Framework for Demystifying M2M Spectrum Regulation

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Abstract: The evolving M2M landscape not only cuts across diverse verticals but also embraces a range of networks and devices. This diversity leads to varied and dynamic requirements, which make regulatory policy formulation a daunting challenge, especially the regulation of spectrum. Through this paper, we would like to share our perspective on the changed way in which a regulator should look at demand, supply, and utilization of spectrum. The proposed framework encapsulates various factors which should be considered by regulators. This study also illustrates how some of the proposed approaches (e.g. understanding spectrum demand) have been implemented by certain regulators. We also augment our view with specific data points from certain vertical industries. Finally, our study details the policy levers (e.g. spectrum fees, sharing regulations, License Authorization Model) which can help a regulator in reaching the desired policy posture.

Overall this framework attempts to demystify the spectrum policy regulation in the age of M2M/IoT. Additionally, our paper can also serve as a reference to new M2M/IOT players, who look forward to the information about the impact of spectrum regulation on their solution or their vertical.

Keywords: M2M, IoT, Regulator Policies, Spectrum, Framework

Introduction

Post the liberalization era of telecom services, there has been a clamour to deregulate the sector and take a true market-based approach towards telecom services. However, telecom services (in most cases) come within the category of essential public services and hence attract significant control and audit by government. Hence, telecom regulations tend to take a hybrid path between regulation and de-regulation. The key objectives of a regulator — promoting universal access, fostering competitive markets, preventing abuse of market power, and

optimizing the use of scarce resources (e.g. radio spectrum, rights of way, identification numbers etc.) — continue to be the same with the advent of Machine-to-Machine (M2M) communications and the Internet of Things (IoT).

Implementation of such a hybrid (regulated free market) approach in an M2M-driven, fast-changing environment is expected to continue to keep the regulators on high alert. To be responsive with an effective, timely and optimal policy regulation, regulators will need to assiduously keep track of spectrum demand movements and utilization trends.

Until the recent past, voice, SMS and web browsing (using broadband) were the only applications that primarily influenced the traffic demand projections. Additionally, other factors such as the number of devices/subscriber combination profiles were also limited: hence demand forecasts were not the biggest of all challenges. However, with the increasing adoption of M2M/IoT, the traffic demands are expected to undergo a sea change. This directly implies that the approach and decisions on spectrum policy (including analysis of demand and supply) would need to adapt as well.

At this juncture, a comprehensive framework or a structured catalogue of factors, which are essential for M2M policy regulation, could immensely help regulators in demystifying the impact of this fast-changing environment on policy regulation.

The regulators would generally consider multiple dimensions while developing such a regulatory model. These dimensions typically consist of Licensing and Authorization of Spectrum, Roaming-related Regulations, numbering plan, BMAQ (Billing, Mobility, Authentication and Quality of Service – QoS), security and privacy postures. While each of these dimensions throws an intricate challenge to the regulator, we believe that the spectrum regulation is one of the most daunting and primary challenges of all.

The typical dilemmas that regulators face in the domain of spectrum can be boiled down to questions like the following. Is the unlicensed band sufficient to maintain scalability with QoS for various use cases? Do the demand and other requirements warrant a separate licensed band for M2M? As expected, there is no panacea for spectrum access regulation. This can be attributed to the fact that the technical requirements (for example, data throughput, reliability, range, and output power) vary dramatically across the gamut of use cases. To exacerbate the confusion in sizing up the varied and fast-changing technical requirements, a regulator is also expected to align its spectrum access policies to regulations and standards of other verticals. The advent of new cognitive radio, Dynamic Spectrum Access (DSA) and other technologies, definitely do not make the task of the regulator any simpler.

Here we present our perspective on the evolved approach (Framework of factors) that could help the regulator in deciphering demand, supply and utilization of spectrum in the age of M2M/IoT.

The Framework

Our proposed framework of factors, when considered, will help regulators look at this new world with the same old dimensions of supply, demand and utilization, but with an evolved lens. An in-depth study and analysis of the three dimensions would help in deciphering an optimal target M2M spectrum policy posture. We also plan to use selective sample analysis of some regulators to illustrate how some aspects of our proposed approaches can be applied. Additionally, in explanation of certain sections of the framework, we also plan to augment our view with specific data points from certain vertical industries.

The target spectrum posture in a specific spectrum band is defined in terms of the application of various policy levers in the specific band of consideration. Hence, the last part of our study plan shall delve into earmarking and detailing the policy levers (e.g. spectrum fees, sharing regulations, License Authorization Model) which can help the regulator in reaching the desired policy posture.

In the next sections, we elaborate how the analysis of spectrum, demand, supply, utilization and policy orchestration has evolved with the influence of M2M/IoT.

Figure 1. Framework for M2M Spectrum Regulation

Factors Shaping Target Spectrum Policy Posture

In this section, we offer a detailed explanation of the factors enumerated in the framework.

Spectrum Demand

This section is dedicated to detail and illustrate the new-age (influenced by M2M/IoT) factors that the typical regulator might look into for sizing and deconstructing spectrum demand and thereupon how the regulator might choose to classify this demand in terms of spectrum requirements. Local demand insights, the impact of global demand and the perspective of vertical specific demands are three principal areas of demand analysis. In the subsequent sections, we shall detail each one of these.

Local Demand Insights

Regulators would typically resolve the answers to the following four questions sequentially to deconstruct local market demand insights.

