Making the most of a limited resource: how to use spectrum more efficiently in the era of 5G

white paper

EXFO

EXECUTIVE SUMMARY

Radio/RF spectrum or simply—for the purposes of this document—spectrum is the lifeblood of wireless communication. Spectrum has been a "hot" mobile industry topic, especially when a new mobile network generation (like 5G now) is introduced. As a finite resource that is critical for mobile network performance and customer experience, spectrum calls for optimal efficiency in its use.

The spectrum (or spectral) efficiency discussion goes beyond mobile network generations, including 5G, or band availability through regulation. The discussion is even more relevant today in the light of exploding mobile data demand, Internet access significance, and new use cases (e.g., IoT industry automation).

Interestingly, efficiency is also emphasized by national/supranational organizations. Licensed spectrum sharing (e.g., CBRS in US) is questioning the long-term, exclusive ownership model. And 5G—a mobile industry transformation catalyst—promises optimal efficiency in using resources, including spectrum. But for 5G to fulfil its promise, a multitude of spectrum challenges should be addressed.

Challenges—These can be grouped in two categories: **cost** and **complexity**. It is costly to acquire (licensed) spectrum and manage it. Spectrum is also inherently complex: the radio environment and interference are major technical challenges. Another challenge lies with 5G. We should not assume that 5G will resolve every issue and ignore or underestimate challenges in using spectrum. Moreover, since various factors (both directly and indirectly) affect spectrum cost and complexity, it is important to be clear on the criteria to include in the definition of spectrum efficiency.

Definition—Spectrum efficiency is **more than a b/s/Hz value**. In practice, it could focus on challenges and metrics such as throughput, accessibility, etc. In some cases, metrics may be weighted and combined into a single value. But more generic—including commercial/business—criteria (e.g., environment, service/application, or users) can be considered. A broader statistical view, a threshold condition (e.g., min data rate in a specific area) or the ratio of a measured/estimated value versus the maximum value for a criterion may be relevant too. Whichever the exact focus, and whether implicit or explicit, increasing spectrum efficiency can be seen as the **ultimate goal** of MNO projects.

Solutions—To increase spectrum efficiency, a number of solutions can be considered, including more efficient technologies and innovative regulation (e.g., the "use it or lose it" model). In practice, the solutions mix depends on the MNO and spectrum management lifecycle phase. Key high-level solutions fall under the areas of **monitoring** (24x7, remote, real-time, granular), **analytics** (actionable insights, not just data), and **automation** (intelligence amplification, artificial intelligence). These solutions are interconnected and provide a foundation that will also be crucial for the 5G success.

Lessons learned—MNO projects worldwide show that **spectrum is not optimally used.** Projects typically focus on a particular aspect or definition of spectrum efficiency, for example optimizing the performance of existing network assets, reducing new infrastructure investment, uncovering service or technology adoption issues, etc.

***Note**: For a more detailed discussion on spectrum—from its distinct challenges or the definition of efficiency to relevant solutions and lessons learned from diverse projects—please contact EXFO.*

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Introduction

Radio/RF spectrum or simply—for the purposes of this document—spectrum has been a “hot” mobile industry topic, especially when a new mobile network generation (like 5G) is introduced. As spectrum constitutes a finite and precious resource for wireless communication, the need for efficient use has always been a top priority and is even more pronounced today.

In fact, the spectrum (or spectral) efficiency discussion goes beyond mobile network generations, including 5G. This white paper aims to contribute to the discussion through theoretical and practical observations related to efficient spectrum utilization. Note that this document focuses on providing food for thought rather than present every aspect of such a complex topic in detail.

A spectrum of opportunities

In April 2000, demand for radio/RF spectrum captured the headlines. The UK auction of 3G spectrum licenses saw five winners bid £22.5 billion in total[1]. The investment by the—soon to become five—UK mobile network operators (MNOs) spoke volumes about the perceived market opportunity that this intangible resource (together with 3G) would enable. But what is this resource?

Radio frequency (RF) or radio spectrum, the lifeblood of wireless communication, is the part of the electromagnetic spectrum that includes frequencies from 30 Hz to 300 GHz. This spectrum is not solely used by the mobile industry—a relative “newcomer” compared with other sectors that use it including defense, broadcasting and satellite.

