17 million, bringing the 2007-2019 decline to a steep 72%.
- In Singapore mobile market revenue per MHz declined from SG$9.4 million in 2007 to SG$4.5 million in 2019 – a 52% decline.

The evidence is clear: Incremental spectrum does not generate incremental revenue.

Additional spectrum may produce some cost savings, however the effect is relatively small because mobile data traffic increases rapidly. Savings as a result of having access to more spectrum are offset by investment to deploy additional radios and backhaul capacity.

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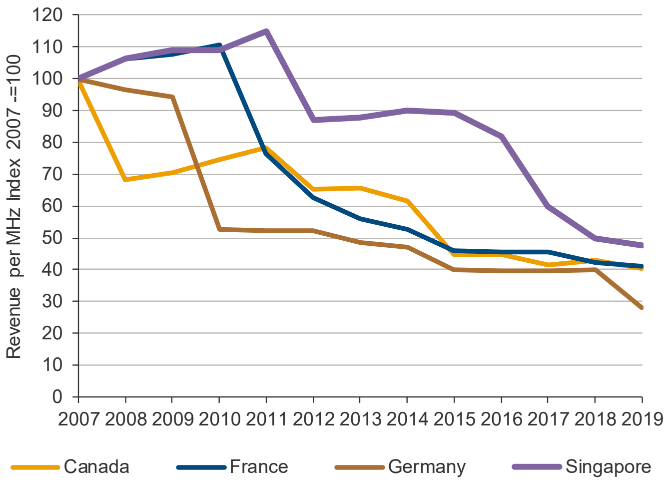
Exhibit 9: Mobile industry revenue per MHz of spectrum deployed



Source: Coleago

3.4 Spectrum for 5G capacity

As explained above, mobile operators will use several times more spectrum in the transition to 5G than they currently use to cope with the increase in data traffic. For example, in the C-Band (3.3-4.2 GHz) most countries have or will assign at least 400MHz. On top of the C-Band new low and mid-band spectrum will be added. Depending on where countries are on their spectrum roadmaps this has double or will double of the amount of spectrum deployed by mobile operators.

The ITU's 5G design calls for the ability to serve 10 Mbit/s per square meter. The combination of 5G New Radio and additional spectrum will make it possible to serve high traffic densities in urban areas. Indeed, the 5G business case is mainly about catering for high traffic densities rather than any new revenue streams or a new business model.

Additional spectrum generates a consumer surplus, but not a producer surplus. Since there is no producer surplus, it is not economically feasible to extract substantial incremental fees for the use of new spectrum.

As explained above, given that revenue will increase only very slightly or not at all, revenue per MHz of spectrum deployed will half during the next two years. In economic terms, the deployment of the C-Band and other new spectrum for 5G does not deliver a producer surplus but instead it delivers a significant consumer surplus. The consumer surplus arises because data volumes are increasing while users do not pay more. Therefore users get vastly better value for money in terms of the price paid per Gbyte of traffic. This is simply the continuation of a by now familiar trend in digital services and products to offer ever better capabilities while the cost of ownership to users does not increase.

Th economics are straight forward. New spectrum is not generating additional producer surplus and therefore it is not economically feasible to extract substantial incremental fees for the use of new spectrum.

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4 Sustainable level of spectrum pricing

4.1 5G policy objectives and spectrum pricing

Policy makers must provide a clear direction to the regulator as to the policy objective in a spectrum auction. All spectrum, if used for 4G and now 5G mobile broadband, fosters the development of a country. Hence, a development policy objective is appropriate. This might direct a regulator to assign as much spectrum as possible, as quickly as possible and as cheaply as possible. Broadly this is the policy adopted in Finland and Sweden, markets in which consumer benefit from excellent mobile broadband services and low prices.

Some countries suffer from a large budget deficit and most developing countries suffer from a thin tax base. Extracting money from the sale of spectrum licences can make a useful contribution to public finances. In the past, some countries succeeded in extracting large amounts of revenue from the sale of spectrum and yet operators still invested in their networks. However, as explained above, revenue is no longer growing and yet continued high levels of investment as well as more spectrum are required to bring about the transition to 5G. Governments need to be mindful of two aspects:

- There is a trade-off between a 5G development objective and extracting cash from the sale of spectrum.
- The ability to extract cash from the sale of spectrum is constrained by the need for mobile operators to have a viable business case for investment in spectrum and 5G.

The ability to extract cash from the sale of spectrum is constrained by the need for mobile operators to have a viable business case for investment in spectrum and 5G.

Let's look at the business case for investment in spectrum and 5G. Exhibit 10 below illustrates the way cash flows through a mobile operator business.

- The mobile operator business case, like any business case, starts with revenue. Revenue is the limiting factor, because it is linked to customers' willingness and ability to pay for mobile services.
- Out of revenue operators have to pay operational expenditure (OPEX) such as network running costs, staff costs, annual spectrum fees (if any) and other government fees. Revenue minus OPEX produces a measure of profit referred to as Earnings Before Interest, Depreciation and Amortisation (EBITDA). EBITDA is essentially the cash generated from operations, but before capital expenditure (CAPEX).
- CAPEX is the investment in physical assets such as radios and towers (tangible CAPEX) and also spectrum assets (intangible CAPEX). EBITDA minus CAPEX is the cash generated by the business (simple free cash flow).
- Operators also pay corporation tax, i.e. there is a further cash outflow.
- Revenue minus operational expenditure, minus corporation tax, and minus capital expenditure is a measure of cash generated by a business, also referred to as free cash flow[6]. From this cash investors can be paid, i.e. lenders receive interest and shareholders receive dividends.

[6] Free cashflow also includes other adjustments such as changes in working capital but these are not material.

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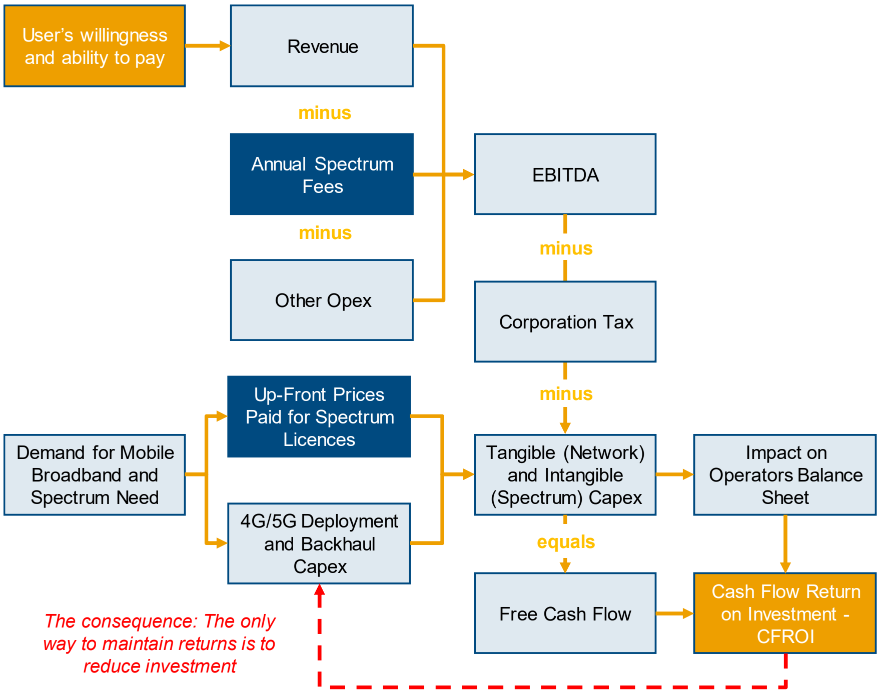
Exhibit 10: Spectrum licence fee impact on network investment



Source: Coleago

If prices for spectrum needed to deploy mobile broadband in form of 4G and 5G are high, the 5G business case is unlikely to workable.

For investment to take place there must be a return on investment. Payments to lenders and shareholders represent the return on investment. If those returns fall to a level below that of investment opportunities with similar risks, it no longer makes sense to invest in the mobile business. Let's assume there is a large cash outflow to pay for a spectrum licence fee following a spectrum auction. Despite this, operators still need to generate cash to compensate investors or they would not be able to finance the investment in spectrum and network. The only lever operators have is to reduce tangible capital expenditure, i.e. invest less in the network to bring the overall capital expenditure to a level that can be financed. In short, if prices for spectrum for 4G and 5G are high, the 5G business case is unlikely to workable. Therefore a revenue extraction objective is not sustainable in the context of 5G.

