

Abdelhaseeb, Muhammed M.; Digham, Fadel

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Technical aspects in effective frequency spectrum pricing

Eng. Muhammed M. Abdelhaseeb

National Telecom Regulatory Authority, Egypt

Dr. Fadel Digham

National Telecom Regulatory Authority, Egypt

Abstract

Microwave spectrum has been the primary solution for the rapid and cost-effective rollout of mobile backhaul infrastructure. Most of the mobile sites worldwide today are connecting via Microwave (MW) or Millimeter Wave (mmW) radio links. The evolution from 4G towards 5G presents significant challenges to all transport technologies and wireless ones make no exception.

The goal of this paper is to investigate technical factors that can be used by regulators in order to achieve an effective frequency spectrum-pricing model applied for Microwave links. Especially in this stage, while all mobile operators need a huge bandwidth of spectrum to accommodate and backhaul high data rates for 4G and 5G applications. There are several strategies in theory that could be used by regulators in order to determine appropriate frequency spectrum fees. In addition, there are different factors when it comes to evaluating the value of spectrum. Many aspects and issues are facing regulators for designing an effective spectrum management, such as efficient spectrum usage, public and social benefits, introduction of new technologies, licensing regimes, etc. Therefore, in this paper we are looking for some technical factors that may be taken into account in order to have an effective frequency spectrum-pricing model for Microwave links.

Keywords: Microwave, Spectrum price, Spectral efficiency, Technology factor, Data rate, XPIC, MIMO.

1. Introduction

Data transfer rates have been increasing dramatically in recent years, especially after mobile operators have introduced the fourth generation services, which have provided the user with the ability to upload files with high speeds and watch online videos as well as online games. Typical backhaul capacity for mobile networks is shown in Table 1 [1].

Site Type	Mobile spectrum and type	Cell type	Backhaul Capacity
Dense Urban	<ul style="list-style-type: none">• LTE up to 50 MHz• 5G 200 MHz 16L MIMO ~4GHz• 5G ≥ 400 MHz 16L MIMO ~30GHz	Macro-cell: ~4GHz <i>and</i> ~30GHz Small-cell: ~4GHz <i>or</i> ~30GHz	>10 Gbps
Urban	<ul style="list-style-type: none">• LTE up to 50 MHz• 5G 100 MHz 8L MIMO ~4GHz• 5G 200 MHz 8L MIMO ~30GHz	Macro-cell: ~4GHz Small-cell: ~4GHz <i>or</i> ~30GHz	<10 Gbps
Sub Urban	<ul style="list-style-type: none">• LTE up to 50 MHz• 5G 100 MHz 8L MIMO ~4GHz	Macro-cell	<4 Gbps
Rural	<ul style="list-style-type: none">• LTE up to 50 MHz• 5G 50 MHz 4L MIMO ~2GHz• 5G 20 MHz 4L MIMO ~700MHz	Macro-cell	<2 Gbps

Table 1 - backhaul capacity per site type

For over 20 years, microwave spectrum has been the primary solution for the rapid and cost-effective rollout of mobile backhaul infrastructure with over 50% of mobile sites worldwide today connected via Microwave (MW) or Millimeter Wave (mmW) radio links, up to over 90% in some networks. Microwave plays a significant role in providing good mobile network performance [1]. However, the constant pressure to increase performance levels translates into a need for more spectrum, and more efficient use of it – not just when it comes to radio access, but for microwave backhaul as well.

Most of mobile operators in African countries that do not own a fiber network or lack affordable access to leased circuits, wireless solutions provide the capacity, performance, flexibility, and cost-effectiveness that they need to backhaul 3G and 4G traffic [2]. In some locations microwave spectrum is severely congested, while in other places it is highly underutilized. As demands on services like mobile broadband continue to rise, operators are going to need more microwave spectrum. However, spectrum is a limited resource [3] and regulators must then search for new methods and push operators to use new technologies that will maximize spectrum efficiency.

One of the tools that can be used by regulators to ensure spectrum efficiency is the annual spectrum fees for microwave backhauling links. The annual spectrum fee is the fee that provides compensation for the use of the spectrum by a Licensee, and is designed to cover the costs of managing the Radio Spectrum. Spectrum fee is paid every year on the anniversary date of the license award and will cover the upcoming year. Spectrum fee is calculated according to a spectrum-use formula, and the amount due will be based on spectrum usage during the preceding year [4].