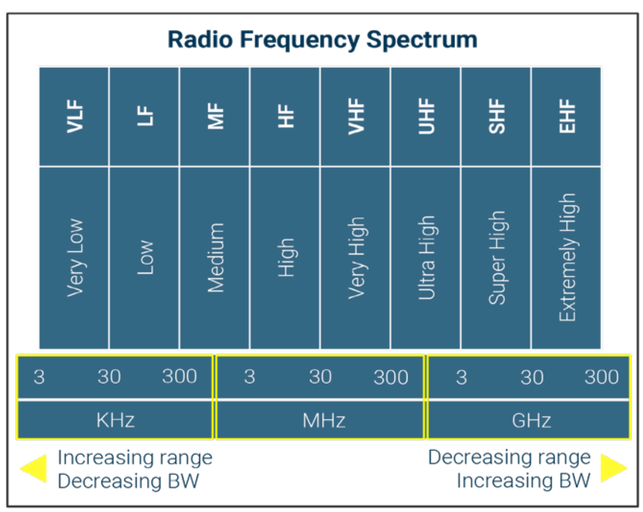

Figure 1. Radio/RF spectrum (frequency range)

1. UK mobile phone auction nets billions. BBC website, 27 April 2000. http://news.bbc.co.uk/1/hi/business/727831.stm

It is important to point out the following:

- *For simplification reasons, this document refers to radio/RF spectrum as spectrum*
- *The focus of the document is on mobile networks and use cases (i.e., there is little reference to other networks/sectors, including WiFi or satellite)*
- *Although radio/RF spectrum is relevant to network backhaul, the focus of the document is radio access*

As per Figure 1, spectrum is a finite resource organized into sections, with each section further split into bands and respective bandwidths. In general, the higher the band, the higher the bandwidth (and potential data rate), but the lower the range (i.e., the higher the signal propagation loss). For that reason, the discussion about 5G mmWave bands (close to or between 30 GHz and 300 GHz) has focused on range.

What is the maximum data rate or capacity per band? This depends on the available bandwidth and signal-to-noise ratio[2]. In practice, sophisticated "tricks" such as the use of better modulation schemes or advanced antenna systems can help increase noise tolerance and maximize band capacity without increasing power (power levels also have to respect public health rules).

Who decides which band can be used, how and where? Spectrum is regulated by international and national regulatory authorities, so as to standardize band use and avoid interference with existing users (such as defense or broadcasting) or across national borders. As in the case of 3G in the UK, interested parties can acquire spectrum band licenses through auctions. And, in addition to licensed, there is the option of unlicensed spectrum, which the success of WiFi has been built on.

On top of mobile communication, spectrum is the enabler of key services, including public safety and emergency calls. Undoubtedly, the significance—and need for availability—of spectrum has been increasing together with the importance of mobile networks and use cases:

- *Mobile data demand is continuing to increase year on year, and already approaches or exceeds 30 exabytes per month worldwide*
- *Mobile broadband facilitates Internet access, which is frequently discussed as an emerging human right*
- *Mobile networks can support a breadth of IoT applications—potentially based on privately- rather than MNO-owned spectrum in the case of 5G—including industry automation*

While more spectrum has become available, it remains a finite resource that must be used efficiently. Although efficiency is a generic requirement, the scarcer a resource, the greater the need to make the best possible use of it. Similarly, the higher the significance of a resource, the higher the importance of using it efficiently. As a critical foundation of mobile network performance and user experience, spectrum calls for optimal efficiency in its use.

Interestingly, the need for spectrum efficiency has been emphasized by MNOs as well as national or supranational organizations[3]. Furthermore, licensed spectrum sharing schemes—such as Citizens Broadband Radio Service (CBRS) in the US, which aims to supplement incumbent federal use with commercial use—are being deployed or discussed. The "use it or lose it" model questions the efficiency of the long-term, MNO-exclusive ownership of spectrum, now and for 5G.

2. The Shannon—Hartley or Shannon theorem provides the upper bound of capacity for a channel/link (in bits per second) as a function of the available bandwidth and signal-to-noise ratio (SNR).
3. For example, in recent years, the European Union (EU) has promoted a new Electronic Communications Code that refers to "more stringent requirements to use spectrum effectively and efficiently."

