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## Conference Paper

# Bring your own spectrum (BYOS) – A tiered architecture supporting flexible spectrum allocation

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# **Bring your own spectrum (BYOS) – A tiered architecture supporting flexible spectrum allocation**

**Madhulika Tripathi\*, Braden Phillips, Matthew Sorell**

## **Abstract:**

In this paper we present an innovative framework suitable for the next generation of wireless spectrum allocation. We call our framework – Bring Your Own Spectrum (BYOS) – to highlight the Spectrum as a Service (SaaS) nature of the architecture that allows all participants to be potential spectrum owners. The BYOS framework has a tiered and flexible architecture that is technology-neutral and allows multiple trading and sharing formats among a varied array of buyers and sellers. To develop the BYOS framework, we tackled the spectrum allocation problem using a top down approach. We make use of a quasi-static model of spectrum allocation in which allocation is specific to the type of operators, to build a tiered architecture. The framework also introduces two other novel concepts – a usage-based trading unit that is common across both long and shorter terms and the token-bucket system (used in network traffic management) for managing competition. The process is automated by making use of smart contract over a public ledger based system.

**Keywords** – spectrum allocation, public ledger, smart contract

## 1. Introduction

In this paper we present an innovative framework suitable for the next generation of wireless spectrum allocation. We call our framework – Bring Your Own Spectrum (BYOS) – to highlight the Spectrum as a Service (SaaS) nature of the architecture that allows all participants to be potential spectrum owners. The BYOS framework has a tiered and flexible architecture that is technology-neutral and allows multiple trading and sharing formats among a varied array of buyers and sellers. To develop the BYOS framework, we tackled the spectrum allocation problem using a top-down approach.

The proposed approach is different from the traditional system used for wireless spectrum allocation that has remained, more or less, unchanged for over a century. Under the traditional regime, federal regulators of a country manage wireless spectrum allocation using a command-and-control model. In this model, frequency bands are reserved for usage under pre-defined categories and are assigned/allocated to spectrum users only for well-defined specific purposes (Jayaweera 2014). This means while a licensee may have the exclusive rights to use the spectrum for a fixed period, the type of operation is fixed and the rights are non-transferable for that period. Despite being the norm there inherent systemic inefficiencies, which were glaringly evident since almost the very beginning. Some issues with the command and control approach are:

- Squatting
- Anti-competitive conduct
- Spectrum fragmentation
- Deliberate outmaneuvering during auctions
- Locking out small-scale innovations
- Contention between government, military and commercial operators

In addition, in the command-and-control approach spectrum licenses are usually acquired speculatively on a long-term basis. Often the spectrum licenses are bundled with the obligation to build out a network and provide network coverage and communication services in a geographical region within a specified time frame. This obligation, combined with the high price of acquisition of wireless frequencies and the cost of the network infrastructure, has been a major incentive for operators to favour the existing long-term license acquisition model.

Yet another consequence of command-and-control regime is spectrum harmonization. This refers to the practice of international agreements to allocate particular frequency bands to a particular application or category of services. While harmonization is broadly a deterrent to frequency band neutrality that would theoretically increase frequency utilization, it is a necessity given the currently available technology. Over the decades this has influenced the development and adoption of newer technologies, possibly even impacting the creation/release of better solutions for improving capacity.

Software-defined radio technology has enabled the idea of cognitive radio and dynamic spectrum access techniques that have taken away the necessity to tether specific frequency bands to application allowing multiple services to coexist without compromising on quality. The problem of efficient spectrum allocation has been analyzed from technical, regulatory, and financial perspectives. There is an extensive body of published work containing several interesting approaches to manage dynamic spectrum allocation and trading. A comprehensive review of the methods of spectrum allocation has been provided in the survey conducted by Tragos, Zeadally et. Al. (Tragos, Zeadally et al. 2013). The survey

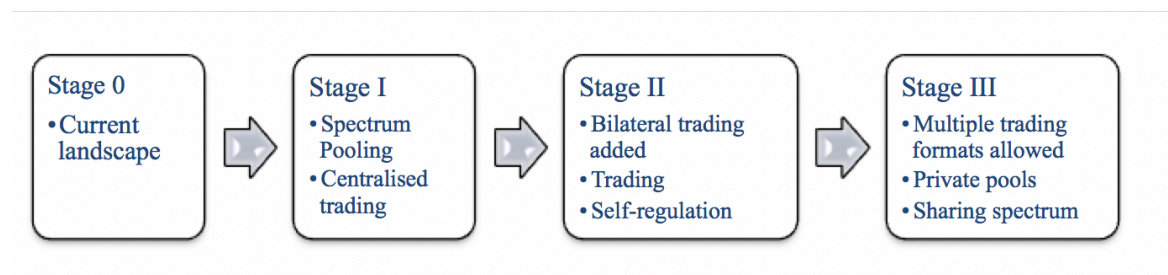
conducted by Tehrani et. Al. provides a taxonomy of the spectrum licensing methods (Tehrani, Vahid et al. 2016). Freyens has provided several potential types of licensing options (Freyens 2012). We found that most researchers have taken a bottom up approach in which the auctions or trades are conducted between the end nodes – either Base stations or end users. Trading at higher levels and longer periods are rarely considered. In addition, researchers working on allocations at node-level have acknowledged that such methods are mathematically intensive (Gandhi, Buragohain et al. 2007).