The question of sustainable spectrum pricing is not theoretical. In some countries, due to excessive spectrum prices, the business case for further 4G related spectrum investment no longer makes sense. In India, Bangladesh, Ghana, Mozambique and several other countries spectrum pricing became unsustainable and held back 4G deployment. For example, India and Bangladesh which have a revenue extraction objective set spectrum auction reserve prices based on previous spectrum sales or benchmarks, but found that at that this level of spectrum pricing is not sustainable:

- In the spectrum auction of October 2016, India did not sell any of the 700MHz spectrum on offer because reserve prices were unsustainable from a business case perspective.
- In Bangladesh 66% of spectrum on offer in the 2018 auction remained unsold leaving spectrum auction revenue 65% below target.

Not only did India and Bangladesh fail in their revenue raising objectives but it also means that mobile broadband users experience lower speeds and in the case of India less rural broadband access. Getting 5G spectrum pricing wrong risks being left behind in 4th industrial revolution.

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4.2 Critique of benchmarking spectrum prices

Many regulators use benchmarking to determine the reserve price or the price for an administered assignment or renewal. They look at prices paid in other countries in terms of $ / MHz / per head of population and make adjustments, for example for differences in per capita GDP. India's regulator benchmarks reserve prices against what prices were paid for spectrum in previous auctions in India.

Using benchmarking to set reserve prices is not appropriate because it is backward looking rather than forward looking.

Using benchmarking to set reserve prices is not appropriate because it is backward looking rather than forward looking. The evidence in Exhibit 9 above shows that mobile operator revenue per MHz of spectrum has declined by over 50% in the past. In other words, spectrum acquired in the past generated more revenue than spectrum acquired more recently. Adding the C-Band to an operator's network will not increase revenue materially, but it will enable operators to compete with higher data bundles while ARPU does not change. Clearly if each additional MHz of spectrum deployed for 5G yields little or no additional revenue, then one cannot compare the current situation with the past. Put simply, the business case is very different. This is why it is fundamentally wrong to use prices paid for spectrum in the past to estimate the value to operators of additional spectrum for 4G or 5G mobile broadband.

Of course benchmarking was always a dubious method to estimate the value of spectrum to operators in a particular market. Benchmarking lacks objectivity as is apparent from the debate on how benchmarks should be adjusted and used. Benchmarking is fundamentally flawed because the value of spectrum in a particular set of circumstances says nothing about the value of spectrum in another set of circumstances.

4.3 The annualised cost of spectrum methodology

When new spectrum is assigned or existing spectrum licences are renewed, the question arises of how to price the spectrum. If there is a spectrum auction, regulators need to set the reserve price, i.e. the minimum price or opening bids. If spectrum is assigned administratively or licences are indefinite, then regulators have to set the price without the benefit of a market based mechanism such as an auction.

As explained above, spectrum price benchmarking is a flawed methodology which is likely to lead regulators to set unsustainably high prices for spectrum. The result of overpriced spectrum are failed spectrum auctions or a delayed or slow deployment of 4G and 5G. There is a simple solution to avoid these pitfalls. Regulators can assess the sustainability of spectrum pricing in their market by looking at the *annualised cost of spectrum as a percentage of mobile operator revenue*.

Regulators can assess the sustainability of spectrum pricing in their market by looking at the annualised cost of spectrum as a percentage of mobile operator revenue.

Depending on the country, the calculation of the annualised cost of spectrum can include one or two elements:

- An up-front spectrum licence fee for a 15 or 20 year licence which tends to be substantial. This is usually the outcome of a spectrum auction but in some cases is simply the same as the (rather high) spectrum auction reserve price. The annual equivalent cost of an up-front spectrum fee can be calculated using an annuity formula. The annuity formula takes account of the amortisation of the licence, i.e. it only lasts 15 or 20 years, and the cost of capital to finance the up-front spectrum fee.
- Some countries charge an annual spectrum licence fee instead of an up-front fee. For example, in the UK after the expiry of the initial licence term operators pay an annual fee set by the regulator. In the recent spectrum auction in Indonesia operators bid an annual fee instead of an up-front fee. In Mexico an annual spectrum fee is set by law with and an additional up-front fee is determined through an auction process.

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Some countries have additional fees. For example India has a so called "Spectrum Usage Fee". However this is a misnomer because it is in effect a tax on revenue rather than a spectrum fee. This is explained in chapter 6 below. Most countries also have an annual spectrum administration fee, purely to cover the regulator's cost of spectrum management. This is not a spectrum licence fee, but simply a cost based charge paid by all spectrum users. Usually this is a relatively small amount compared to a spectrum licence fee and can be ignored when looking at the cost of spectrum to operators.

It is easy to convert an up-front spectrum fee into an annualised cost of spectrum. The annual cost of spectrum to mobile operators is calculated at industry level. The information required is readily available to regulators:

- Prices paid for spectrum in past auctions in the country;
- The licence durations in years;
- The cost of capital to operators, a metric obtained from the operators in the market or investment banks; and
- The total mobile market revenue in the current and the trend for the next 5 years.

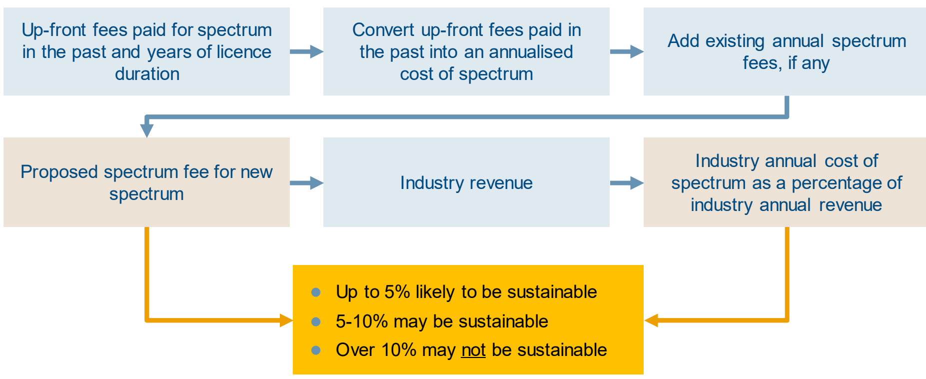
The up-front fee paid for spectrum can be used in a standard annuity formula which translates the up-front fee into an equivalent annual cost of spectrum, i.e. the annualised cost of spectrum.

The up-front fee paid for spectrum can be used in a standard annuity formula which translates the up-front fee into an equivalent annual cost of spectrum, i.e. the annualised cost of spectrum. Fees paid for spectrum in the past need to be financed by loans or by shareholders. Interest has to be paid on loans, i.e. this is a cost. Over the term of the licence, for example 20 years, the cost of the spectrum licence which sits on the operators' balance sheet is amortised, i.e. each year 1/20% is passed as a cost though the income statement. These two elements are used to convert an upfront annual fee into an annual equivalent, i.e. the annualised cost of spectrum.

As mentioned above, in some markets there are also annual spectrum fees. These fees need to be added to the annualised cost of upfront spectrum fees to obtain the total annual cost of spectrum. The total annual cost of spectrum can then be compared with the annual industry revenue.

The annualised cost of spectrum methodology provides a single metric which allows regulators to compare the price of spectrum relative to the size of the mobile industry in their country. The key advantage of this approach is that it is forward looking rather than using benchmarks from past auctions. Using the annualised cost of spectrum methodology, regulators can look at their spectrum assignment roadmap and assess what level of spectrum pricing would be sustainable in the context of the mobile industry in their market. The "annualised cost of spectrum as % of revenue" metric makes it easy to identify excessive spectrum fees and communicate this to a non-expert audience, such as the ministry of finance or politicians.

Exhibit 11: Gauging the sustainability of fees for new spectrum



Source: Coleago

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Exhibit 12: Annuity calculation formula

The annuity calculation formula to convert up-front spectrum fees into an annualised cost of spectrum
Annualised cost = Up-front spectrum fee x cost of capital / (1 - (1 / (1 + cost of capital)) ^ years of licence term)
Note: The cost of capital is the weighted average cost of capital (WACC), a figure also used for regulatory cost accounting and hence available to regulators

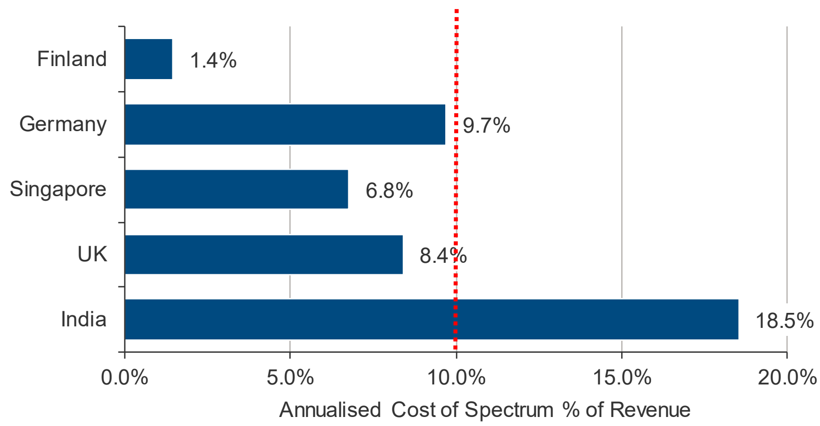
Source: Coleago

Coleago has calculated the annualised cost of spectrum in a sample of countries as shown in Exhibit 13. Based on mobile industry service revenue the annualised cost of spectrum in Finland was 1.2%, in Germany 9.7% of revenue, in Singapore 6.8%, in the UK 8.4%, and in India 14.8%. Detailed calculations are provided in Appendix A.