5G

The 5G promise

5G is a mobile network and industry transformation catalyst which promises to provide optimal efficiency in the use of resources as well as enhanced user experience, service agility, new business models, and increased MNO relevance to new verticals. Automotive, transport, logistics, utilities, manufacturing, media and entertainment, finance, and health are expected to benefit from 5G.

In the context of 5G, the spectrum discussion has focused mainly on band availability and cost. This discussion has covered fixed wireless access (FWA)—and the utilization of new (mmWave) bands—as well as the regulation and worldwide harmonization of 5G bands to achieve economies of scale and simplify network/device equipment design. In most countries, auctions of 5G spectrum have not yet taken place.

In terms of cost and overall framework, many hope that 5G will be able to transform the way that regulators manage spectrum. If 5G is to live up to expectations and benefit consumers and enterprises, a new approach (i.e., faster, less expensive, and potentially more market focused) is the best route forward.

For 5G to fulfil its promise, there are other spectrum-related concerns, including the complex 5G architecture[4] and dependence on 4G. In fact, 4G should be considered not just for initial non-standalone (NSA) deployment but also as a fallback mechanism for 5G standalone (SA) deployments in the future. Moreover, for optimal 5G network slicing, the air interface—and therefore spectrum—is critical. The high-level challenges for spectrum efficiency (including but not limited to 5G) are described in the next section.

A spectrum of challenges

Making the most of spectrum is not a straightforward exercise. In practice, a multitude of challenges hinder the optimal use of this essential resource. On a high level, we could group spectrum efficiency challenges in two interrelated categories: cost, and complexity.

Figure 2. Simplified diagram of the key high-level challenges for spectrum efficiency

4. Check a webinar on the 5G architecture for more details: www.EXFO.com/en/resources/webinars/testing-5g-challenges-lessons-learned/.

Cost

Licensed spectrum can be a considerable expense for MNOs. Of course, market conditions have changed since the heights of the UK 3G spectrum auction. Nevertheless, the acquisition cost of a spectrum band license should not be ignored. And while unlicensed spectrum may be used too, the benefits of "exclusivity" make spectrum licensing the preferred option.

Spectrum is also costly to manage. To deploy a more spectrally efficient technology such as 5G, substantial investment is needed[5]. In some cases, investment includes equipment (such as massive MIMO) that would increase spectrum efficiency but push site and network costs upwards.

Furthermore, spectrum licenses typically come with requirements that MNOs must satisfy. These requirements—usually related with area and population coverage—may be more use than efficiency focused. Still, they directly affect the MNO deployment plan and cost. In addition, to monitor and optimize spectrum use, significant expertise and sophisticated features are required.

Although cost (CAPEX and OPEX) should be considered in the efficiency discussion, semantics issues arise such as the distinction between "spectrum" and "network" expenditure. In any case, the cost of managing spectrum is linked to spectrum complexity.

Complexity

Spectrum is inherently complex. To begin with, its use is subject to the laws of physics. Wireless signal propagation depends on the spectrum band and factors such as the weather and the natural environment (e.g., the impact of rain and trees has been a popular topic for 5G mmWave). Maximum capacity is also dependent on the bandwidth available per band.

Moreover, interference is a major concern. Whether narrowband or broadband, constant or transient, RF or passive intermodulation (PIM), interference directly affects spectrum efficiency. To make matters worse, the "everything flows", dynamic nature of the radio environment means that the optimal use of spectrum necessitates ongoing monitoring.

On top of interference, various network or device/handset issues[6] can be detrimental: from suboptimal configuration and technology (e.g., 5G-4G) interworking or insufficient capacity to underlying infrastructure (e.g., fiber) or server performance degradation and downtime. Even some features for better spectrum efficiency are complex. The combination of licensed and unlicensed spectrum (e.g., through 4G and WiFi) or the use of "smart antennas" are just two examples.

New network architectures—such as cloud RAN or the notion of fronthaul and midhaul—should also be considered. And what about deploying site infrastructure, which is often blocked by concerns over electromagnetic radiation, aesthetics or construction? As with cost, semantics[7] are an issue here. Finally, there is complexity in regulating spectrum worldwide. Harmonization is likely to remain a concern for standardization and allocation of spectrum bands in each country.