1. Describe and categorize use cases that are forecasted to grow in short/medium and long term.
2. For various use case categories, evaluate the options in terms of:
   a. Band of Operation;
   b. Available Access Technology.
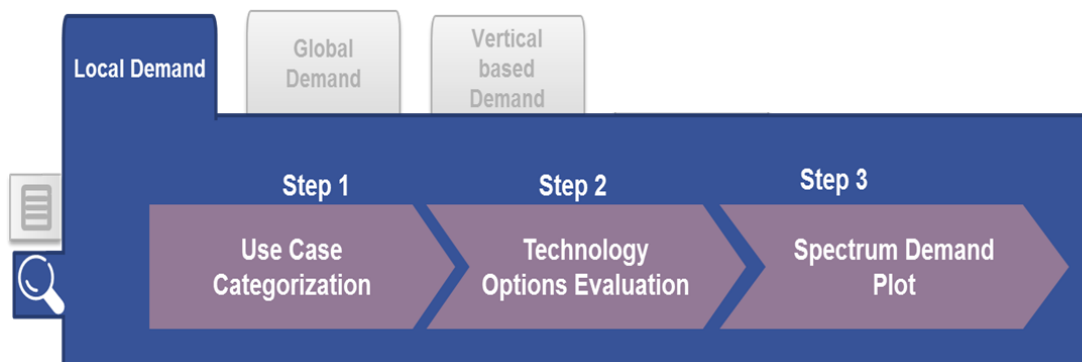3. Decipher implications of the above on spectrum demand.

Figure 2. Local Demand Analysis

As a first step, the regulator must identify the use cases that are expected to grow within the geography of its influence: it is essential for the regulator to do an independent and in-depth analysis of each identified use case. Typically, the regulator should enlist all the parameters of identified use cases shown in Figure 3.
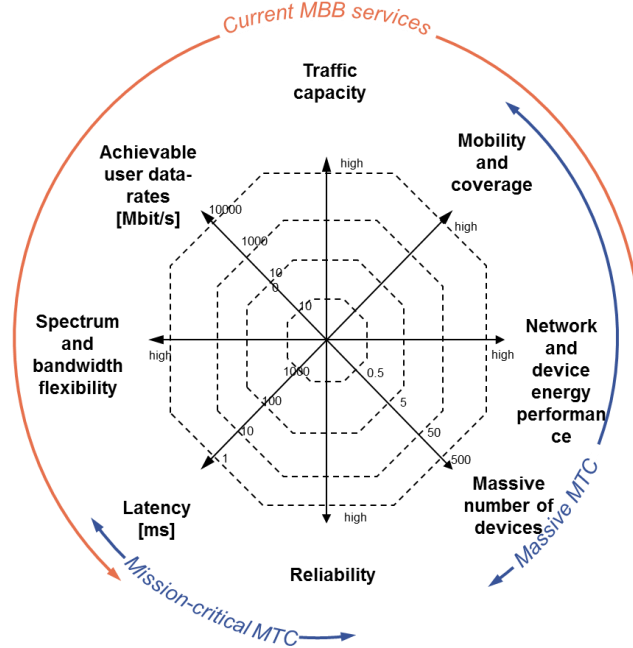
Figure 3. M2M Use Case Analysis Dimensions (Source: Murara, 2017, p. 15)

When a regulator delves into all 8 dimensions of use cases, they shall be able to categorize use cases and model the requirements. Below is an example of such a categorization exercise that was undertaken by Hattachi & Erfanian (2015).

Table 1. Example M2M Use Cases Categorization (Source: Hattachi & Erfanian, 2015, p.27)

Use Case Category	User Experience Data Rate	Data Latency	Mobility
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 0-100 km/h
Indoor ultra-high broadband access	DL: 1 Gbps UL: 500 Mbps	10 ms	Pedestrian
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0-120 km/h
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	On demand, 0-50 km/h
Mobile broadband (MBB) in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h
Airplanes connectivity	DL:15 Mbps per user UL: 7.5 Mbps per user	10 ms	Up to 1000 km/h
Massive low-cost/long-range/low-power MTC (Machine type Communications)	Low (typically 1-100 kbps)	Seconds to hours	On demand, 0-500 km/h
Broadband MTC	See the requirements for Broadband access in dense areas and 50+Mbps everywhere categories		
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian
Resilience and traffic surge	DL: 0.1-1 Mbps UL: 0.1-1 Mbps	Regular communication: not critical	0-120 km/h

Use Case Category	User Experience Data Rate	Data Latency	Mobility
Ultra-high reliability & Ultra-low latency	DL: From 50 kbps to 10 Mbps UL: From few bps to 10 Mbps	1 ms	On demand: 0-500 km/h
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand: 0-500 km/h
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	<100 ms	On demand: 0- 500 km/h

A regulator would also need to consider the topographic distribution of use cases in the above categories.

Subsequently, in step 2 (Technology Options Evaluation – see Figure 2), the regulator typically superimposes the use case requirements categories in step 1 onto the spectrum band and available technology options. For identifying the appropriate spectrum band, a regulator can come up with feasible options for each category of use cases by understanding the behaviour of these bands. Multiple studies have analyzed the factors to be considered for selecting a suitable operational band for a specific use case. Typically, these studies articulate that the selection of a carrier frequency band is a trade-off between radio-frequency (RF) propagation characteristics, noise floor, and terminal antenna size.
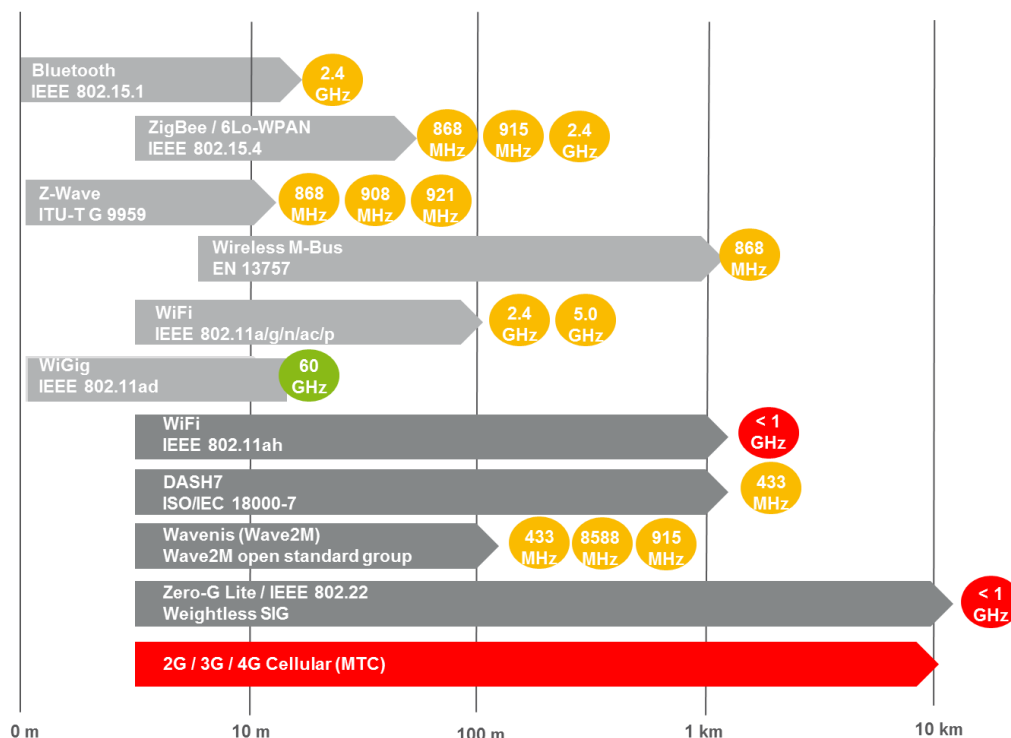