- A cost of spectrum of up to 5% is unlikely to slow down investment in mobile broadband and 5G. The evidence from Finland (see chapter 5.5) indicates that a lower percentage is likely to deliver better outcomes for 5G deployment.
- In many well developed 4G mobile broadband markets the annualised cost of spectrum is 5-9% of mobile operator service revenue as illustrated by the example from Singapore, Germany and the UK. This indicates that below 10% the annualised may not have material negative impact on network deployment.
- When the cost of spectrum amounts to 10% of mobile operator service revenue, mobile operators may hit budget constraints, i.e. investment in mobile broadband and 5G is likely to be slower than it otherwise would be. A cost of spectrum above 10% of revenue presents a threat to the development of 5G.

When the cost of spectrum amounts to 10% of mobile operator service revenue, mobile operators may hit budget constraints, i.e. investment in mobile broadband and 5G is likely to be slower than it otherwise would be.

Exhibit 13: Annualised cost of spectrum % of revenue, selected countries



Source: Coleago

Good policy makers understand that the socio-economic benefit of mobile broadband is far greater than spectrum licence fee revenue could possibly generate.

- Finland has a clear policy of minimising spectrum fees instead seeks to incentivise operators to invest in the network. The annualised cost of spectrum in Finland is only 1.2% of mobile operator revenue. This has resulted in Finland being on top of the mobile broadband league table in terms of per SIM mobile date usage download speeds.
- Germany and Singapore are well regulated telecoms markets with a high level of transparency and have very similar spectrum costs. Revenue maximisation from the sale of spectrum is not a policy objective.

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4.4 Avoiding spectrum auction failure

In India, revenue maximisation was an objective for the 2016 spectrum auction. The Indian regulator, TRAI, used benchmarking to set reserve prices but failed to sell most of the spectrum and the auction only generated 11.6% of the targeted revenue. This bad outcome could have been avoided if TRAI had used the annualised cost of spectrum methodology instead of benchmarking to set reserve prices.

- Prior to the October 2016 auction for 700, 850, 900, 1800, 2100, 2300 and 2500MHz spectrum the annualised cost of spectrum based on 2016 revenue stood at 12.1%. This is a high figure, particularly given other high taxes on the mobile industry in India.
- At the end of 2016 spectrum auction, the figure had risen to 14.8% based on 2016 mobile industry revenue. Mobile operators started to struggle. Rcom become insolvent while Vodafone and Airtel sought to reduce costs by merging their businesses.
- Due to excessive reserve prices in the 2016 spectrum auction, much of the spectrum remained unsold including all of the 700MHz spectrum. Had all the spectrum been sold at the reserve price, the annualised cost of spectrum would have increased to 34.6% of 2016 revenue, a figure which is clearly not sustainable.
- Since 2016,mobile industry revenue in India has declined sharply, so that by 2018 the annualised cost of spectrum stood at 18.5% of revenue. This is well above a level that sustains investment in the industry. India is now gearing up to sell C-Band and 700MHz spectrum.

The 700MHz spectrum would have been useful to bring much needed mobile broadband connectivity, especially in rural areas but instead it lies fallow. Not only did the DoT generated a mere 11.6% of the revenue they aimed to raise but they also damaged India's digital development by preventing Indian mobile users from benefiting from the use of 700MHz spectrum. The situation is particularly regrettable, because following the announcement of the reserve price of the auction, in 2016 the GSMA sponsored Coleago to give a detailed presentation to the Department of Telecommunication (DoT) advising them that at the proposed reserve price none of the 700MHz would be sold.

Exhibit 14: Annualised cost of spectrum methodology vs. benchmarking

Benchmarking to set spectrum prices	Annualised cost of spectrum as a percentage of revenue method
✗ Requires large data-sets from other markets to be statistically significant	✓ Requires only data from the market in question
✗ Adjustments need to be made for GDP, exchange rates, licence duration, annual fees, renewal, coverage obligations and other factors; this introduces subjectivity	✓ Does not require any adjustment, it is entirely internal to the market
✗ Is backward looking, cannot cope with 5G evolution	✓ Is forward looking and takes account of spectrum roadmap
✗ Complex to produce	✓ Easy to produce
✗ Adjustments create a degree of arbitrariness	✓ Uses only data from the market in question and is objective
✗ Outputs from benchmarking exercise require interpretation: Should we benchmark against the arithmetic mean or the median? Should outliers be eliminated?	✓ The output is a single metric, namely the annualised cost of spectrum as a percentage of revenue, which is easily understood

Source: Coleago

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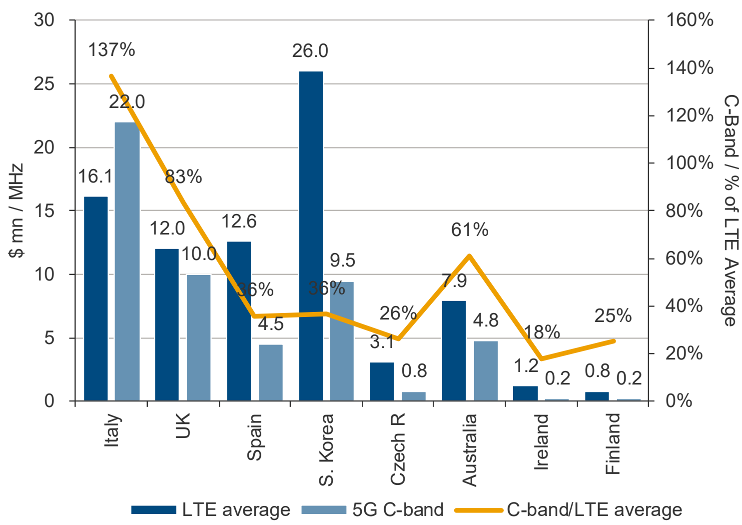
4.5 The spectrum price index

As explained above, the introduction of 5G will require a lot more spectrum but there is little if any incremental revenue. Therefore licence fees paid for spectrum associated with the introduction of 5G must be materially lower than fees paid for the introduction of 4G. Furthermore, 5G requires more spectrum than 4G, notably 100MHz or more per operator in the C-Band (3.3-4.2GHz). This means that on a per MHz basis spectrum fees for the C-Band spectrum must be much lower than prices paid for capacity spectrum associated with the introduction of 4G, such as 2600MHz spectrum.

In addition to the C-Band, spectrum for 5G also includes spectrum for 5G coverage, for example 700MHz (600MHz in North America) as well as mm wave spectrum for ultra high density traffic areas.

Given that mobile operator revenue is unlikely to increase by much and the substantial incremental capital expenditure associated by the deployment of 5G, notably many more cell sites, licence fees paid for spectrum associated with the launch 5G should be considerably lower than licence fees for spectrum associated with the launch of 4G. Exhibit 15 shows prices paid at auction for 4G related spectrum and C-Band spectrum. One average prices paid for C-Band spectrum are lower, but in some countries high C-Band prices are problematic.

Exhibit 15: C-Band prices vs. 4G related spectrum prices



Source: Industry data

Another way of looking at reasonableness of spectrum pricing, notably the C-Band, is to compute the Spectrum Price Index (SPI).

Looking at the ratio of prices paid for spectrum to launch 4G vs. prices paid for spectrum to deploy 5G is only part of the story. Another way of looking at reasonableness of spectrum pricing, notably the C-Band, is to compute the Spectrum Price Index (SPI). The SPI for 3G related spectrum is calculated by taking the total amount paid for spectrum associated with the deployment of 3G and dividing it by the number of mobile users and then by ARPU. The same methodology can be used for 4G and 5G related spectrum. The three charts below show the SPI for 3G, 4G and 5G for some countries and some conclusions can be drawn:

- The auctions for 3G related spectrum, chiefly 2100MHz, coincided with the dotcom boom and led to very high prices. Countries with an SPI above 6 experienced difficulties, including write down of licence fees, mergers which led to a lessening of competition, licences handed back without deployment and slower than expected 3G roll-out.