For our work, we reviewed the spectrum allocation problem from a combination of technical-regulatory-financial perspectives. We have used this to develop a framework that seamlessly integrates spectrum allocation over the longer and shorter periods. This paper discusses the key features of our framework.

We start by providing the key features of BYOS framework in section 2. This section also introduces a stage-based approach to reach from the current allocation regime to a potential blue-sky frequency-agnostic state. In section 3 we define the architecture BYOS which is based on quasi-static allocation. In our framework, spectrum is allocated over multiple time-periods starting with a long-term allocation and then proceeding to shorter intervals of time. In section 4 we introduce the trading unit used in the BYOS framework. Instead of allocating frequency channels, we propose using a usage-based unit for spectrum allocation. In section 5 we introduce a mechanism to manage competition, which is based on managing network traffic. Finally we discuss how a public ledger smart contract can be used to develop the system.

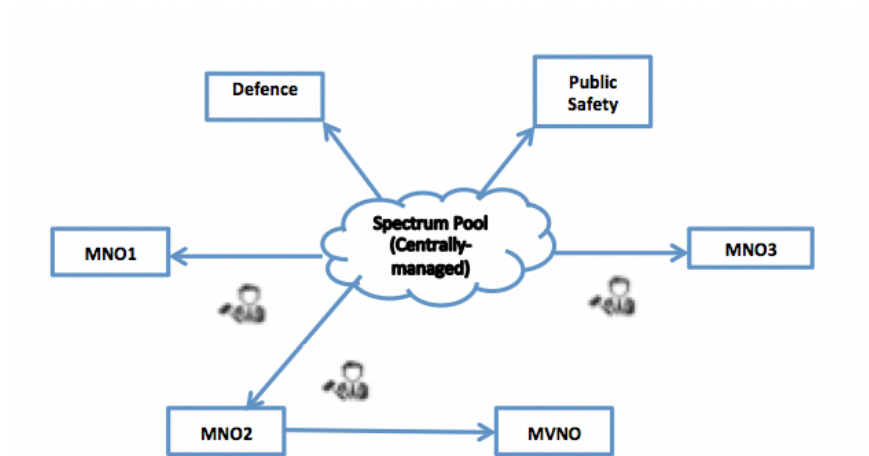
## 2. Staggered opening of the sector

Prior to the development of BYOS framework, we conducted an exhaustive research into the wireless spectrum allocation background of 35 countries. This research provided valuable insights that helped in the development of our framework. In addition to evidence of policy diffusion – we found that regardless of country’s socio-economic-political background (except United States), the transformation of the telecommunications sector from government monopoly ownership to a corporate structure was achieved in stages. This format also seems intuitive given the current technological capabilities and the simultaneous push towards harmonization and service generality. Figure 1 below shows the key stages of the change process:



*Figure 1: BYOS architecture through different maturity stages*

- *Stage 0* represents the current spectrum landscape, as described above. The figure below represents the main players and the interactions between them.



*Figure 2: Stage 1 – Current landscape*

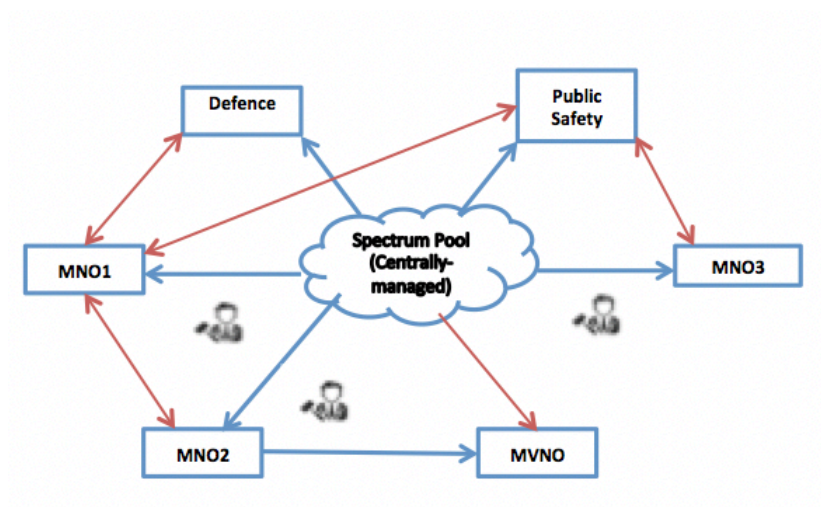
- *Stage 1*: At this stage all available spectrum is pooled (analogous to electricity pooling), and the regulator acts as the spectrum owner. At this point, the BYOS framework is introduced which has the following unique features:
  - Quasi-static: Spectrum is offered for different time periods
  - Categorized: Spectrum ownership periods differ for different categories of operators