Figure 4. Example M2M Technologies and Spectrum Bands (Gupta, 2017, p. 14)

The next key step that the regulator must look at is the availability of technology options for those use cases in identified bands. We illustrate one such analysis (undertaken by the Institution of Engineering and Technology) in Figure 4.

Lastly as step 3, based on all the above factors, including all 8 dimensions of use cases, the preferable band of operation and technology availability, a regulator can come up with a local spectrum demand forecast. In order to do this, a regulator can classify requirements into categories like spectrum requirements for wide area coverage and short-range coverage. We illustrate this below with a similar thought process adopted by RSPG (2016b).
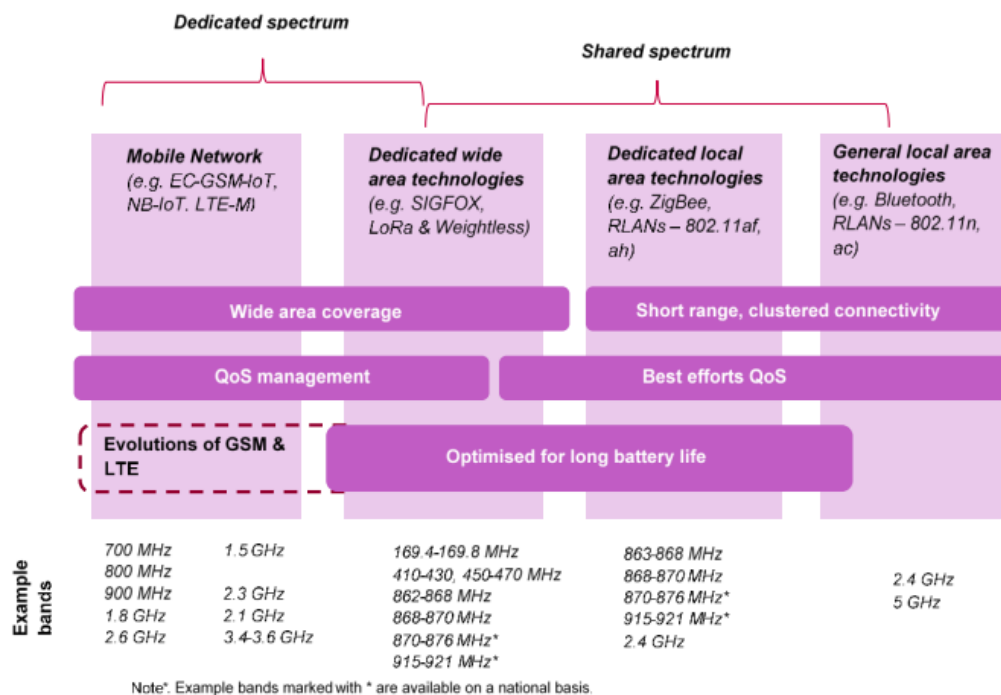

Figure 5. Example M2M Demand Plot (Source: RSPG, 2016b).

With such a classification, the regulator can ensure that it has considered demand in different bands and bandwidths for use cases that require dedicated as well as shared spectrum.

Global Demand Insights

As M2M is inherently a global business, over and above the local analysis it is imperative that regulatory policy caters to the impact of global M2M use cases. The policy must recognize as well as facilitate cross-border data flow, amongst many other requirements. A regulator must consider the scenarios wherein a significant number of roaming M2M SIMs or devices can be expected to enter the regulator's region of authority. For instance, if BMW cars come with pre-fitted global SIMs and are operating on LTE-M, then, while calculating demand, this factor must be accounted for as well. Conclusively, on top of local demand, for some sectors, the regulator might need to add a sliver of demand generated due to the global nature of the business.

Vertical-Based Point of View:

To date, regulators have never had to give specific attention to technical or regulatory requirements of different verticals. But, based on the scale that M2M is expected to take and the impact it is anticipated to have on all verticals, telecom regulators have to work not only with vertical stakeholders but also with vertical regulators to understand the requirements and forecast spectrum demand. Hence, joint consideration is a key underpinning of any equitable and just policy framework. As an illustration, we highlight the points of view of select verticals in the following sub-sections.

Utility Vertical

One of the biggest applications of M2M is smart metering. Smart meters are increasingly being deployed by utility companies to automate meter reading and provide opportunities to save energy, e.g. by providing real-time information on energy use. The deployment of smart meters is forecasted to connect 53 million meters by 2020 (Machina Research, 2014).

The existing and future communication requirements of utilities can be met in various ways. Differences in the grid layout, grid density, geographic grid coverage, amounts and types of renewable energy to be integrated, as well as varying demands in terms of resilience, security, latency, longevity, security, data rates, availability and criticality of communication, determine which communication solution is optimal in technical terms.