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- The SPI related to deploying 4G is lower in most cases. At the time of 4G related spectrum auctions, it had become clear that there were no material incremental revenues to be had. The big outliers in terms of 4G related spectrum pricing are India and Thailand. However, high prices led to much of the spectrum intended for 4G being unsold and the auction processes in Thailand do not deliver good outcomes for the much needed development of mobile broadband in Thailand.
- The SPI related to spectrum to support the deployment of 5G, notably the C-Band, is lower in most countries. An SPI above 2 may lead to slower than expected deployment or even unsold spectrum. Exhibit 18 shows Italy as an outlier. The C-Band auction in Italy was designed to maximise prices paid by withholding spectrum and packaging the spectrum in a manner designed to create auction distortion. Italy suffers from a very high budget deficit which motivated the revenue extraction policy. Consumers and business will pay the price from reduced competition in 5G services.

There is a correlation between a high SPI and failed spectrum auctions. Hence the SPI provides an additional check as to what level of spectrum pricing may be sustainable. We recommend using the SPI in addition to the annualised cost of spectrum methodology.

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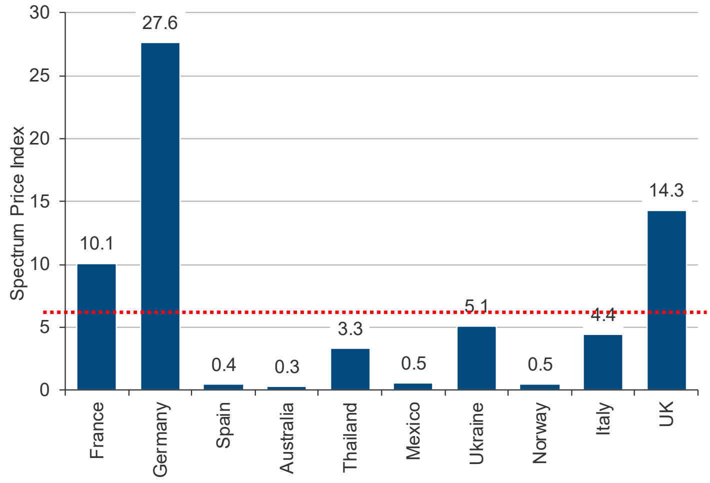
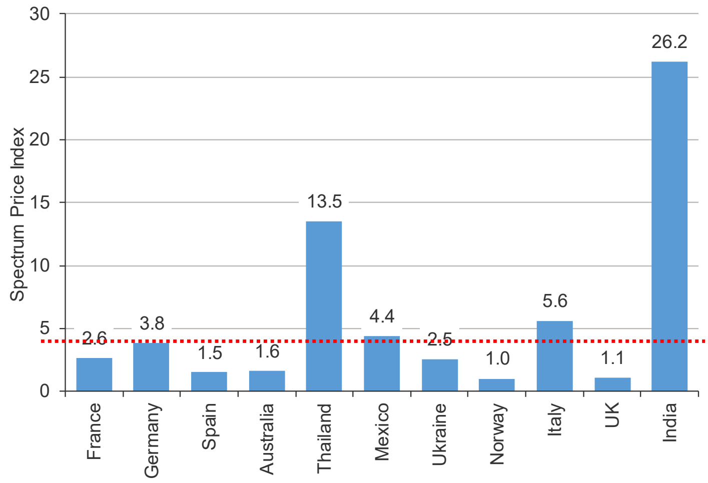
Exhibit 16: 3G Spectrum Price Index



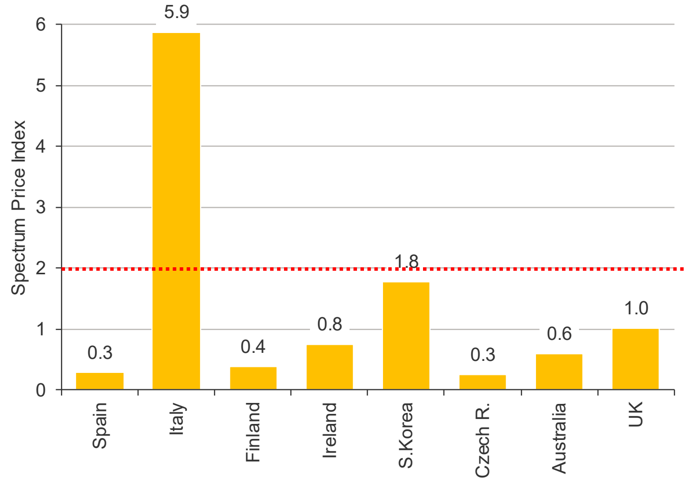
Source: Industry data

Exhibit 17: 4G Spectrum Price Index



Source: Industry data

Exhibit 18: 5G Spectrum Price Index



Source: Industry data

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5 Achieving sustainable spectrum prices

5.1 Per MHz spectrum fees must decline substantially

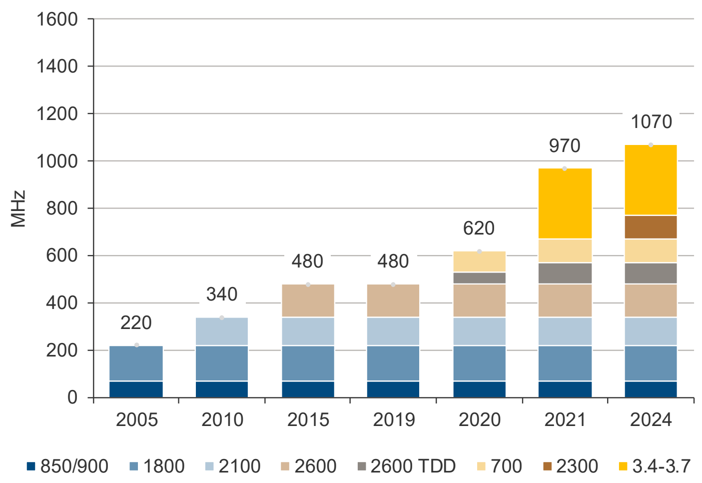
Many countries increased revenue for the sale of spectrum and may be tempted to do so in future. However, given that mobile operator revenue is flat, but more spectrum is required for 5G, notably the C-Band, per MHz spectrum licence fees need to decline substantially to ensure that the annualised cost of spectrum remains sustainable, i.e. that the cash paid out by mobile operators for spectrum licences does not delay or reduce 5G deployment.

Since mobile operator revenue is flat, but more spectrum is required for 5G, notably the C-Band, per MHz spectrum licence fees need to decline substantially to ensure that the annualised cost of spectrum remains sustainable

Exhibit 19 shows a worked example for a typical country. In the country 850MHz, 900MHz, 1800MHz, 2100MHz, and 2600MHz FDD had previously been assigned through an auction process. The country had a policy of driving up spectrum prices. The average price paid per MHz was US$ 1.7 million and the annualised cost of spectrum amounts to 9% of revenue as shown in Exhibit 20 below.

The spectrum roadmap envisages assignment of 2x45MHz of FDD spectrum in 700MHz (Band 28), 100MHz of TDD spectrum in 2300MHz (Band 40), and 300MHz of TDD spectrum 3400-3700MHz (Band n78).

Exhibit 19: Spectrum assigned and roadmap in typical country



Source: Coleago

Existing spectrum licences are expiring and the 2100MHz licences will need to be renewed in 2020, 850/900MHz in 2021, 1800MHz in 2023.

Mobile operator revenue declined slightly during the last two years and is expected to remain at its current level. A level of 9% of annualised cost of spectrum has been identified as the maximum sustainable level. In the worked example, this implies that the average per MHz licence fee needs to decline from $1.7 million to $ 0.8 million as shown in Exhibit 21.

Of course this does not mean that spectrum auction reserve prices should be pitched at that level, because the closer reserve prices are set to the maximum sustainable level, the greater the risk of auction failure, with some or all of the spectrum remaining unsold. Ideally reserve prices should be much lower than the maximum sustainable spectrum fee so that the market price is determined through the auction process. After all, if operators end up paying low prices for spectrum, in a competitive market this will either be passed on to mobile users in the form of lower prices or higher network investment.

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Exhibit 20: Historic annualised cost of spectrum

Auction date	Band Name	Type	Band #	MHz Sold	Price Paid $ Million	$ million per MMz	Licence Duration Years	Annualised Cost $ million
2006	850/900	FDD	5/8	70	260	3.7	15	30
2007	1800	FDD	3	150	180	1.2	15	21
2010	2100	FDD	1	120	280	2.3	20	29
2016	2600	FDD	7	140	90	0.6	15	11
Total				480	810	1.7		90
Cost of Capital (WACC)				%				8.0%
Annual industry service revenue				$ mn				1,000
Spectrum cost % of revenue				**%**				**9.0%**

Source: Coleago

Exhibit 21: Future annualised cost of spectrum

Auction or renewal date	Band Name	Type	Band #	MHz	Price $ Million	$ million per MMz	Licence Duration Years	Annualised Cost $ million
2016	2600	FDD	7	140	90	0.6	15	11
2020	2600	TDD	38	50	9	0.2	15	1
2020	700	FDD	28	90	170	1.9	15	20
2020	2100	FDD	1	120	113	0.9	15	13
2021	850/900	FDD	5/8	70	132	1.9	15	15
2021	3.4-3.7	TDD	n77	300	85	0.3	15	10
2023	1800	FDD	3	150	142	0.9	15	17
2024	2300	TDD	n40	100	28	0.3	15	3
Total				1,020	770	0.8		90
Cost of Capital (WACC)				%				8.0%
Annual industry service revenue				$ mn				1,000
Spectrum cost % of revenue				**%**				**9.0%**

Source: Coleago

5.2 Setting reserve prices in spectrum auctions

Spectrum auctions were initially introduced to deliver “efficient” use of spectrum and to ensure that the assignment process was transparent and objective. What do policy makers mean when they talk about “efficiency” in spectrum assignments? An efficient assignment of spectrum means assigning spectrum to those who generate the greatest economic value to society from the use of the spectrum.