5. Initiatives around open-source hardware and software infrastructure have focused on reducing the cost of mobile networks. Such considerations would add to the complexity of including cost in the definition of spectrum efficiency.
6. Any factor that may affect spectrum efficiency directly or indirectly should be considered, including handset performance issues. Of course, the consideration of every single factor is not easy in practice.
7. Quantifying the cost of spectrum is not straightforward. This is further commented in the next section.

So, how do we address these challenges of a technical (including physical aspects) and business (regulation and financial) nature? 5G seems to be promising, but. . .

The 5G paradox

As commented earlier, the 5G spectrum discussion tends to focus on regulation and acquisition cost. Challenges around the use—and monitoring—of spectrum appear to be secondary. Why?

To keep it simple, there are two main reasons. First, 5G depends on exciting foundations such as network virtualization, analytics and automation. Important discussion topics for past "Gs" are less interesting than, say, artificial intelligence. Spectrum (and radio) does not "sell" as much.

The second reason lies in the nature of 5G: a key 5G characteristic is the efficiency in its use of network resources. To paraphrase a best-selling book about the end of history, if spectrum can be used as efficiently as possible, 5G would appear to bring an "end" to spectrum efficiency challenges.

This is the paradox with 5G: it inadvertently adds to the spectrum challenges that it will help us address. We should not assume that 5G will resolve every single efficiency issue (definitely not when first deployed). And we should be clear about the definition of spectrum efficiency.

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The essence of spectrum efficiency

Efficiency [ĭ-fĭsh'ən-sē], noun (general and science definition on dictionary.com)

- *The state or quality of being efficient or able to* ***accomplish something*** *with the* ***least waste of time and effort****; competency in* ***performance*** *(General)*
- *The* ***ratio*** *of the effective or useful output to the total input in any* ***system*** *(Science)*

The reference to efficiency can imply different things. Based on the definition of the word, the points below should be of interest in determining the focus of any effort to maximize spectrum efficiency.

Something (capacity)

What is this "something" we want to accomplish through spectrum? In effect, it is capacity or bits of information in time (seconds) and frequency (Hz). Alternatively, and as spectrum bands and bandwidths are discussed in Hz, we are after data rate or throughput (bits/second or b/s) per Hz.

Either way, we typically refer to b/s/Hz to compare the spectrum efficiency[8] for different mobile technologies. So, this standard definition should suffice. Or does it?

8. Spectrum efficiency may refer to users/s/Hz (by associating users with a minimum average data rate). In terms of b/s/Hz efficiency, technology comparisons may not always be on the same basis, as different band characteristics or extra capabilities (e.g., the use of massive MIMO for 5G) increase the maximum possible efficiency.

Time and effort (cost)

Take a new technology that is 20 % more spectrally efficient (in b/s/Hz) than an existing one. If a prerequisite for this efficiency is a network cost increase of 25 %, would the new technology still be seen as more spectrally efficient? And what about the acquisition cost of spectrum licenses?

In practice, new mobile generations should be less costly than past "Gs". But the cost consideration can add complexity and cause debate around the factors to incorporate in the definition of spectrum efficiency. So, a technical or output focus may constitute the most realistic approach.

Performance (nominal and actual)

Any reference to efficiency should be clear in terms of definition/measurement. Is the quoted efficiency the maximum possible value measured in a controlled environment, such as a lab? Is it the best possible value achieved in the field, for example in a network with only a single user and at line of sight? What about the useful or net, non-signaling related, data use of spectrum?

Spectrum efficiency depends on the network and user characteristics. Fluctuations should also be expected during the day or from day to day. So, is the reference to a single value sufficient?

Ratio (output versus input)

The b/s/Hz ratio[9] could be mapped into a spectrum efficiency index, potentially expressed as an alphabetical character, similar to the energy efficiency index (see Figure 3 below).

Figure 3. Simplified diagram of a spectrum efficiency index (similar to energy efficiency)

However, in addition to various limitations, this ratio is not a percentage value[10]. In other words, the ratio can be used to compare different technologies, but when trying to assess spectrum efficiency versus its maximum possible value, a different definition would be required.

9. Effectively a ratio of throughput (b/s) over frequency (Hz).
10. A commercially focused percentage ratio could be ROI-like, i.e., revenue over the acquisition or overall cost of spectrum.

System (in space and over time)

A better definition may include a "spatial" factor, typically the number of sites/cells. By referring to b/s/Hz/cell, a technology less efficient in b/s/Hz but requiring fewer cells could outperform another technology. The number of cells also introduces a cost consideration, albeit crude[11].