To meet these requirements, utilities need access to radio spectrum in a range of frequency bands. Utility-sector-based M2M solution providers are currently focusing on the 450-470 MHz band as a preferred band to meet current and future needs. In addition to this, in future, spectrum above 1 GHz (i.e. 1500 MHz range) may also be needed to support data-intensive applications. These bands offer an ideal compromise between coverage and the limited bandwidth requirements of the critically important utility applications. A harmonized spectrum allocation for utilities will facilitate synergies between utility companies, bring industrial benefits, facilitate cross-border coordination, increase the security of supply and lower energy costs to consumers.

To bring the perspective of a vertical based regulator, let us consider UTCC, Utilities Technology Council of Canada. UTCC supports access to additional spectrum by utilities and other critical infrastructure industries. UTCC has opined that it is critically important for public policies to support access to additional spectrum for utilities because everything in modern society depends on electricity, heat, and water (UTCC, 2017).

The key takeaways for the regulator from the above analysis could be summarized in the following 3 points:

a) How many of those 53 million meters are forecasted in the regulator's territory?

b) What is the license policy and utilization status of the preferred band (450-470 MHz)?

c) Is the technology ecosystem needed to support this thriving in our economy?

It would be prudent to give these issues their due importance when policy regulation is being formulated.

Automotive Vertical

In the automotive vertical, spectrum is essential in providing a host of valuable services, such as navigation services, concierge services, emergency calling and road-side assistance, door unlock, stolen vehicle tracking, crash notifications, and hands-free voice calling.

The automotive M2M sector comprises two main elements, namely factory-fitted "Vehicle Platforms", which support multiple applications, and aftermarket devices typically designed for a single function, such as stolen vehicle recovery or usage-based telematics.

It is anticipated that by 2022 80% or more of new vehicles will be connected with factory-fitted embedded connectivity, which is equivalent to 41% of all vehicles on the road in 2022 (Machina Research, 2014).

The after-market devices come in many different types, including usage-based insurance, stolen vehicle recovery, and navigation. This is driven by vehicle replacement rates and the adoption of usage-based insurance (UBI). From around 1% today, UBI is forecasted to become the norm by 2022 (Machina Research, 2014). These high-demand automotive applications will be significantly affected by constraints on the supply of spectrum. The automotive sector requires a large number of radio frequencies, as given in the below table.

Table 2. M2M Automotive Spectrum Requirements (Source: Bhattacharya, 2015)

Spectrum Band	Automotive Requirement
24.05-81 GHz	Blind-spot detection, lane departure prevention system, collision avoidance system, adaptive cruise control
22-29 GHz	Automatic start/stop technique
5.9 GHz	Car-to-car, car-to-infrastructure communication
1.602 GHz	Global navigation satellite system
1.575 GHz	Global positioning system
868.10 to 868.40 MHz	Short-range communication, keyless on/off

Spectrum Band	Automotive Requirement
433 to 434.79 MHz	Remote keyless entry, tyre pressure monitoring system (TPMS), immobilizers, keyless go
314 to 315 MHz	Remote keyless go, TPMS

Regulators see the need for interference-free access to spectrum in order for that technology to work as expected. We also notice steps that ITU is taking to enable a harmonized approach towards addressing such sector-specific requirements. For instance, ITU has recently allocated 79 GHz frequency spectrum for the operation of short-range high-resolution automotive radar (ITU, 2015). The allocation of the 79 GHz frequency band provides a globally harmonized regulatory frequency for automotive radar to prevent collisions, which will improve vehicular safety and reduce traffic accidents. Based on the criticality of the autonomous driving use case, it is expected that an automotive regulator might have its own regulations in place. Hence, over and above the three key takeaways that we mentioned in the utility sector, in Automotive it is imperative that telecom regulators take the perspective of automotive standards and regulations into account.

Overall, it is important that in this M2M-driven changed environment a telecom regulator looks at the above vertical-based market forecasts, technical requirements and vertical regulators' perspective for a policy that is optimally tuned to stimulate and harness the potential of all key verticals.

Over and above local demand, global demand and vertical-based points of view, there are two key stakeholders, whose interests are one of the primary drivers of telecom regulation – Mobile Network Operators (MNOs) and Mobile Virtual Network Operators (MVNOs).

MNO

Since AT&T is a force to reckon with in the MNO landscape, we choose to take AT&T's perspective on spectrum regulation in M2M/IoT as representative of MNOs. AT&T's documented response to a regulator's (TRAI) call for consultation reads:

> [T]here is no need for governments to allocate dedicated spectrum specifically for IoT or IoT segments. The government should continue efforts to find and reallocate spectrum for commercial mobile broadband use. If sufficient licensed spectrum is allocated for mobile broadband use, there is no reason to expect that dedicated spectrum to support IoT devices should be needed: it should be left up to Spectrum licensees to manage and employ their spectrum in an optimized fashion for the mix of traffic types that may be simultaneously using licensed bands. (AT&T, 2016)

In fact, not only AT&T but most telcos appear at odds with the sector regulator's call to delicense 1 MHz of spectrum at 867-868 MHz and another six MHz from the 915-935 MHz range for machine-to-machine (M2M) communication services. They also see no immediate need to delicense the 'V band' (in the range 57-64 GHz).

Overall it is evident that unlicensed spectrum and associated authorization policy might encourage new players to enter the M2M/IoT space, which telcos want to discourage. We expect global responses from the other telcos to be on the same lines as well.

MVNO/M2M Service Provider

We do not expect the MVNO point of view to be aligned with the MNO on this subject. Dedicated license-free spectrum along with an MVNO's core network would reduce the MVNO's dependence on an MNO for radio spectrum requirements. Though the forecasts suggest an exponential increase in the number of M2M/IoT devices and connections (the majority expected to operate in an unlicensed band), the spectrum allocation continues to be lopsided in favour of a licensed band. For instance, in most developed countries the licensed bands are to the tune of 400-700 MHz, whereas the unlicensed remains to be less than 26 MHz. Additionally, most of this 26 MHz is also shared with other ISM applications. Hence, we expect MVNO's to clamour for a dedicated unlicensed band.