- *“The key goal of any auction is to guide goods to those who value them the most. Spectrum auctions help identify the highest value use and users”.* New Zealand Ministry of Business, Innovation and Enterprise - May 2013

An auction also has the advantage of objectivity and transparency. Transparency is an advantage that auctions have over assignment by comparative tender (beauty contest).

When the first countries introduced spectrum auctions, the intention was not to maximise revenue from the sale of spectrum licences, but to achieve efficiency, transparency and objectivity. As is common in auctions, regulators set a minimum price for spectrum, also referred to as the opening bid or reserve price. The rationale for doing so is, at the very least, to cover costs. These costs are the costs of staging the auction and, if applicable, the cost of compensating incumbent users to free up the spectrum. A reserve price also guarantees that society receives at least some compensation from assigning spectrum rights to a private entities. Markets that have good mobile services tend to have set low but material reserve prices.

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Most importantly, if maximisation of revenue from the sale of spectrum is not an objective, regulators do not have to estimate the value of spectrum to operators. The point of an auction is to determine the value of spectrum. Therefore the reserve price should be a price at which the government can be confident that all spectrum put up for auction will be sold. After all, spectrum which is not sold is not put to use and spectrum that lays fallow does not generate any socio-economic value. Not selling all spectrum put up for auction indicates a failed auction.

Governments in some markets realised that spectrum sales can be a significant source of government revenues. The notion took hold in many emerging markets which suffer from a thin tax base such as India, Mozambique, Bangladesh and Ghana, and also some developed markets such as Italy and Greece where governments had a large budget deficit.

A study by Hazlett and Munoz showed that setting high reserve prices does not maximise the value of spectrum.

However, setting high prices for spectrum is problematic. In their 2010 research paper, "What Really Matters in Spectrum Allocation Design" Hazlett and Munoz showed that setting high reserve prices does not maximise the value of spectrum: *"[T]he ratio of social gains [is of] the order of 240-to-1 in favour of services over licence revenues…Delicate adjustments that seek to juice auction receipts, but which also alter competitive forces in wireless operating markets are inherently risky. A policy that has an enormous impact in increasing licence revenues need impose only tiny proportional costs in output markets to undermine its social utility. …In short, to maximise consumer welfare, spectrum allocation should avoid being distracted by side issues like government licence revenues."*[7]

Excessive reserve prices are the root cause of an increasing number of failed spectrum auctions, i.e. auctions where some or all of the spectrum put up for sale remained unassigned. In Asia-Pacific examples include India, Bangladesh, Thailand and Australia. In Africa excessive reserve prices led to failed auctions in Mozambique, Ghana, Senegal and Nigeria.

Regulators who are keen that their country is not left behind in mobile broadband and 5G should set reserve prices that guarantee that all spectrum is sold and that there is no distortion of competition. Reserve prices should cover the cost of holding the auction and, if applicable, the cost of moving incumbent users. They should not be set based on benchmarks of previous auction results.

5.3 Designing auctions to avoid damaging high final prices

In many auctions demand for spectrum significantly exceeds supply. Mobile operators may not always make the right decisions which can result in a situation where spectrum prices are so high that it leads to a shortage of cash among mobile operators who are then forced to cut back their capital expenditure. This leads to slow deployment of the new spectrum. In other words, the socio-economic benefit of spectrum is reduced or at least delayed.

While there is no guarantee that a spectrum auction will not lead to excessively high prices, there are steps regulators can take to reduce the probability of this outcome.

While there is no guarantee that a spectrum auction will not lead to excessively high prices, there are steps regulators can take to reduce the probability of this outcome:

- All available spectrum should be put up for auction. Prices in an auction are driven by demand for spectrum from operators and the supply of spectrum by the regulator. Holding back spectrum drives up prices and should be avoided.
- A spectrum auction can be viewed as a negotiation between bidders, answering the following questions: where do we settle, who pays how much and how much to we all pay? Of course this is only possible if bidders know on a round by round basis how much has been bid by which bidder for what block. This implies that the auctioneer should provide maximum information to bidders after each round of bidding to allow such quasi negotiation to unfold. This is the case in, for example, the USA and Germany.

[7] Hazlett and Munoz, "What Really Matters in Spectrum Allocation Design", 2010

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- Spectrum packaging, i.e. block sizes, should allow for an equilibrium outcome of a spectrum auction where each mobile operator has an opportunity to acquire a fair share of spectrum. This can be achieved by offering spectrum in 2x5MHz FDD or 10MHz TDD block sizes. This recommendation was not adopted in Italy, with likely negative consequences for 5G deployment the competition. In October 2018 in Italy, a market with four mobile operators, the C-Band spectrum was auctioned in two blocks of 80MHz and two blocks of 20MHz. The only possible outcome is that the two operators who obtain the 20MHz block are put at competitive disadvantage because deploying the C-Band in only 20MHz is not cost effective and does not deliver the highest access speed claim. As bidders tried not be left in a competitively disadvantaged position, the price per MHz per pop for C-Band spectrum Italy ended up being 5 to 10 times higher than the price paid in other European countries. Designing an auction to engineer a competitive imbalance will result in high prices but is detrimental to competition. To consider an extreme case, the highest price spectrum would be achieved by selling all spectrum to the highest bidder and kill competition.
- Regulators should avoid other distortions such as setting aside spectrum for specific purposes or a new entrant. Studies show that such measures distort auctions and result in inefficient spectrum assignment outcome and adverse socio-economic consequences [8]. For example, if spectrum is set aside for new entrants, this effectively means that new entrants are subsidised. This has been the case in Canada where subsequently the new entrant who acquired spectrum at a discount sold out to incumbent operators. Investors in the new entrant made a windfall profit from the set-aside spectrum and spectrum was deployed in a sub-optimal manner.

Even if regulators have a mobile broadband development objective rather than a cash extraction objective, a spectrum auction may inadvertently lead to spectrum licence fees which are so high that they pose a threat to the regulator's development objective. This situation occurred in the Czech Republic.

In March 2013 the Czech telecoms regulator (CTU), halted an auction for 800MHz, 1800MHz and 2600 MHz spectrum. The reserve price for all bands was CZK7.4 billion ($377m). When bidding reached CZK20 billion the CTU called a halt to the auction. The CTU was cognisant of the fact that if spectrum costs are too high, customers will suffer through higher mobile broadband bills and a slowdown of 4G network rollout. *"When announcing the conditions in the first half of last year, we stressed that the main motivation of the auction was the quick availability of a 4G network for Czech citizens and the possible entry of a fourth operator – never about profits for the state".* (Pavel Dvorak, Head of CTU). Following a rerun of the auction with different rules, the spectrum sold for CZK 8,529.5 million. This was just above the reserve and 57% below the CZK 20 billion reached in the first attempt to auction the spectrum.

5.4 Setting spectrum licence fees in an administered assignment

In an auction based spectrum assignment process licence fees are merely a means to an end, the end being a) efficient use of spectrum and b) transparency in the assignment process. Since in an auction raising revenue from the sale of spectrum is not an objective, in an administered spectrum assignment raising revenue does not need to be an objective either. However, the question arises how to price spectrum if there is no auction, i.e. no market based mechanism for spectrum assignment. There are several aspects which regulators can take into account to set an appropriate spectrum licence fee:

[8] The Cost of Spectrum Auction Distortions, Review of spectrum auction policies and economic assessment of the impact of inefficient outcomes, GSMA, October 2014

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- The cost of spectrum to mobile operators could be set at opportunity cost. The opportunity cost is the price other users would be prepared to pay for the spectrum. However, because spectrum will have been identified in the national frequency table (which is in turn aligned with WRC band identifications) for mobile use, the opportunity cost may be very small or nil.
- Society can expect some form of compensation for licencing the scarce national resource that is spectrum to mobile operators. A low but material fee could be justified.
- Imposing a low but material cost on operators could be used to ensure that spectrum will be used rather than hoarded. However, the same goal could be achieved with a "use it or lose it" provision in the licence or minimal deployment rule.