But if we talk about spatial factors, should we not be more specific (e.g., refer to urban, suburban or rural environments)? And what about considering only the areas where a performance threshold is achieved? Spectrum efficiency trends, (i.e., evolution over time) should also be important (and of interest to regulators and supranational organizations too).

. . .

For many, the best definition of spectrum efficiency should be ROI-like or at least comprise commercial/business metrics such as revenue or number of users or NPS. For others, the definition should focus on the consumer/enterprise and societal benefit (which would also link it to the spectrum auction priorities). Of course, as explained in the previous section, any cost consideration would be debatable. In any case, as per the above points, spectrum efficiency in practice could be based on the following.

Focus	Details
Network	Network-specific criteria such as control/user plane, UL/DL, band/carrier, technology, vendor, cell/site; alternatively, reference to % KPIs/KQIs such as accessibility, retainability, etc.
General	Generic metrics such as time, area/environment, service/application, users, use case or verticals, operator, operator group, region (potentially, revenue or NPS too)
Statistical	High-level statistical nature such as minimum (min), maximum (max), mean or standard deviation (stdev) value
Conditional	Measuring spectrum use only if a certain threshold (e.g., minimum data rate for users in a specific area) is satisfied
Weighted combination	Combining statistical (e.g., mean and standard deviation) or different criteria (e.g., spectrum efficiency per area and spectrum efficiency per user)
Percentage	Based on the measured/estimated value (as per the chosen criterion) versus the maximum respective value; see also alternative definition for Network above

Table 1. Spectrum efficiency definition focus (factors/criteria)

11. The cost per site/cell comprises a number of factors. As commented earlier, to consider all relevant factors would be a challenging exercise. It would also raise the question about spectrum and network "equivalence".

If we use η_S to denote spectrum efficiency[12], the following mathematical expressions would apply to the weighted combination and percentage value calculations. The spectrum efficiency definition examples shown in Table 3 should also be useful.

Weighted value	Percentage value
$\eta_S(c_i) = \sum_j \{w_{ij} \times \eta_S(m_{ij})\}$	$\eta_S(c_i^{\%}) = \frac{measured(m_i^{\%})}{max(m_i^{\%})}$
c_i: criterion i (absolute or % value), m_{ij}: metrics for criterion i, w_{ij}: weight per metric m_{ij}, $\sum_j w_{ij}$=1 (or 100 %)	*$c_i^{\%}$: criterion i (% value), m_i: measured/estimated metric for criterion i Note: Percentage values for weighted metrics may be considered too*

Table 2. Weighted and percentage calculation of spectrum efficiency

Examples	NW	GEN	STAT	COND	WGHT	%
Mean DL data rate in urban environments	DL, data rate	urban	mean	-	-	-
Max number of users with acceptable QoS (or QoE)	QoS (or QoE)	users	max	accept. QoS (or QoE)	-	-
Min data rate % + min number of users % + accessibility % + retainability %	various	users	min	-	25% each	%
UP DL data rate per VIP user in busy hour	UP, DL, data rate	VIP users, busy hour	mean, stdev	-	70%, 30%	-
% of cells with acceptable data rate	DL, data rate, cells	-	-	accept. data rate	-	%
NW: Network; GEN: General; STAT: Statistical; COND: Conditional; WGHT: Weighted; %: Percentage						

Table 3. Spectrum efficiency definition examples

In practice, spectrum efficiency focuses on specific challenges and metrics such as throughput[13], accessibility, retainability, etc. These should be seen as “alternative” definitions, based on trends (e.g., performance for “equivalent” periods of 7 days) and measured/estimated (not nominal or simulated) values. In some cases, the considered metrics are weighted and combined.

A business-as-usual approach, complexity and lack of data may have hindered more sophisticated spectrum efficiency definitions. Big data and advanced insights, together with the need to squeeze more from network resources including spectrum, are likely to change this. They will also influence the focus of spectrum efficiency solutions.

12. The Greek letter “η” (pronounced “eta”) is used in engineering to denote efficiency.
13. The standard (capacity) definition of spectrum efficiency is data throughput/rate focused.