Though it is important for regulators to be aware of the views of all stakeholders in terms of the spectrum bands, quantum of bandwidth and associated licensing model, the decision should be more driven by offering an actual use-case-based demand-driven analysis and conclusions.

Once a regulator has considered all the above factors of spectrum demand, despite the advent of M2M/IoT and changed ecosystem, we believe regulator would have not only an understanding of spectrum demand in each band but also the mapping of the demand to the vertical and use case driving that demand.

From a hypothetical instance perspective, which illustrates the entire spectrum demand analysis thought process, we believe a run-down of demand analysis activity might not be unlike the following description.

Illustration (Australia example): From an Australian perspective, multiple secondary research firms suggest that Smart Agriculture would be the sector with the most number of devices in Australia by 2026. To be precise, one study (Mackenzie, 2018) suggests nearly 16 million smart agricultural devices in Australia by 2026. Once the Australian agriculture regulator validates the plausibility of these forecasts and shares a typical expected geographic or demographic distribution, the telecom regulator's work begins. Though an Australian regulator would

formulate its own classification table, for our illustration sake, we assume that the regulator is following the classification suggested in Table 1. This would imply that Smart Agriculture can be a sub-category within the Massive low-cost/long-range/low-power MTC category. For smart agriculture we do not see a variety of difference in technical requirements from different use cases. However, had that not been the case, the regulator could have defined an additional sliver of subcategories within a Low-power MTC–Smart Agriculture category. A simple call for consultation would easily make the regulator aware of all the technologies (with proposed bands) available to address the use cases within this category. For illustration, let us assume the call for consultation returns LoRa (838 MHz) band (Semtech, 2018) and NBIoT (GSM bands) (Flynn, 2015) as the most appropriate technologies. The regulator, at this stage, might have its own spectrum demand picture like the one illustrated in Figure 5. Thereupon, as the next step, the regulator would need to build a model to forecast the carrier bandwidth required for addressing the 16 million prospective users with similar device and application profiles. Additionally, the regulator would take into account any global impact. (From the perspective of use cases that we are considering, for illustration, we do not foresee any global impact as such.) Lastly, the regulator would hold a round of discussion with the vertical regulator and stakeholders to cater to their perspective on the future in terms of technology and use cases (vertical specific). Hence, from a demand posture perspective, a regulator can have a clear goal for 2026; for example: "We need to provide for 16 million smart agricultural device types in the 868 MHz band". A similar thought process can be applied to all other relevant verticals.

Spectrum Supply

The two key aspects that regulators typically consider from the perspective of spectrum supply are: a) supply should be able to cater to demand forecasts; b) regulations should encourage technologies that have higher spectral efficiency. In the wake of M2M/IoT, it is essential to consider the above two factors in terms of both local and global perspectives for licensed and unlicensed bands. Overall, regulators must look at spectrum supply across bands and apply the above principles across the following three key steps.

Step 1: Band Selection

The objective of this step is to identify the spectrum bands that are relevant from the demand forecast perspective. To identify the appropriate bands, a regulator's own version of Figure 4 can be considered to be a good starting point. For each category of requirements defined in Table 1, the regulator needs to check the bands in which currently available technologies work. For instance, for a category "LPWA (low power wireless access) networks with no QoS requirements", LoRa is a potential candidate technology. LoRa can operate in both licensed and license-free ISM bands, like 335 MHz, 433 MHz, 868 MHz, and 915 MHz etc. An

alternative technology Sigfox (n.d.) radio link uses unlicensed ISM radio bands as well, the frequencies of which are according to national regulation: in US, 915 MHz is used, while in Europe the 868 MHz band is used. By choosing any of the above options, the regulator can ensure that the spectrum supply policy enables one or a set of technologies to address the category of "LPWA networks with no QoS requirements". Just to illustrate the importance of the above perspective, we would like to take the example of an Indian regulator, which missed taking timely action on this front. In India, 865 MHz to 867 MHz was part of an unlicensed band until recently but 868 MHz was not part of this license-free band. It was only in 2017 that TRAI (Indian telecom regulator) recommended to include 868 MHz in this license-free bloc as well (TRAI, 2017). In such scenarios, wherein a regulator has to retrospectively reallocate an existing band for IoT, we anticipate two key impacts: firstly, it delays the adoption of technology in the country; secondly, there are chances of impact on existing users as well.

Step 2: Spectrum Quantum Selection

As a second step, a regulator must look at supply in selected bands from the perspective of the capability to support the prospective scale of demand. Each selected band in step 1 will typically service a particular set of device types. For spectrum supply determination, we believe the regulator can start by categorizing different regions based on device density expected. Then, based on application(s) being served, the regulator can discern peak and average throughput expected per device and optimal duty-cycle times for applications to run reliably. Thereupon, based on the technologies available in the band under consideration, regulators can estimate the supported spectral efficiency and typical coverage range of a cell. Eventually, this will help in the calculation of the number of cells per Km^2 and finally the amount of spectrum required. The significant difference between the M2M/IoT environment and the traditional environment is heterogeneity. The profile types of device/application combinations, available technologies and bands under consideration throw up a wide variety of possibilities. Additionally, variables such as some applications requiring indoor coverage, validity of current propagation models (such as the Hata Model (Hata, 1980)) and vulnerability to interference at higher order carrier bands make the whole estimation process quite complex. As licensed band technologies typically operate in a regulated environment, modelling interference and propagation might not be considered as the most challenging aspect of policy formulation. However, the regulator will have to handle the complexity rendered by a host of new technological paradigms, such as cloud-based radio access network (RAN), dynamic spectrum access, cognitive radio, models of spectrum sharing and possibilities via white spaces. Lastly, multiple technologies operating in the same band might make it difficult to predict the latency that the spectrum quantum can deliver.