These two features are discussed in more detail Section 3.

- Prioritized: Some of the operators, like the Public Safety services, could be given priority access to spectrum

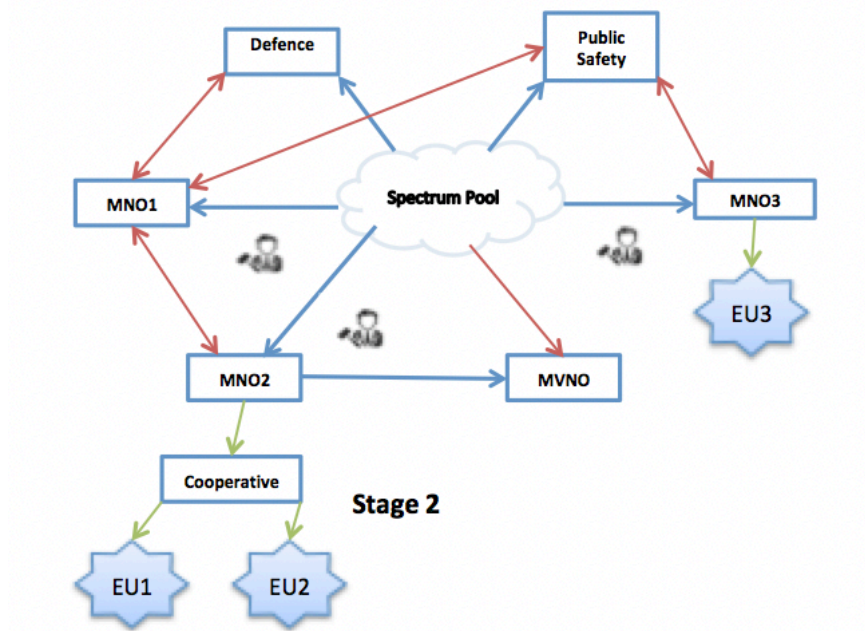
In addition, we propose two additional features that would make the system autonomous in the future. These features would ensure that regulators could take a hands-off approach to spectrum allocation.

- Tokens, to manage competition in the market. The idea is taken from and is similar to managing traffic in networks
- Public-ledger based smart contracts, to automate the process of spectrum trading providing trust and transparency between buyers and sellers, while maintaining efficiency and privacy (for maintaining competitive advantage)



*Figure 3: Stage 1 – Single pool of spectrum*

- *Stage 2* relegates the regulators to a completely hands-off role and the market becomes self-regulatory. We propose two additional features that highlight the expected maturity level of the system at this stage.
  - Bilateral trading between parties is introduced at this stage and as a consequence the buyers are now categorized giving rise to different ownership rights. (In Stage I, only sellers were categorized).
  - Regulators only enter the system if there is a specific request from one of the parties for arbitration e.g. if a concerned party reports that the spectrum purchase is underutilized and there is a demand for it in the market.