Setting low prices for spectrum is not a problem. In a competitive market the benefit of lower costs will be passed on to consumers in the form of lower prices.

Setting low prices for spectrum is not a problem. In a competitive market the benefit of lower costs will be passed on to consumers in the form of lower prices. This is why, for example, Finland consistently opts for the lowest possible spectrum licence fees. This policy delivered excellent outcomes in terms of mobile broadband and 5G development as detailed in chapter 5.5 below.

Finland is not alone is this approach. For example, the French government did not hold an auction to renew 900MHz, 1800MHz and 2100 MHz spectrum licences up for renewal in 2021-22. Instead there will be low annual fees combined with a 4G mobile broadband rural coverage obligation.

While low spectrum licence fees are not a problem, setting prices too high is a problem because, as explained above, it is likely to reduce mobile network investment and may even lead to unsold spectrum. How can regulators avoid setting prices that are not sustainable? Looking at annualised cost of spectrum is particularly helpful. To determine a sustainable level of spectrum pricing, regulators should look at the spectrum roadmap as well as upcoming spectrum licence renewals. It is important to look 5 to 10 years ahead because what matters is the overall cost of spectrum to mobile operators.

For example, if a regulator plans to assign administratively 700MHz spectrum, followed by the C-Band as well as mm wave spectrum in the next year, and 2100MHz spectrum licences are expiring in the year after that, then setting the prices for these bands should be considered together. The total annualised cost of spectrum must be sustainable, i.e. not exceed a level which would threaten investment in 5G.

Unsold spectrum that lies fallow does not generate any socio-economic benefit for a country. In setting administered spectrum prices, regulators need to ask themselves whether they aim a) to have a mobile market more like Finland with low prices, high mobile broadband usage and high download speeds, or b) to have a mobile market like Bangladesh, one of last countries to launch LTE, with low data usage and very low download speeds.

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5.5 Low spectrum fees and world-leading mobile broadband in Finland

In Finland the annualised cost of spectrum amounts to a mere 1.4% of mobile industry revenue. As a result mobile operators in Finland have built a very high density mobile network which delivers excellent availability and high download speeds.

Finland has consistently pursued a policy of low spectrum fees in order to enable operators to invest the maximum in their networks. The annualised cost of spectrum amounts to a mere 1.4% of mobile industry revenue. As a result mobile operators in Finland have built a very high density mobile network which delivers excellent availability and high download speeds.

Finland has the densest LTE cell site grids, but below average number of spectrum bands deployed per LTE site and outperforms most European countries in key LTE performance metrics – even in the most loaded hours of the day – despite having 8x the European average and 17x the German traffic load, normalised for population[9].

The benefit for users is clear: The average monthly mobile data usage per SIM in Finland is, at around 20 Gbytes, the highest in the world together with Kuwait and some other Gulf states. Three of the top four best performing mobile broadband networks are in Finland as shown in Exhibit 22 below.

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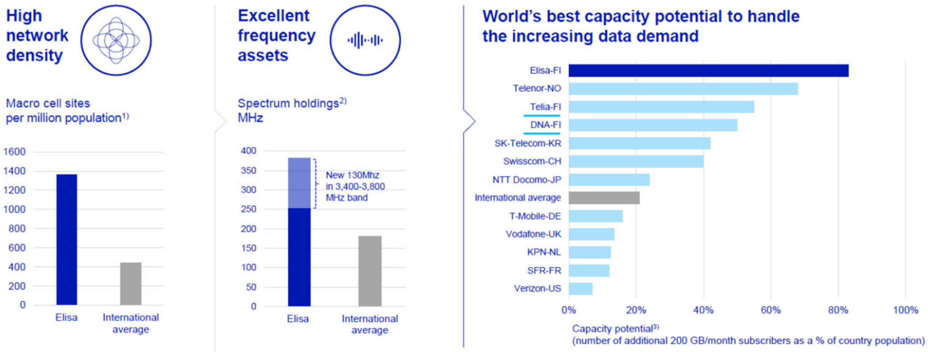
Exhibit 22: Finland leads in mobile broadband



Source: Elisa Capital Markets Day presentation, 2018

9 Rewheel-Tutela public research study, 18th February 2019

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6 Spectrum pricing based on revenue

Regulators should not set spectrum licence fees as a percentage of revenue. Charging for spectrum based on revenue is in fact a misnomer because the charge depends on revenue, i.e. it is in effect a tax on turnover or a sales tax. To illustrate the point, let's consider the following example: If a speculator acquires spectrum but does not use it and hence has zero revenue, the spectrum fee would be zero.

Charging for spectrum based on revenue is in fact a misnomer because the charge depends on revenue, i.e. it is in effect a tax on turnover or a sales tax.

The objective of spectrum management is to ensure that the scarce resource that is spectrum is used efficiently. The more traffic passes through a MHz of spectrum, the more efficiently that MHz is used. However, charging for spectrum as a percentage of revenue actually penalises operators who use spectrum efficiently so is contrary to spectrum management best practice. Comparing two hypothetical operators provides an illustration of the effect of network investment on value extracted from spectrum.

Exhibit 23 below shows data for two mobile operators in a country. Each holds the same amount of spectrum. Operator B invested twice as much as operator A so that operator B has 4,000 sites compared to operator A's 2,000 sites. Since operator B has a much better network, operator B attracted 60% more customers than operator A. As a result of better network quality B's customers use more data and generate a higher ARPU. Therefore Operator B produces more socio-economic value for spectrum than Operator A. Spectrum policy should encourage the behaviour of Operator B.

Exhibit 23: Investment and socio-economic value extracted from spectrum

Operator A	Operator B	Comments
Holds 2x10MHz of spectrum	Holds 2x10MHz of spectrum	There are two mobile operators in a country. Each holds the same amount of spectrum
Invested $300 million 2,000 sites	Invested $600 million 4,000 sites	Operator B invested twice as much as operator A.
1 million customers Monthly data traffic per customer: 1 Gbyte 12 million Gbytes per year Monthly ARPU: $10 Annual revenue: $120.0 million	1.6 million customers Monthly data traffic per customer: 1.1 Gbytes 21.12 million Gbytes per year Monthly ARPU: $11 Annual revenue: $211.2 million	Since operator B has a much better network, operator B attracted 60% more users than operator A. As a result of better network quality B's customers use more data and generate a higher ARPU.
600,000 Gbytes per MHz per year	1,056,000 Gbytes per MHz per year	Operator B passes almost twice as much traffic through each MHz of spectrum

Source: Coleago

Exhibit 24 shows that greater network investment increases efficient use of spectrum measured in Gbytes per MHz per year. Both operators hold the same amount of spectrum. Operator A produces 600,000 Gbytes of data traffic per MHz per year. Operator B produces 1,056,000 million Gbytes per MHz per year. As a result of higher investment operator B uses the spectrum more efficiently. However, operator A extracts more value for private investors whereas operator B generates more value for the country.

Now the government decides to levy a fee of 4% of revenue and describes it as a "spectrum usage charge". Operator B's profitability declines more that operator A and the return on investment declines more in relative and absolute terms. A rational investor would invest less and pursue operator A's strategy. As a result, the country would lose out.

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Exhibit 24: Effect of 4% of revenue spectrum charge on incentive to invest

	Before 4% charge		After 4% charge	
	Operator A	Operator B	Operator A	Operator B
Annual revenue $ mn	120.0	211.2	120.0	211.2
Spectrum usage fee $ mn	-	-	(4.8)	(8.4)
EBITDA	40%	40%	36%	36%
EBITDA $ mn	48.0	84.5	43.2	76.0
Annual capex $ mn	15.0	30.0	15.0	30.0
Free cash flow $ mn	33.0	54.5	28.2	46.0
Return on investment (ROI)	11.0%	9.1%	9.4%	7.7%
Drop in free cash flow $ mn			(4.8)	(8.4)
% drop in ROI			14.5%	18.0%

Source: Coleago

Exhibit 25: Spectrum pricing methodologies compared

A fee per MHz of spectrum	A fee based on revenue
Encourages operators to make as much use of spectrum as possible, i.e. encourages investment	Penalises operators who make efficient use of spectrum
Is easily calculated and transparent	Discourages investment in the network
Covers the opportunity cost of spectrum	Reduces the socio-economic value of spectrum

Source: Coleago

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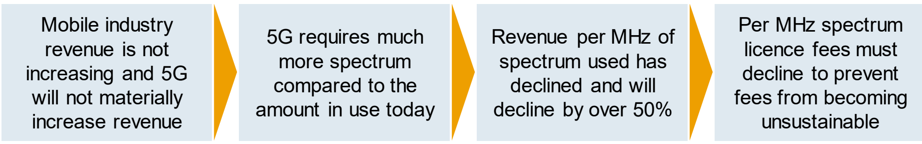
7 Conclusions and recommendations

To ensure that your country is not left behind in the 4th industrial revolution spectrum policy and pricing must be calibrated to foster the deployment of 5G mobile in a timely manner. The business case for 5G is challenging and it is essential that licence fees for spectrum required for the launch of 5G are sustainable in the context of mobile industry revenue.