Practical solutions for better spectrum efficiency

The spectrum efficiency definition inevitably affects the nature of solutions to increase that efficiency, if needed. On a high level, there are a plethora of “obvious” solutions.

To begin with, an “obvious” solution is to deploy a more spectrally efficient technology that will complement and gradually replace—through spectrum re-farming—legacy technologies[14]. In fact, 5G boasts use-case specific (spectrum) efficiency as part of its versatile nature and network slicing capability.

Better planning in the use of spectrum is another solution. Each spectrum band, as already described, has distinct characteristics in terms of signal propagation and bandwidth. So, spectrum deployment needs to target specific use cases, based on solid business grounds.

Even if spectrum cost is not directly considered, it remains a concern, very much linked to regulation. For better efficiency, innovative regulation models will be required. Such models may well focus on the actual use of spectrum. The end of exclusivity based on the “use it or lose it” model and the sharing of licensed spectrum may indeed be the future.

On the organizational side, availability of more bands (potentially through repurposing) and better band harmonization will be helpful too. Timing is also a key factor, as per debates on the availability of licensed spectrum for 5G. To be accurate, a “right time” rather than a “the earlier, the better” strategy would be recommended. In addition, the significance of unlicensed spectrum will increase.

We should not forget specific technical solutions that can help, such as directional antennas, sectorization, frequency reuse, smart antennas, FDD and TDD combination as well as better modulation schemes. And, semantics issues aside, what about solutions for issues that indirectly affect the use of spectrum? For instance, as fiber becomes increasingly more important, the ability to quickly identify and resolve fiber network issues will be mandatory.

All in all, the approach[15] to spectrum efficiency spans a number of areas and would depend on each MNO (network characteristics, challenges, priorities, etc.) and the spectrum management lifecycle phase involved, from acquisition to deployment to optimization to re-farming. But there are generic enablers or solutions to address the challenges of complexity and cost, and to make the most of the available spectrum.

Figure 4. Focus on monitoring, analytics and automation as key enablers for spectrum efficiency

. . . best-in-class geolocation accuracy to optimize network deployment and increase RAN performance efficiency.

– Juan Carlos Garcia, RAN GCTO Director, Telefonica Group

14. While areas are typically considered in two dimensions, the potential relevance and need to also account for elevation (i.e., three dimensions) should not be excluded.
15. Specific solution areas, such as Test & Measurement or Service Assurance, are not described here in detail.

Monitoring

Can we enhance something that we do not monitor? To increase spectrum efficiency, we need solutions that help us understand how spectrum is used.

For example, interference—even narrowband interference of transient nature—can be detrimental. Which is why monitoring solutions should provide us with real-time, granular visibility into such issues. This information may be based on field (onsite) measurements taken using portable equipment. But remote (centralized) 24x7 monitoring should be the norm. For a number of reasons, including less time for issue resolution, such solutions are key to increase spectrum efficiency.

This is also true as network transformation and 5G introduce new challenges. For example, in cloud RAN it is crucial to detect fronthaul issues such as PIM that directly affect spectrum efficiency. In addition, despite its indirect impact, the underlying fiber infrastructure should be monitored.

. . . customer intelligence [to] turn data into market differentiation and efficiency improvements.

– Khawla Al-Jaber, Technology Strategy Director, Zain Group

Analytics

The difference between data and intelligence should be clear. For optimal spectrum efficiency, we need solutions that provide us with actionable insights, not just raw data.

Of course, access to data should not be underestimated. Just the definition of spectrum efficiency can be multifaceted, as we have seen. To focus on specific areas or users, such information must be available (e.g., through geolocation[16]). But it is not just about data, saved in big data repositories. Actionable insights can optimize spectrum management, for example through proactive troubleshooting and complex issue diagnostics.

In fact, network expertise and data science driven insights will be critical for 5G. But they are also crucial today to optimize the use of spectrum and assist in efforts to re-farm it. The move to predictive and prescriptive insights will also help improve spectrum efficiency.

Automation

Both the cost and complexity of spectrum management call for an enhanced operational approach. Such an approach would be based on automation.

Although the 5G discussion has been combined with advanced automation concepts such as machine learning and artificial intelligence, automation is a broader topic. Yes, autonomous networks that can learn from, anticipate and pre-empt issues are of great interest. But there is scope to increase automation today and enhance spectrum efficiency based on a combination of human (expertise) and machine capabilities.