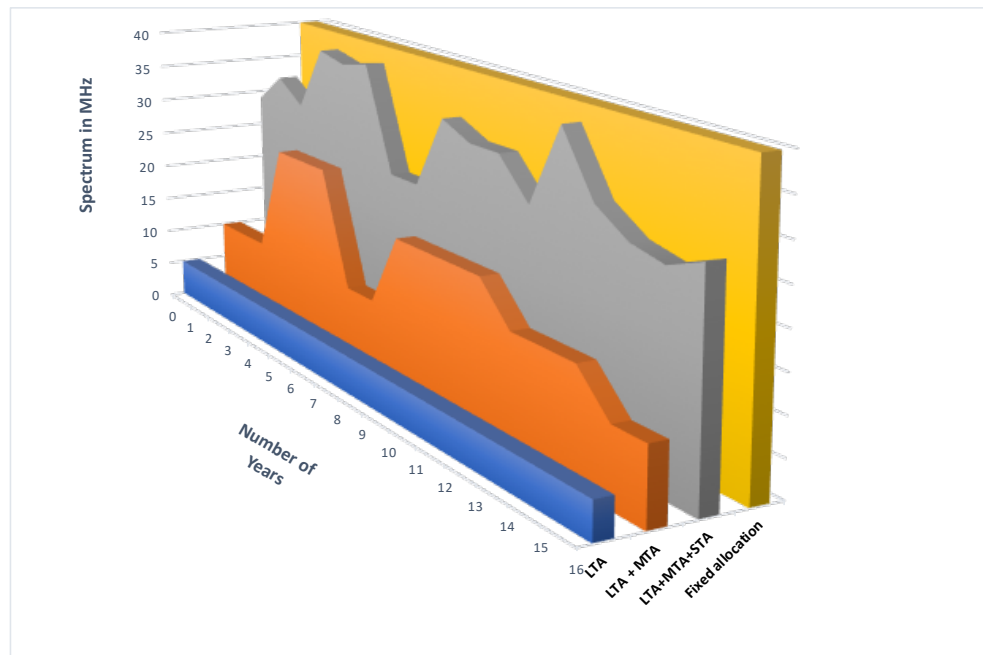


*Figure 4: Stage 2 – Autonomous framework with multiple pools*

- *Stage 3* is the blue-sky possibility i.e. when the market is deemed stable following its auto-regulation capability. At this stage other means of trading like options, futures (contracts and derivatives), sharing, private pools etc. can be introduced, first as a test over shorter terms. These can be subsequently introduced for longer periods, as the options are successfully validated.

### 3. Quasi-static spectrum allocation

The figure 5 below shows the quasi-static model for spectrum allocation. The yellow block shows spectrum acquired through the standard long-term speculative acquisition model used by wireless telecom regulatory authorities throughout the world.



*Figure 5: Quasi-static spectrum allocation format*

We propose that instead of holding a single big chunk of spectrum over a fixed long-term, spectrum can be acquired in three stages:

- *Long-term allocation (LTA)*: For satisfying the base capacity i.e. the base minimum spectrum that is required to run a network. This is shown by the dark blue block in figure 5 above.
  - LTA allows operators to gain guaranteed spectrum for a long term (without participating in an auction). Spectrum is bundled with MNO license, but the quantity is limited.
  - LTA allows the operators to plan their network in the long term.
  - LTA allows MNOs to develop the network infrastructure (core network, backhaul etc.) based on long-term capacity plans. MNOs can then choose to act as infrastructure providers or service operators or both.
- *Medium-term allocation (MTA)*: For satisfying the planned capacity within a region i.e. acquiring the spectrum depending on network design and technology used in a region. This type of holding allows operators to add capacity or to shed capacity/infrastructure to optimize CapEx and OpEx. The orange block in figure 5 above shows the spectrum portfolio for an incumbent operator after acquiring spectrum over shorter medium term periods (over an above the long term chunk already owned).
  - MTA allows incumbent operators to build upon their network infrastructure and also allows newer operators to build limited sustainable capacity networks that can then be extended.
  - MTA allows flexible allocation mechanisms, as allowed by the regulators – competitive or administrative modes.
  - MTA can be used to grant limited rights to access-limited bands, which allows more bands to be added into the available spectrum pool.
- *Short-term allocation (STAs)*: For satisfying the peak capacity within a region. This part is where opportunistic models fit and spectrum can be held for periods as short as an hour. The gray block in figure 7 above shows the spectrum portfolio for an

incumbent operator after acquiring spectrum over shorter medium term periods for satisfying periodic or peak demands (at this stage the operator already has a stable network and has designed the network around a pre-planned capacity level).

- STA allows incumbents and other MNOs to satisfy instantaneous or periodic peak capacity demands.
- STA allows operators using newer cognitive access technologies to test their network. Ownership period can be extended when the network viability is determined.
- STA also allows public safety networks to satisfy instantaneous demand for emergency situations

The following aspects define the quasi-static model:

- a. Instead of once in a long-term auction (every 15+ years) or continuous/demand-based/real-time (like in a dynamic auction), auctions are conducted periodically.
- b. Each auction time period is pre-decided. We have chosen an exponential scale of 2 in hours, days, and years) to a max of 16 years (at this stage) – the approximate timeline of spectrum ownership until recently. The scale was chosen because we observed that the allocation periods in various countries over the decade can be expressed as a combination of the periods, in years, and we replicated this principle for the short-term. We have tabulated the allocation periods below for simplicity. A sample set of rules is shown in able Figure 6 below
- c. At the first time, we assume that the auctions are serially conducted – first available for longer time periods, then for progressively shorter time periods.