The business case for 5G is challenging and it is essential that licence fees for spectrum required for the launch of 5G are sustainable in the context of mobile industry revenue.

- Mobile operators face stagnating revenues and 5G will not materially increase mobile operator revenue.
- 5G requires substantially more spectrum compared to the amount of spectrum in use today.
- Given that more spectrum is required for 5G but revenue is not increasing, each MHz of spectrum generates less and less revenue.
- Therefore, spectrum licence fees must decline to ensure that the cost of spectrum does not become unsustainable.

Exhibit 26: Mobile operator revenue per MHz of spectrum is declining

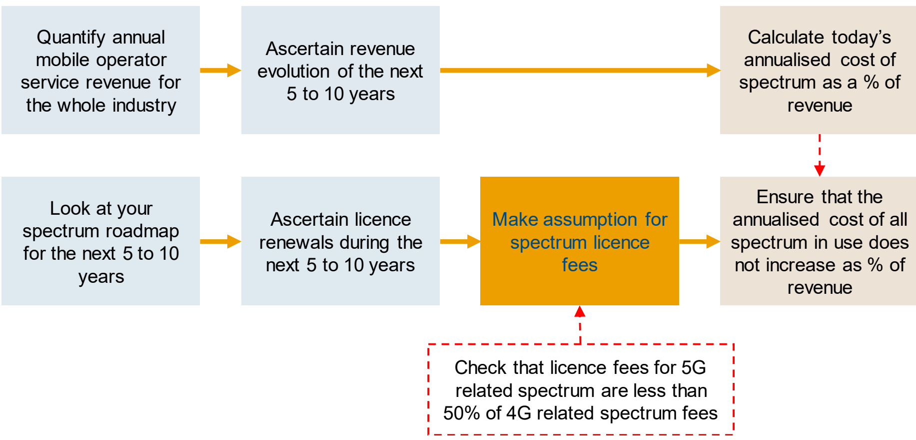


Source: Coleago

Looking at your spectrum roadmap and upcoming spectrum licence renewals, you can assess the level of spectrum fees that may be sustainable. This can be done by comparing today's annualised cost of spectrum as a percentage of mobile operator revenue with the projected future annualised cost. Spectrum fees for new 5G related spectrum and fees for spectrum licence renewal must be calibrated to a level that does not result in an increase in the annualised cost of spectrum as a percentage of mobile operator revenue. A further check is to look at the spectrum price index. The cost of spectrum required for 5G should be less than 50% of the cost of spectrum associated with the launch of 4G.

Spectrum auctions should be designed to allow for the lowest prices to emerge by making the maximum amount of spectrum available, packaging spectrum in small 2x5MHz FDD or 10MHz TDD block sizes, providing information to bidders during the auction, and not subsidising new entrants by setting aside spectrum.

Exhibit 27: Ensuring sustainable spectrum licence fees



Source: Coleago

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Appendices

Appendix A: **Annualised cost of spectrum examples**

Germany

The table below shows an example of calculating the annualised cost of spectrum in Germany. The table below shows the following data:

- The date of the auction date and the licence duration are needed to ensure that licences that have expired are not included in the calculation. Expired licences are fully amortised, i.e. the there is no longer a cost of capital associated with these.
- The band name and number and type of spectrum as well as the amount of spectrum sold are not required for the calculation but provides a check that all spectrum currently in use is included the calculation.
- The price paid and the licence duration are the key elements which flow into the annualised cost of spectrum calculation.
- The annualised cost of spectrum for each band and the total for all unexpired licences.
- The average weighted cost of capital (WACC).
- 2018 mobile industry revenue in Germany.
- The annualised cost of spectrum and percentage of revenue which is key metric used to determine the sustainability of spectrum licence fees.

The annualised cost of all spectrum used by mobile operators in Germany as of 2018 amounted to 6.2% of 2018 revenue. This is sustainable level. However, following the auction for 3.5GHz spectrum and renewal of 2100MHz licences, the annualised cost of spectrum jumped to 9.7% of revenue. The main reason for this are the high final auction prices paid for 3.5GHz spectrum because the regulator set aside 100MHz for verticals. This distorted the auction outcome because it created an artificial spectrum shortage.

Exhibit 28: Annualised cost of spectrum in Germany

Date	Band Name	Type	Band #	MHz Sold	Price Paid € Million	Licence Duration Years	Annualised Cost € million
May-10	800	FDD	20	60	3,576	15	385.3
May-10	1800	FDD	3	50	104	15	11.2
May-10	2600	FDD	7	140	258	15	27.8
May-10	2600	TDD	38	50	87	15	9.3
May-10	2100	FDD	1	40	348	15	37.5
May-10	2100	FDD	33/34	19	11	15	1.2
Jun-15	700	FDD	28	60	1,000	15	107.8
Jun-15	900	FDD	8	70	1,346	17	135.0
Jun-15	1800	FDD	3	100	2,405	17	241.3
Jun-15	1500	SDL	32	40	330	17	33.1
Jun-19	2100	FDD	1	120	2,374	15	255.7
Jun-19	3500	TDD	n67	300	4,176	15	449.8
Total				1,049	16,016		1,695

Cost of Capital (WACC)	%	6.7%
Annual industry service revenue 2018	€ million	17,479
Spectrum cost % of revenue	**%**	**9.7%**

Source: Coleago

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Singapore

The annualised cost of spectrum in Singapore is 6.7%. This is a sustainable percentage. Singapore is a well-regulated telecoms market with a high level of transparency and has very similar spectrum costs to Germany prior to 2019 auction. In Singapore revenue maximisation from spectrum is not an objective, instead the government focuses on good broadband connectivity and ensuring a competitive market. For example, in the uncompetitive 2100MHz auction (3G auction) following consultation with operators the regulator reduced the initially proposed SG$ 150 million price per lot to SG$ 100 million and all three operators bought spectrum licences and deployed the spectrum.

Exhibit 29: Annualised cost of spectrum in Singapore

Date	**Band Name**	**Type**	**Band #**	**MHz Sold**	**Price Paid SG$ Million**	**Licence Duration Years**	**Annualised Cost SG$ million**
Apr-01	2100	FDD&TDD	1	104	300	20	28
Oct-10	2100	FDD	1	30	60	20	6
Jun-13	1800	FDD	3	150	240	13	28
Jun-13	2600	FDD	7	120	120	15	13
Dec-16	900&2300	FDD/TDD	8&40	60	105	20	10
Apr-17	700	FDD	28	90	846	15	91
Apr-17	900	FDD	8	40	192	16	20
Apr-17	2600	TDD	38	45	107	16	11
Total				639	1,970		206
Cost of Capital (WACC)			%				6.7%
Annual industry service revenue 2018			SG$ mn				3,047
Spectrum cost % of revenue			**%**				**6.8%**

Source: Coleago

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Finland

Finland has consistently pursued a policy of low spectrum fees with the objective to enable operators to investment a maximum in their networks. The annualised cost of spectrum is only 1.2% of 2018 mobile industry revenue. As a result, Finland has one of the densest mobile networks, delivering excellent availability and high download speeds. The benefit for users is clear: The average monthly mobile data usage per SIM in Finland is with around 20 Gbytes the highest in the world, together with Kuwait and some other Gulf states.

Initially spectrum is auctioned with low prices are low. With only three mobile operators demand for spectrum often does not exceed supply. For example, in the recent C-band auction, each operator obtained 130MHz at the reserve price. At the end of 2018, 900MHz, 1800MHz and 2100MHz spectrum licences were renewed. Operators pay a low annual licence fees but did not have to pay for an up-front spectrum licence fee.

Exhibit 30: Annualized cost of spectrum Finland

Licence fees for initial duration

Date	Band Name	Type	Band #	MHz Sold	Price Paid € Million	Licence Duration Years	Annualised Cost € million
Nov-09	2600	FDD	7	140	2.3	20	0.2
Oct-13	800	FDD	20	60	108.1	20	10.0
Nov-16	700	FDD	28	60	66.3	20	6.1
Oct-18	3500	TDD	n78	390	77.6	15	8.4
Total				650	254.4		25

Annual fees after expiry of initial term

	Band Name	Type	Band #	MHz	€ '000 / MHz / year	Annual Fee € Million
Current	900	FDD	8	70	13	0.9
Current	1800	FDD	3	150	9	1.4
Current	2100	FDD	1	120	9	1.1
						3.4

		€ Million
Annualised costs plus annual fees		28.0
Cost of Capital (WACC)	%	6.7%
Annual industry service revenue 2018	€ million	1,943
Spectrum cost % of revenue	**%**	**1.4%**

Source: Coleago

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United Kingdom

The annualised cost of spectrum as a percentage of revenue in the UK was 8.4%. The figure is higher compared to Germany and Singapore. The UK has moved to an indefinite licencing regime. The initial spectrum award is conducted through an auction process with successful bidders paying an up-front fee for a 20 year licence.