The main objective of this paper is to provide technical aspects that regulators can use while determining and calculating the microwave spectrum fee in order to maximize spectrum efficiency. The paper is organized in six sections. First is the Introduction. The second section provides information about strategies for spectrum fees. Third describes the factors used to evaluate microwave spectrum fees. In the fourth section, the authors are discussing different case studies for microwave spectrum fees. The fifth section addresses the achievement of a spectrum efficiency model. Conclusion is provided in the sixth section of the paper.

2. Strategies for spectrum fees

When regulators need to determine a general strategy for spectrum fees, they should consider its efficient usage, public and social benefits, innovation and growth, framework conditions, licensing regimes and etc. General strategies for regulators are [5]:

- Cost based strategy: calculating fees based on associated costs of spectrum management;
- Contribution based strategy: calculating fees as a contribution to the national budget;
- Market based strategy: applying market mechanisms to ensure efficient usage.

Cost based strategy is maximizing benefits for investors while market based strategy is maximizing benefits for government and helping achieve optimal usage of spectrum. While deciding a spectrum fee strategy, the regulators should consider efficient or optimal use of spectrum. Therefore, regulators should choose an appropriate manner and technical conditions for spectrum assignment and fees calculation.

3. Evaluation of Microwave spectrum

When we are talking about spectrum value and price it is necessary to understand that prices are not only determined based on costs but also on expectation of future revenues or benefits that this spectrum would bring. When regulators are set to determine and calculate spectrum value, some factors could not be ignored. These factors could be divided into two groups [6].

1. Technical factors – these factors are pertaining to the spectrum itself and they cannot be changed.
2. Non- Technical factors – these factors are applying differently in every country and they could cover different aspects including physical and demographic characteristics, cultural or legal heritage, and national policies. Those factors are given in Table 2.

Technical Factors	Non- Technical factors
Occupied Bandwidth	Population density
Location of spectrum	Radio Stations Density
Number of Frequency Channels	GDP
Polarization	User's income
Service Area	Duration of use
Coverage Area	Inflation
Power (EIRP)	Type of Radio License
Antenna Height	Geographical and Regional issue
Type of Service	Interconnections

Table 2- factors affecting the assessment of spectrum value

4. Microwave spectrum fees case studies

This section presents case studies from the International Telecom Union (ITU) and different countries such as (Egypt, Kenya, Nigeria, South Africa, United Kingdom and Australia) in order to explore the technical factors used by regulators in their spectrum fees model. The most common technical factors used to calculate microwave spectrum fees in the selected case studies are unit price for the spectrum (U), frequency band (F), bandwidth (BW), geographic area (G) and

exclusivity (E). Regulators are using these factors to calculate the spectrum fees for microwave links according to the following formula:

$$\text{Annual Spectrum Fees (per a MW link)} = U * F * BW * G * E \quad (1)$$

A cross-matrix illustrating the adoption of these factors by different countries and ITU is illustrated in Table 3 followed by a brief description of each factor.

Country	Unit Price (U)	Frequency factor (F)	Bandwidth factor (BW)	Geographic factor (G)	Exclusivity factor (E)
ITU [7]	√	√	√		
EGYPT [8]	√		√		
Kenya [9]	√	√	√		
Nigeria [10]	√	√	√		
South Africa [11]	√	√	√	√	√
United Kingdom [12]	√	√	√		√
Australia [13]	√	√	√	√	√

Table 3- summary of the case studies

- Unit price factor (U)

The regulator defines this factor in order to set the price of the spectrum in a level to be in line with the economic status of the country. When regulators calculate the value of this factor for the microwave spectrum, they need to consider price and value of other alternatives for microwave links such as fiber and satellite services. The value of unit price is a fixed value.

- Frequency factor (F)

This factor is used to differentiate between lower and higher frequency bands. The physics of radio waves propagation determine the relation among capacity, availability and link length. The lower frequency bands are used in long distance links while the higher frequency bands are used in short distance links. In most of the cases, the lower frequencies have the high value factor and vice versa for higher frequencies. The normalized value of the frequency factor ranges typically from around 1 to 5 where the lowest value is used for higher frequency bands and the highest value is used for lower frequency bands.