Having said that, it is not debatable that the most challenging area in defining spectrum quantum will be the unlicensed spectrum. From a regulator's perspective, the M2M/IoT world has brought about a sea change in the world of unlicensed bands. The license-exempt bands with limitations on EIRP (Equivalent Isotropically Radiated Power), duty cycle etc., were defined based on fundamentals of short-range usage. However, for massive IoT, license-exempt bands are being used for long-range communications. Additionally, retrospectively, it was the downlink which was usually the constraint, but in massive IoT the uplink throughput and number of messages are more critical. These factors will directly impact the interference and performance issues; hence, they need to be modelled in unlicensed band quantum calculations. (IoTA, 2016, p. 10)

Lastly, while defining the spectrum quantum, regulators could also take leanings from other countries and their ratio of licensed to unlicensed spectrum. To illustrate the kind of learning that a regulator can draw from relative comparisons, we would take an example. Example: Australia has a concept of a class licence, which authorises open and shared access to segments of spectrum for designated services.
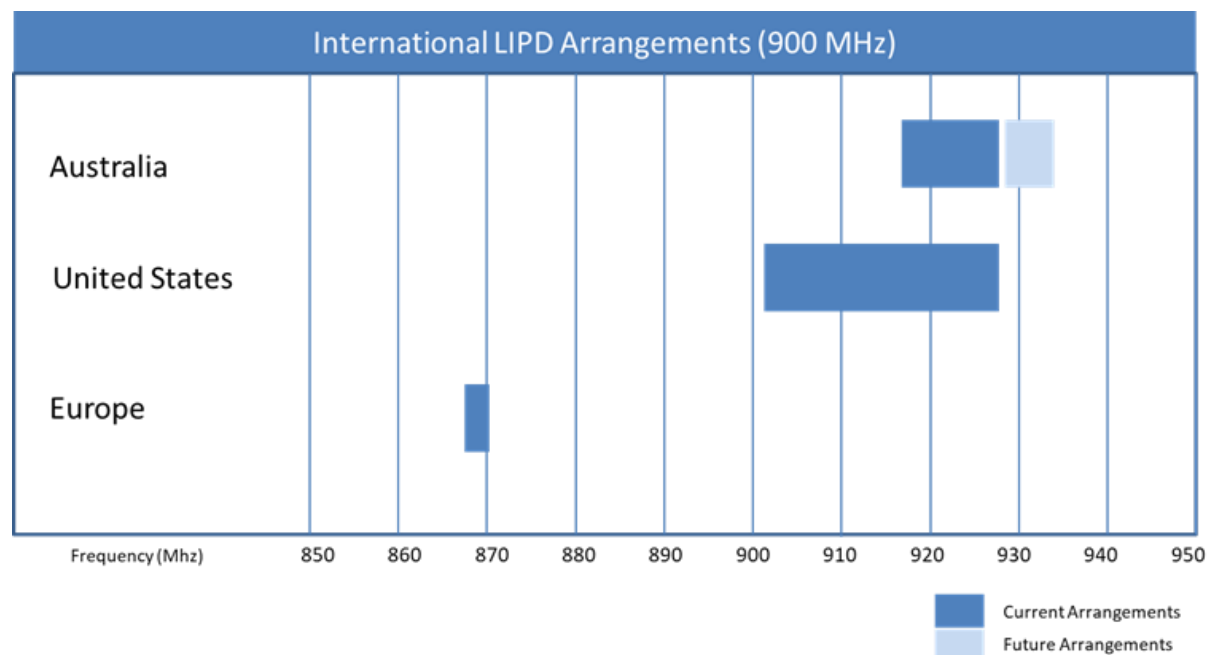

Figure 6. Comparison of Class Licenses (LIPD: Low Interference Potential Devices) in 800-950 MHz Bands (IoTA, 2016, p.4)

The above diagram illustrates the differences in class license allocation in the 800-950 MHz band across Australia, United States and Europe. It is evident that some IoT solutions in specific US bands (900-915 MHz) might not work out of the box in Australia. Another example could be the 868 MHz band, which is globally quite popular for LPWA deployments (with low duty cycle) but which is already allocated to land mobile services in Australia.

Similarly, a regulator can also compare the total quantum of unlicensed band to licensed band locally or compare unlicensed bands in local and global contexts. Such comparisons can help a regulator in selective and strategic harmonization of spectrum.

Step 3: Future Technology Trends

Lastly, it is also important to shape the current policy keeping expected short-term and long-term ecosystem changes in view. As far as some of the current trends are concerned, MNOs are typically using NBIoT, LTE-M and extended-coverage GSM technologies for massive IoT use cases. Some players are augmenting these technologies with other ISM band technologies, like LoRa and Sigfox. For critical IoT use cases, LTE and License Assisted Access seem to be the technologies of choice. A lot of operators are also choosing to switch off their 2G network, which may make available the 800 MHz and 1800 MHz bands.

As a future trend, we foresee a significant number of operators considering TV white spaces, spectrum sharing, cognitive radio and cloud RAN in the very near term.

Finally, on almost every operator's roadmap radar is 5G. Though the final recommendation on official spectrum bands of 5G will be formulated by the World Radiocommunication Conference in 2019, many telcos are launching pre-standard and pre-commercial 5G solutions. Regulators would need to keep a close watch on global 5G movements.

Each of the above future trends can have a profound impact on the spectrum supply posture of a regulator.

Overall, from a spectrum supply perspective, we believe a regulator's spectrum-supply-related decision-making model needs to evolve. In the wake of M2M/IoT-based changes in the ecosystem, if a regulator chooses to consider all factors mentioned in the above section, it will certainly help the regulator in arriving at an optimal spectrum supply policy

Spectrum Utilization

The third step of the analysis is to determine the present utilization of allocated spectrum in all the bands under consideration. The objective of a regulator is to balance the cost of interference against the spectrum utilization gains. The regulator achieves this objective by spectrum monitoring. The core aspects that are monitored include place, frequency and time (van der Vorst, Veldman & van Rees, 2016, p. 85). For a given interval of time, spectrum monitoring verifies if the earmarked spectrum for radio communication is being used appropriately and, as well, that the geographic location aligns with the applicable spectrum regulations. There are various instruments that can be used for monitoring. Typically, each monitoring node is equipped with high-quality software-defined radios (SDRs) that can be configured to collect data on specific frequency bands in specific time frames (Anker, 2010, p.