Indeed, intelligence amplification driven, semi-automated approaches should not be discounted. Their impact is seen in spectrum efficiency projects where software with embedded network expertise accelerates and enhances decision making by both operational and engineering teams. Of course, the next stage of network autonomy and optimal spectrum efficiency may not be far away.

The following section presents some of the lessons learned in practice, which are related to the high-level spectrum efficiency solutions of monitoring, analytics, and automation.

16. This would typically refer to customer experience geolocation solutions that use IMSI/IMEI-relevant network data to provide granular insights on an area (through the so-called “heat” maps) rather than cell or drive test route limited basis.

Spectrum efficiency lessons learned in practice

Projects worldwide show that the vital resource of spectrum is not optimally used. The following subsections reflect MNO efforts to address various types of spectrum efficiency challenges.

***Note**: The examples below are only summarized descriptions of MNO projects, and do not form an exhaustive list of case studies directly/indirectly related to spectrum efficiency.*

Squeeze existing network resources

To maximize spectrum efficiency without extra infrastructure, network performance should be analyzed. Even in mature mobile networks, at least one of the deployed bands and technologies unveils inefficiencies when scrutinized. Significant improvements may be possible by optimizing the performance of existing network assets through changes that do not incur substantial cost.

HIGHLIGHTED CASE STUDY: Focus on network parameters—Tier 1 Operator Group OpCo, Latin America

In a 4G optimization project in Latin America, “cell edge” performance improved following in-depth analysis and mobility parameter reconfiguration (e.g., reselection, handover). By reducing the mean number and variability of drops and blocks in affected areas, the MNO achieved an estimated 23 % improvement in 4G network quality, and enhanced spectrum efficiency with minimal cost.

Reduce investment in required new infrastructure

Spectrum efficiency can be linked to the number of sites/cells. The ability to achieve similar network performance but with fewer sites/cells from the same chunk of spectrum is definitely of interest to MNOs. Such a notion of efficiency may also become relevant when new site/cell installations are up for approval by local authorities.

HIGHLIGHTED CASE STUDY: Focus on the number of small cells—Tier 1 MNO, Europe

A European MNO looked into a new process for small cell deployment, based on automation and more accurate geolocation of data hotspots. By following the new process, the MNO could potentially reduce the number of new small cells by 25 %. With spectrum efficiency linked to the number of deployed sites/cells, improvements would be seen per new cell and overall.

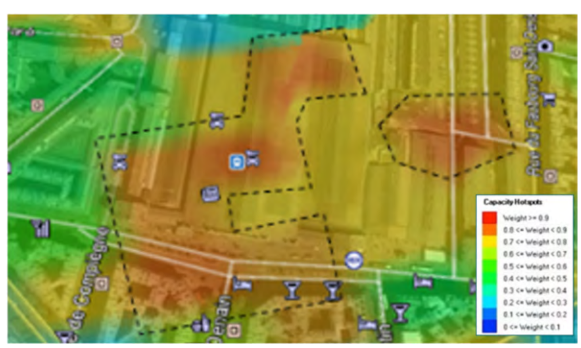

Figure 5. Locations (in red) for better small cell deployment and spectrum efficiency (note: representative EXFO Nova RAN screenshot that does not refer to the MNO in the highlighted case study)

Understand domain-specific and end-to-end network performance

Spectrum efficiency is not just about radio performance. End-to-end network visibility is crucial to help understand why available spectrum is not optimally utilized. End-to-end visibility also means that the performance of each network domain should be monitored and optimized. For example, in the case of VoLTE, the IMS performance affects the service and the optimal use of radio resources.

HIGHLIGHTED CASE STUDY: Focus on VoLTE E2E—Innovative MNO, N. America

After launching VoLTE, an MNO examined the RAN, core (EPC), IMS and end-to-end network performance, and analyzed the user-perceived VoLTE call quality[17] and its correlation with radio network KPIs. The MNO wanted to identify and address any issues that might affect the adoption of VoLTE, which was key for enhanced voice calls and spectrum efficiency.

Expect the unexpected when troubleshooting

It is important to monitor (radio) network performance and troubleshoot issues with an open mind. While experience remains crucial, network operations/engineering teams should not exclude sources of interference that may not have been noticed before. This is particularly true as networks become denser and more complex, and as the number and type of interference sources increases.