- Bandwidth factor (BW)

This factor reflects the actual bandwidth or number of channels assigned in each frequency band for operator. Therefore, if the operator has more spectrum he will pay more fees. The regulators assign channel bandwidth in each frequency band in accordance to ITU-R Recommendations (F-series) which describe the channel arrangement for different microwave frequency bands [14]. The value of this factor is grow linearly depends on bandwidth assigned to each microwave link. Bandwidth is varying from 7 MHz up to 112 MHz and in future, it will reach 224 MHz. Typically, the normalized BW factor is 1 when using 7 MHz and keeps increasing to reach 16 with 112 MHz and 32 with 224 MHz. We must highlight that, for LTE advance and 5G sites, data rates will reach up to 10 Gbps, then the operator will use microwave links with bandwidth (112 MHz / 224 MHz) to accommodate high data rates, implying high BW factor.

- Geographic factor (G)

This factor is used to differentiate between high-density cities and rural areas. Typically, high-density regions take the higher value and rural areas take on the lower one.

- Exclusivity factor (E)

This factor indicates if the frequency spectrum assigned to the operator in a shared or exclusive (region / country) basis. If the frequency channel is shared it takes the value of (1), and if assigned on an exclusive basis it then takes a higher value depending on the assignment basis by region or nationwide.

From the selected case studies and other models applied in different countries, the parameters U, F, G, and E have a fixed range based on certain characteristics and are pre-determinant given the underlying environment and model. Given such variables, the increased demand of capacity can be fulfilled by traditionally increasing the bandwidth (BW) of number of channels. In turn, the spectrum fees grow linearly with BW, as evidenced by Eq. (1). Therefore, if the operators use microwave links with wider channels (112MHz, even 224MHz where possible) to accommodate and backhaul high traffic data rates coming from future mobile technologies (LTE and 5G), they will have an expensive spectrum fees which will disturb their business model. In the next section, we will discuss a new factor that can be introduced by regulators in the microwave spectrum fees model to relax the fees especially when we are talking about high capacity links.

5. How to achieve a spectrum efficiency model?

In order to have an answer to this question, we need to indicate that there are new technologies either available or under development to make full use of existing traditional microwave frequency bands (6 – 42 GHz) and millimeter waves (mmW) (E-band (70/80 GHz), W-band (90 – 110 GHz) and D-band (110 – 150 GHz)) in a more efficient way. Therefore, regulators must think to introduce a new factor in their spectrum-pricing model to encourage operators to use these new technologies. This action should result in using the spectrum more efficiently. Figure 1 shows the characteristics of traditional microwave frequency bands and millimeter waves and their usage [15].