5). From a broad perspective, spectrum monitoring of diverse applications with different requirements is expected to be much more complex than the spectrum monitoring for technologies supporting traditional voice, SMS and broadband service only.

In licensed bands, the typical application of monitoring spectrum utilization is to ensure that stakeholders that acquire the licenses deploy legitimate bearer services with allowed technology variants, in the shortest time from the date of acquisition of licenses. The other application of monitoring the spectrum in a licensed band is so that the regulator can ensure that the quality of service experienced by users meets the defined benchmarks for urban and rural areas. The tools and practices for licensed band monitoring are also quite mature. The only change that we anticipate is in terms of spectrum monitoring in higher order frequencies (mm-wave) and for new RF modulations, which might be released as a part of 5G specifications. Conclusively maintaining effectiveness and efficiency in licensed band use cases might not be a challenge in general. However, for application-based monitoring, especially for use cases with requirements such as 1-10 ms latency, the regulator might have to adapt the incumbent tools and practices.

While the tools for monitoring spectral efficiency in licensed bands are available and known, unlicensed bands so far were primarily monitored for EIRP. In an M2M/IoT environment, we anticipate the following challenges in spectrum monitoring:

1. An unlicensed band might be carrying data for both short-range and long-range applications;
2. An unlicensed band might be carrying different long-range technologies in the same band.

Here, we would like to give an example of a change that might be required from the spectrum monitoring perspective (van der Vorst, Veldman & van Rees, 2016). Typically, the current monitoring network provides the data 24/7 at a 5 kHz and 1 minute resolution. However, if the actual monitoring of IoT networks is to be implemented, then the occupation of 125 kHz channels at a resolution of 50 ms (LoRa) and the occupation of 100 Hz channels at a time resolution of 1 second (Sigfox) should be made measurable (van der Vorst, Veldman & van Rees, 2016, p. 88).

Formulating the Spectrum Policy Posture

Based on all steps listed above, including a detailed demand analysis, supply analysis, utilization levels and considering the vertical stakeholder views, the regulator can choose its own spectrum target posture. This target posture basically signifies all the spectrum bands the regulator chooses to regulate heavily and the bands that are chosen to be handled with a light

touch. But to actually regulate and reach the target posture, the regulator uses the levers which are to his disposal. In the next section, we identify and delve into these policy levers

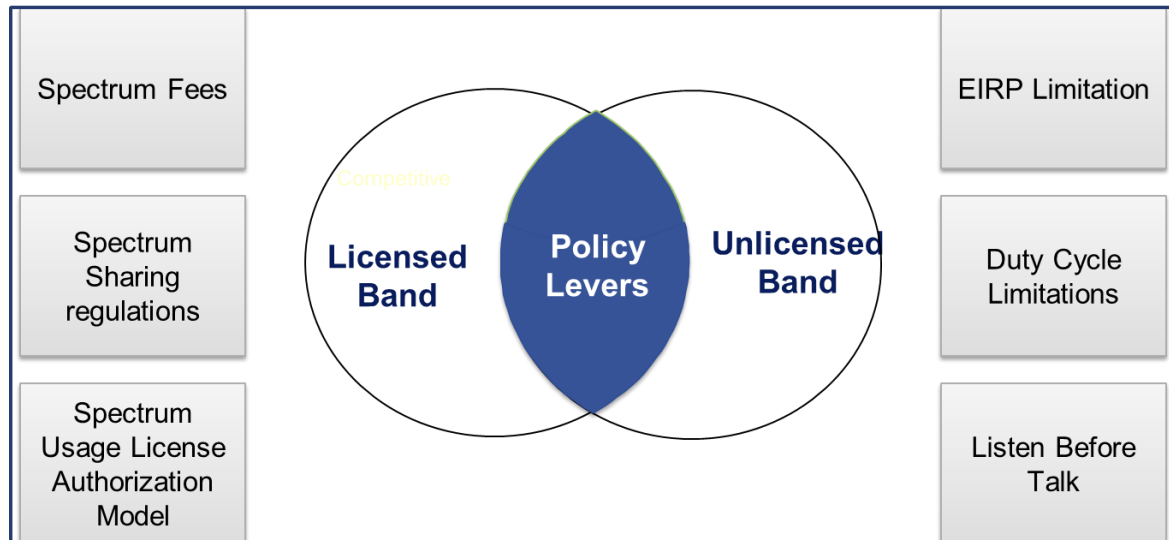# Levers for Shaping the Spectrum Policy

Figure 7. M2M Spectrum Regulatory Levers

A regulator has different levers to identify and regulate the licensed and unlicensed spectrum.

For licensed spectrum, a regulator looks at orchestrating:

- Spectrum fees
- Spectrum sharing regulations;
- Spectrum Usage License Authorization Model.

For unlicensed, a regulator typically looks at

- Technical specification based regulation.

Spectrum fees typically have two key components: spectrum acquisition fees and revenue-based spectrum usage charges.

Regulators have multiple options/approaches to value acquisition fees (Bakker, 2016). One of the methods is to make the acquisition fee equal to the cost of management of that spectrum. This method is, however, not tied to the value of spectrum used and hence may not encourage spectrum efficiency. Another method is to base the prices on market simulation-based shadow prices (based on willingness to pay). There are multiple detailed papers written on the pros and cons of auction-based spectrum acquisition pricing and the impact of a lack of an aftermarket on auction-based pricing, which is beyond the scope of this paper.

The second component of spectrum fees is revenue-based spectrum usage charges, which, though easy to administer, indirectly disincentivizes the efficient use of spectrum. Some

experts in the field (Mazar & Azzarelli, 2016) have come up with formulas for such fee determinations, based on bandwidth allocated, position within RF band, allowed area for usage and more. However, this is just one way of calculating revenue-based fees; based on scenarios, many such permutations can be developed. Overall spectrum fees in specific bands should be determined by the usage in that band and with a vision to encourage free market-based pricing and efficient use of spectrum. Since this is a new evolving market, we urge regulators to initially take annual spectrum management fees (for massive IoT spectrum, if allocated separately in a licensed band) and subsequently, once the sector matures, the renewal can be based on willingness to pay. For critical IoT use cases, for instance, which are 5G based and expected to accrue attractive revenues to telcos, regulators can consider auction-based allocation, e.g. in higher-order mm wave bands near 60 GHz.