HIGHLIGHTED CASE STUDY: Focus on RF interference—Tier 1 MNO, N. America

When the MNO network operations team detected narrowband RF interference affecting a site, they had to investigate further to discover the cause: two unlicensed UHF monitors at two distinct locations close to the site. They also determined that nine additional sites were affected. After the sources of RF interference were removed, the network KPIs and spectrum efficiency in the area improved.

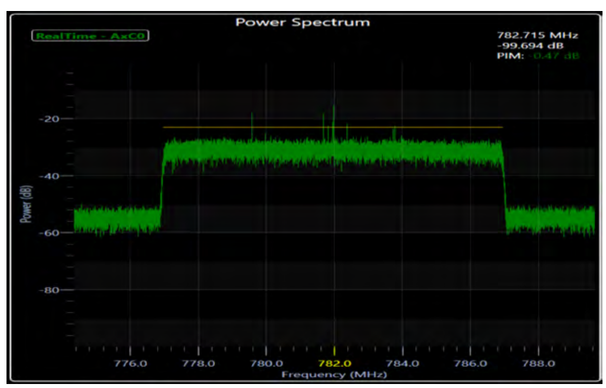

Figure 6. Narrowband RF interference affecting spectrum efficiency (note: representative EXFO SkyRAN screenshot that does not refer to the MNO in the highlighted case study)

17. Based on mean opinion score (MOS).

Learn more

[Website]

[Case studies]

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Uncover service/technology adoption issues

To fully benefit from new and more spectrally efficient technologies, customer usage needs to move from existing legacy networks to new networks (for example, from 3G to 4G). Any delay in the adoption of a new service or technology—regardless of the underlying device or network performance cause—effectively implies a delay in the optimal use of available spectrum resources.

HIGHLIGHTED CASE STUDY: Focus on users/devices—Leading MNO Group, Middle East and Africa

When analyzing 4G adoption across OpCos, an MNO group noticed a high percentage of 2G/3G-only devices and data. Worryingly, an OpCo showed a high percentage of 2G/3G data relative to 2G/3G devices (35 % versus 25 %). The MNO group identified and targeted the potential reasons limiting 4G adoption and spectrum efficiency, such as 4G promotion or areas with 4G coverage/other issues.

Conclusion

Radio/RF spectrum or simply—for the purposes of this document—spectrum remains a "hot" mobile industry topic. As data demand increases and use cases multiply and change in nature, even the 5G promise of optimal network resource efficiency should not cause us to ignore the challenges of using spectrum. Indeed, we need to tread carefully, especially with the initial deployments of 5G.

This white paper presented a high-level attempt to discuss and tackle the main challenges related with the optimal use of spectrum in the era of 5G. The document looked into key topics such as the definition of efficiency—not as straightforward as we would typically think—or solutions to increase spectrum efficiency in practice. This white paper also presented some lessons learned to highlight approaches followed by different MNOs worldwide.

Note*: For a more detailed discussion on spectrum—from its distinct challenges or the definition of efficiency to relevant solutions and lessons learned from diverse projects—please contact EXFO.*

Acronyms

2G/3G/4G/5G	2nd/3rd/4th/5th generation mobile communications standard
CAPEX	Capital expenditure
CBRS	Citizens broadband radio service
E2E	End to end
EPC	Evolved packet core
FDD	Frequency division duplex
FWA	Fixed wireless access
GCTO	Group chief technology officer
IMEI	International mobile equipment identity
IMS	IP (Internet Protocol) multimedia subsystem
IMSI	International mobile subscriber identity
IoT	Internet of Things
KPI	Key performance indicator
KQI	Key quality indicator
MIMO	Multiple input multiple output
MNO	Mobile network operator
MOS	Mean opinion score
NPS	Net promoter score
NSA	Non-standalone (5G mode)
OpCo	Operating company
OPEX	Operational expenditure
PIM	Passive intermodulation
QoE	Quality of experience
QoS	Quality of service
RAN	Radio access network
RF	Radio frequency
ROI	Return on investment
SA	Standalone (5G mode)
SNR	Signal-to-noise ratio
UHF	Ultra high frequency
TDD	Time division duplex
VIP	Very important person
VoLTE	Voice over LTE (Long Term Evolution, 4G standard)
WiFi	"Wireless fidelity"