After the expiry of the initial term, operators pay an annual fee per MHz of spectrum. Therefore in addition to the annualised fee the table shows the information for the annual fees payable for spectrum following the expiry of the initial licence term.

The annual fee varies by band and is set based on auction benchmark prices. As explained above, using the benchmark methodology is backward looking and produces numbers that do not take account of the fact that mobile operator revenue per MHz of spectrum has declined. This explains in part why the annualised cost of spectrum in the UK is higher compared to Germany and Singapore.

Exhibit 31: Annualised cost of spectrum in the UK

Licence fees for initial duration

Date	Band Name	Type	Band #	MHz Sold	Price Paid GBP Million	Licence Duration Years	Annualised Cost GBP million
Apr-00	2100	FDD	1	120	7,867	20	725.4
Feb-13	800	FDD	20	60	1,550	20	142.9
Feb-13	2600	FDD	7	140	728	20	67.1
Feb-13	2600	TDD	38	45	69	20	6.3
Apr-18	2300	TDD	40	40	206	20	19.0
Apr-18	3500	TDD	42	150	1,164	20	107.3
Total				555	11,583		1,068

Annual fees after expiry of initial term

	Band Name	Type	Band #	MHz	GBP '000 / MHz / year	Annual Fee GBP Million
Current	900	FDD	8	70	1,093	77
Current	1800	FDD	3	150	805	121
						197

		GBP Million
Annualised costs plus annual fees		1,265
Cost of Capital (WACC)	%	6.7%
Annual industry service revenue 2018	GBP million	15,074
Spectrum cost % of revenue	**%**	**8.4%**

Source: Coleago

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India

India is a good example to show how the annualised cost of spectrum methodology can be used to ascertain whether proposed spectrum reserve prices were sustainable:

- Prior to the 2016 auction for 700, 850, 900, 1800, 2100, 2300 and 2500MHz spectrum the annualised cost of spectrum based on 2016 revenue stood at 12.1%. This is a high figure, particularly given other high taxes on the mobile industry.
- At the end of 2016 spectrum auction the figure had risen to 14.8% based on 2016 mobile industry revenue.
- Due to excessive reserve prices, much of the spectrum remained unsold including all of the 700MHz and 900MHz spectrum. Had all the spectrum been sold at the reserve price, the annualised cost of spectrum would have increased to 34.6% of 2016 revenue, a figure that is clearly not sustainable.
- Since 2016,mobile industry revenue in India declined sharply, so that by 2018 the annualised cost of spectrum stood at 18.5% of revenue. This is well above a level that sustain investment in the industry.

In India there is also a so called "Spectrum Usage Fee". However this is a misnomer because it is in effect a tax on revenue rather than spectrum fee. We have excluded this fee from the calculation, but of course the SUC and similar turnover related fees increase the % of mobile industry revenue that flow to the state rather than network investment and investors.

Exhibit 32: Annualised cost of spectrum in India

Date	Band Name	Type	Band #	Price Paid INR Crore	Price Paid INR Bn	Licence Duration Years	Annualised Cost INR bn
2010	2100	FDD	1	67,718	677	20	62
2010	2300	TDD	1	38,543	385	20	36
2012	1800	FDD	3	9,408	94	20	9
2013	800	FDD	5	0	0	20	0
2014	900	FDD	8	23,590	236	20	22
2014	1800	FDD	3	37,573	376	20	35
2015	800	FDD	5	17,159	172	20	16
2015	900	FDD	8	72,965	730	20	67
2015	1800	FDD	3	9,636	96	20	9
2015	2100	FDD	1	10,115	101	20	9
2016	850	FDD	5	3,640	36	20	3
2016	1800	FDD	3	17,749	177	20	16
2016	2100	TDD	1	16,140	161	20	15
2016	2300	FDD	40	15,790	158	20	15
2016	2500	FDD	41	12,202	122	20	11
Total				352,226	3,522		325

Annualised cost of spectrum		
Cost of Capital (WACC)	%	6.7%
Annual industry service revenue 2018	INR bn	1,753
Spectrum cost % of revenue	**%**	**18.5%**

Source: Coleago

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Appendix B: **Examples of failed spectrum auctions**

Bangladesh

“We are not happy” was how Shahjahan Mahmood, Chairman of the Bangladeshi Telecoms Regulator BTRC, assessed the outcome of the spectrum auction which concluded on 13th February 2018. BTRC had put up for auction 36 MHz of 1800MHz, 50 MHz of 2100MHz, and 6.8 MHz of 900MHz spectrum. Having set a reserve price of US$ 540 million for 1800MHz spectrum, US$ 675 million for 2100MHz, and US$ 102 million for 900MHz, BTRC expected to receive US$ 1,317 million from operators. In the event Grameenphone bought 10MHz of 1800MHz spectrum and Banglalink 11.2MHz whereas Robi did not buy any spectrum . The state-owned operator TeleTalk did not even show up for the auction. Total auction receipts amounted to only US$ 464 million, i.e. 65% below the BTRC’s target and 66% of the spectrum remained unsold. This was a strikingly bad outcome in terms of raising revenue and clearly shows that the strategy not to introduce technology neutrality did not pay off.

India

The October 2016 spectrum auction in India ended in failure as none of the 700MHz spectrum was sold. The cause of the failure were the reserve prices, notably for 700MHz spectrum. The reserve prices were out of proportion to the cash generated by Indian mobile operators. The reserve prices for all spectrum on offer in the auction amounted to INR 5,362 billion. This is equivalent to:

- Over twice the annual industry revenue
- 22 years' worth of operating free cash flow

At those prices it would be impossible to achieve a return on investment and hence impossible to raise the finance to acquire the spectrum licences and deploy 4G mobile broadband in the 700MHz band. Reserve prices would need to be 90% lower in order sell all spectrum licences.

There was a massive failure to reach the revenue target from the sale of spectrum. Based on advice from TRAI, the Government of India planned to raise Rs 536,239 crores (US$ 80 bn) but only raised 12% of the target (Rs 65,789 crores / US$ 10 bn). Since the 700MHz is not assigned to mobile operators this constitutes a failure to deliver better wide area LTE coverage it also a failure to deliver ICT development objectives, namely the National Telecoms Policy 2012 and therefore is a blow to ICT development in India.

Ghana

In 2015 the NCA, the regulatory authority of Ghana, set extremely high reserve prices for 800MHz (Band 20) spectrum. The 800MHz licences were technology neutral whereas existing spectrum licences did not allow operators use the spectrum for 4G. Buying an 800MHz licence was the only rout open to operators to launch 4G. The mobile operators in Ghana advised the NCA that with the extremely high prices for spectrum there was no business case. However, in the event only MTN bought 800MHz spectrum and proceeded to launch 4G in that band thus becoming the monopoly mobile 4G provider. From a regulatory perspective this was a sub-optimal outcome because competition and telecoms policy should focus on fostering competition and not damaging it.

Finally, in December 2018, a second operator (Vodafone) acquired 800MHz spectrum and with it the right to launch 4G services. However, AirtelTigo (a company created through the merger of the previously independent operators Airtel and Tigo) and Glo still did not offer 4G as of March 2019. Furthermore, not all of the 800MHz spectrum has been licenced and does not generate any socio-economic benefit for Ghana.

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Mozambique

800MHz spectrum auction in 2013, none of the spectrum was sold. There were 3 potential bidders for six 2x5 MHz blocks. To restrict supply, one of six blocks was withheld from the auction. The reserve price per 2x5 MHz block was US$ 30 million, equivalent to 0.115 US$ / MHz / pop. On a GDP adjusted basis, the reserve in Mozambique was around 10 times higher than prices paid elsewhere for digital dividend spectrum.

Comparing the reserve price for 800MHz spectrum in Mozambique, a low-income country, with the price paid for 800MHz spectrum in Germany, one of the richest countries in the world with high ARPUs illustrates how out of scale the reserve prices for 800MHz spectrum in Mozambique were. In a fiercely contested auction in Germany in 2010 (4 operators bidding for 6 blocks) the price paid was 0.91 US$ / MHz / per head of population. In Mozambique the GDP per capita is US$ 610. The GDP per capita in Germany is US$ 47,250. Adjusting the Mozambique reserve price for GDP per capita relative to Germany produces a reserve price of 8.94 US$ / MHz / pop (US$ 0.115 / 610 x 47,250 = US$ 8.94), a ridiculously high amount which was bound to lead to a failed auction.

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