The next aspect is that of spectrum-sharing regulations, which until very recently encompassed only static spectrum-sharing regulations. However, the impending crunch in demand versus. supply is propelling ideas like dynamic spectrum sharing. With discussion of software-defined radio and cognitive radio, Dynamic Spectrum Access (DSA) is no longer only an academic theory. From a regulator's perspective, just like other unresolved questions, the debate about dynamic vs static spectrum management can be expected to be centre stage in future. We understand that no regulator can immediately adopt a dynamic spectrum management approach. However, from an implementation perspective, we agree with the paper by Anker (2010, p. 2), where it recommends a stepwise approach for implementing DSA. The stepwise approach encompasses introduction of cognitive radio within the current regime, creation of a spectrum commons and realization of a more fluid market for spectrum property rights. Interestingly, at the time of writing, there is no international regulation in place that prohibits the use of cognitive radio. However, any cognitive radio has to meet the interference, sharing and other conditions for the service that it is delivering in the respective band. Additionally, regulators will have a choice to exercise the interweave, underlay or overlay models for allowing DSA. We do not have a generic opinion as to which model is better. In fact, it is quite possible that different models are optimal in different circumstances (Song *et al.,* 2012).

Additionally, one other form that spectrum sharing acquires is spectrum leasing. Spectrum leasing can be of multiple types: for instance, a) where a licensee decides to allow other licensees to use its spectrum, but it retains the ownership; b) whereby owners of spectrum usage rights can sell or lease all or part of the rights associated with the license; and c) whereby owners of licenses can have their spectrum usage rights changed if they meet conditions defined by the regulator. Spectrum leasing is quite a subject on its own; hence we do not plan to delve deeper into it here (Srivastava, 2017).

Thirdly, a License or Authorization Model is by far one of the most powerful tools of a regulator. Using this privilege, a player can be authorized to use a specific span of channels in identified band:

- In a Specific Circle/Area or Pan-national;
- For a Service or Service agnostic;
- Via a particular technology or technology agnostic (liberalized).

Additionally, regulators can bind a licensee to deliver services not only in profitable areas, but also in rural circles/areas. From the perspective of geography, we anticipate most M2M licenses (if a separate licensed band is allocated) to be national and service agnostic. From the standpoint of technology, liberalization is still an open question. Technology Liberalization policy mostly refers to technology lockins within a particular spectrum band. For instance, in a liberalized 900 MHz band, a licensee would be free to choose any technology that fits the purpose. Considering the fact that M2M technologies are evolving, we believe that a liberal stand would be more reasonable. However, it is very important that, at this juncture, we bring out the contrary view that we encountered in the research. Some stakeholders believe that it is important that M2M bands are licensed and not technology neutral, as this would encourage ecosystem development around the technology of choice. Lastly, it would need assessment of local considerations, such as incumbent technologies. For instance, in Australia both LoRa and Sigfox networks have entered and hence it would be wise to take a liberal approach, whereas, in an underdeveloped economy, where there is less incentive for players to go in, a non-liberal environment might be more appropriate.

For the unlicensed band, typically to allow fair usage, regulators put a limit on EIRP (radiated power) and duty cycles, and mandate listen-before-talk kind of protocols. For massive M2M, when a technology is using an unlicensed band, these limitations allow a more efficient use of spectrum, and hence are very well suited. We do not expect critical IoT use cases to utilize unlicensed spectrum; hence, these regulations will typically not be applicable to critical IoT use cases.

Overall, regulators use the above levers to create an environment not only to allow fair and equitable access to the national resource of spectrum, but also to monitor and manage the players such that spectrum is efficiently and effectively used for the good of society at large.

Conclusion

The challenges that M2M services pose for a regulator cannot be understated. The diversity of verticals, use cases and stakeholders make spectrum regulation a very daunting challenge. The

objective of this paper is to indicate major elements to focus on when formulating radio spectrum policy for new applications and services in the realm of M2M/IoT.

The traditional spectrum demand analysis was primarily dependent on the forecast of voice, SMS and broadband services. Via our analysis, we uncovered the perspective of looking at demand on a per-application basis. Our analysis implied that the same device profile can expect very different spectrum requirements based on the application being invoked. Our framework on demand also tried to bring to attention the importance and impact of global demand on local demand. Lastly, our research clearly propounds the relevance of collaboration between regulators across verticals for demand analysis, which was unheard of until the advent of M2M/IoT.

Our research on spectrum supply has pointed to a clear change of path in terms of both licensed and license-exempt bands. We highlighted how the complexity rendered by a host of new technological paradigms, such as cloud RAN, dynamic spectrum access, cognitive radio, models of spectrum sharing and possibilities via white spaces, is significantly changing the licensed band spectrum supply considerations. In the unlicensed bands arena, we strongly recommend the regulator consider the challenges of long-range technologies operating in license-exempt bands, which were essentially designed for short range. We urge the regulator to look at the impact of uplink messages in the unlicensed bands, which was never the case previously.

Based on our understanding, especially in the area of massive IoT, we have recommended the regulator apply annual spectrum charges in the initial years. Subsequently, once the sector matures, we have advised that fees based on willingness to pay might be a much more suitable approach for spectrum pricing.

Though we did not come across a significant change in the objectives of spectrum monitoring, we did highlight the elevated impact of QoS monitoring in critical IoT use cases and interference monitoring in license-exempt LPWA bands.

Last but not the least, our study points to the reasons that have brought look-before-talk protocols back into regulatory discussions.

Overall, our proposed framework offers not only a comprehensive list of design factors to consider for defining an optimal target M2M spectrum policy posture, but also indicates the policy levers available to achieve the same.

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