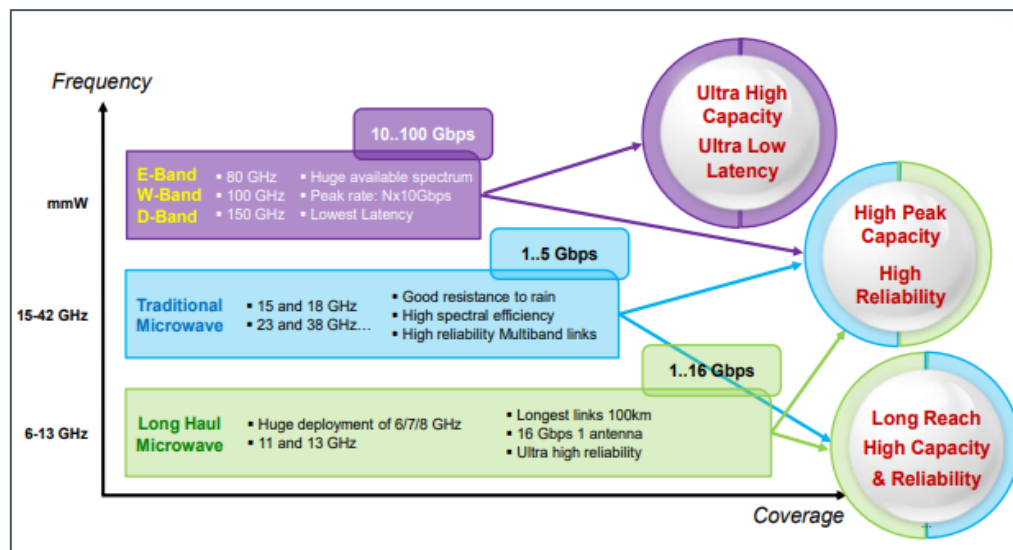


Figure 1- Characteristics of microwave frequency bands

The key aspects in new microwave technologies available today are:

- Hierarchical quadrature amplitude modulation (HQAM), which uses higher order modulation to maximize spectral efficiency over a microwave communications channel.
- Packet compression mechanisms, which reduce the overhead introduced by a frame or packet structure to help increase in spectral efficiency in a full packet-based environment.
- XPIC (Cross Polar Interference Cancellation), which uses to increase capacity and spectral efficiency of a microwave link. XPIC technology doubles the potential capacity of a Microwave path by transmitting the data using both the vertical & horizontal polarization.

- Line of Sight (LoS) MIMO (Multiple-Input / Multiple-Output), which uses for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation.
- Other techniques like, higher directivity antennas and active interference cancellation should be encouraged with licensing provisioning to incentivize spectrum efficiency by a higher degree of channel reusability.

Therefore, we propose a new factor to be used in the spectrum pricing formula in order to motivate and incentivize operators to use the microwave spectrum more efficiently. We propose to call this factor “*the technology factor*” (T). The pricing formula in Eq. (1) will then be modified as follows:

$$\text{Annual Spectrum Fees (per a MW link)} = U * F * BW * G * E * T \quad (2)$$

The corresponding value for the technology factor must be less than one to reduce the spectrum fees to a reasonable value.

The next issue to be investigated is how to appropriately determine the value of the technology factor. The approach that we use in this paper is to analyze and calculate the value of the technology factor by comparing theoretical data rates offered from different microwave technologies.

Figure 2 shows theoretical gross data rates for a single microwave channel using the technologies described above [16].

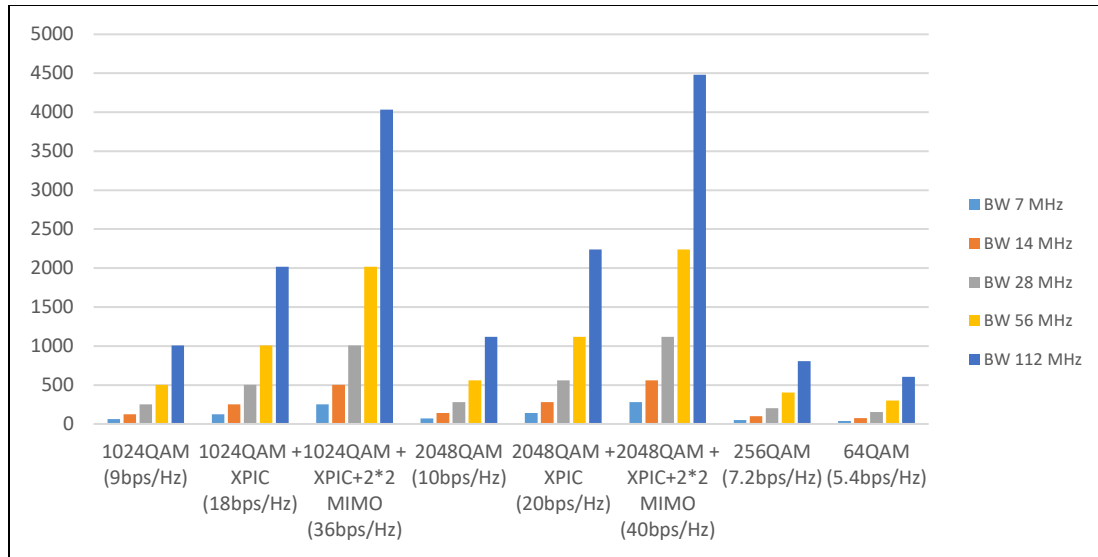


Figure 2- data rates vs microwave technology

- Higher order modulation schemes: with single-carrier radio (BW 56 MHz), an operator can reach (400 MHz) when using (256 QAM) and data rate can be increased to (560 Mbps) when using (2048 QAM).

In addition, if the operator needs to reach higher data rate (1 Gbps), channel BW will be doubled to (112 MHz) and hence microwave fees will be doubled accordingly.

- XPIC: Deploy an XPIC option that uses both horizontal and vertical frequency polarizations to double frequency capacity. In the case of (BW 56 MHz), an operator can reach (560 MHz) when using (2048 QAM) and data rate can be increased to (1120 Mbps) when using (2048 QAM) and (XPIC).

In this case, the operator will use two outdoor radios instead of using one radio. Therefore, CAPEX (MW radio cost) is doubled but OPEX (spectrum fees) is still the same.

- LoS MIMO: enables transmission of two independent bit streams over the same frequency and same polarization. This means 100% more capacity in a 2X2 MIMO configuration compared to one single link without wasting additional spectrum resources. In the case of (BW 56 MHz), an operator can reach (560 MHz) when using (2048 QAM) and data rate can be increased to (2240 Mbps) when using (2048 QAM) with (XPIC + MIMO). Namely, data rate can be increased by four times in the same channel BW of 56 MHz when using (XPIC+MIMO).

In this case, the operator will use four outdoor radios instead of using one radio. Therefore, CAPEX (MW radio cost) is increased by four times but OPEX (spectrum fees) is still the same.

We have to highlight that, XPIC is implemented with one antenna. While, LoS MIMO requires two antennas at each site. Installation is based on calculated antenna separation distance that is multiple of the wavelengths of the frequency band used.

If we take into consideration the depreciation rate for microwave radios which is (10) years [17]. Therefore, from the analysis above for the number of radios used and associated cost, we can assume that the operator is paying annually an additional cost of (0.2 of the total equipment cost) or (0.4 of the total equipment cost) when using (XPIC) or (XPIC+MIMO) radios, respectively compared to (0.1 of the total equipment cost) when using traditional equipment.

We then propose to reduce the annual spectrum fees per each MW link linearly as the annual CAPEX of the equipment increases. Namely, we propose that:

$$\text{Technology factor (T)} = 1 - \text{depreciation factor} \quad (3)$$

In other words, we can say that the technology factor can take on the value of (0.6) for (XPIC + MIMO) technologies, and (0.8) for (XPIC) technology. We should bear in mind that the operator will not use one trend of technology on his network, but he can use (XPIC) links only or (XPIC + MIMO) links depending on availability of towers space. Therefore, for simplicity and regardless of the technology used, we can assign the technology factor the average value of 0.6 and 0.8 to be (0.7) across the whole network.

Such a reduction in spectrum fees per link shall account for an adequate overall reduction when considering all links per a certain operator. This should incentivize the operator to adopt spectrally efficient radio equipment despite their increased cost. This push for more spectrally efficient devices serves two objectives: (i) fulfill the capacity needs of the operator without requesting additional BW which may not be available and (ii) better utilization of the whole spectrum and then accommodating more users and services.

6. CONCLUSION

It is important for regulators to ensure efficient usage of spectrum and to achieve set up goals by the government by entering new technologies like 5G. For a mobile operator, the choice of backhaul is a challenging one, because many factors have to be taken into account. Spectrum availability and fees are typically the main determinants. For regulators, microwave spectrum assignment should be simple, transparent and should maximize revenues but also promote competition and allow the possibility to develop new technologies. As the spectrum is a limited resource, regulators must ensure efficient use of this resource, therefore, they must enhance their pricing model by introducing new factors incentivizing operators to use spectrum efficiently. In this paper, the authors have proposed a new factor called “technology factor” that could be included in the microwave spectrum fees. By applying this technology factor in the formula of microwave spectrum fees, it will guarantee that operators will change their traditional radios to use new technologies that will ensure efficient use of spectrum. Microwave technologies like XPIC and MIMO are not just about multiplying capacity; there are also about multiplying spectral efficiency. With more data transmitted over less spectrum, operators will save microwave spectrum fees (OPEX).

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