Allocation type	Ownership period	When are these conducted?
Long-term allotments (LTAs)	16 years (2 <sup>4</sup> years)	Periodically (assumed once in 16 years once the current ownership expires)
Medium-term auctions (MTAs)	8 years (2 <sup>3</sup> years), 4 years (2 <sup>2</sup> years), 2 years (2 <sup>1</sup> years), 1 years (2 <sup>0</sup> year)	Periodic auctions. For this thesis we assume a single 16-year period, with allocations at pre-specified periods. This replicates the current structure of spectrum auctions
Short-term auctions (STAs)	Hours (Potentially days and/or weeks)	Spectrum is allotted in chunks of hours: (a) Allotment doesn't roll over to the next period and (b) larger chunks can be allotted only at pre-set times.

*Figure 6: Allocation types and ownership periods*

Categorized allocation – This has been discussed under the different levels of allocation. The incumbent MNOs (that have a long term presence in the market) can purchase their operator licenses with a basic long-term allocation that allows them to plan the network on a period similar to their current acquisition periods. Following this, incumbents (and limited new entrants) can purchase spectrum on medium term(s) to operate a commercially viable network that can also be planned on a longer term. The potential availability of spectrum on a periodic basis will also allow the operators to save on holding the spectrum costs and expand their network based on pragmatic extrapolations. In case the operators require spectrum to satisfy peak capacity requirements, the spectrum can then be acquired on a

short-term basis. The spectrum holding for operators now changes from a big-fixed-chunk over a long-term to a more flexible demand-based ownership.

#### 4. Trading unit used in BYOS

One of the key research issues in dynamic spectrum access is the idea of “what to sell”. The notion of trading spectrum is based on the assumption that it is a resource similar to other resources like electricity, gas etc. But spectrum is actually a medium, and purchasing it for the purpose of communication is actually similar to purchasing a highway when an operator wishes to purchase the right to move traffic between two points – not entirely efficient, if the number of highways is limited.

As a solution to this dilemma, we have proposed a noise-emissions-based parameter as the trading unit instead of trading based on exchange/transfer of channels. This scheme is similar in principle to an emissions trading scheme. In an emissions trading scheme, carbon or greenhouse gases are released into the atmosphere due to various processes and these emissions are traded in the form of permits. The overall goal of an emissions trading scheme is to limit the amount of greenhouse gases released into the atmosphere.

Similar to this, wireless communication of any kind is essentially the release of emissions that essentially ‘pollutes’ the frequency-bandwidth, essentially degrading the resource for all other interested users. Continuing the highway analogy, we consider spectrum to be similar to a multi-lane bidirectional highway with different vehicles in space-time. Vehicles represent the information bits/packets travelling using the lanes as a medium. An operator can reserve the use of a particular lane for a fixed time. Needless to say, exclusive reservation carries a higher price for lanes that are in high demand. Instead of exclusively leasing a large number of lanes for a long period of time (which is analogous to the original method), operators book the lanes paying for the use based on typical traffic patterns. Capacity can be added and shed as required and peak capacity can be added over short-terms in near real time situation or to manage periodic daily peak levels. Different lanes have different characteristics (discussed in section 4.2) accounting for differences in prices for using the particular lanes.

The operator can sub-lease the lane by allowing traffic to steadily flow either in an underlay format (e.g. vehicles small enough to travel through the space between undercarriage) or in an overlay format (e.g. bikes zipping through the spaces between the different vehicles) or interweave format (e.g. during the low-traffic periods typical to that particular operator). The sub-lessee operator traffic is tailored according to the specifications set by the primary leaseholder. Two operators can lease the lane on a time and/or capacity shared basis.

##### 4.1. Components of the basic trading unit (BTU)

The proposed interference rights based parameter has two key dimensions:

- Power,  $P$  in Watts is the average energy per second
- Bandwidth:  $W$  in Hz

These two are the fundamental resources available for designing a communication system. One of these two resources is generally more precious than the other:

- Signal power is limited in case of deep space and ultra wideband systems (UWB). The capacity in this case increases linearly with SNR and is independent of bandwidth
- Bandwidth is limited in case of 1<sup>st</sup> and 2<sup>nd</sup> generation TDMA/FDMA communication systems like AMPS and GSM

Communication systems designers make a trade-off between the two variables during system design.

According to Shannon-Hartley's channel capacity theorem, the capacity  $C_{AWGN}$ , in bits/second, for a continuous time AWGN channel is given by

$$C_{AWGN}(P, W) = W \log_2(1 + SNR)$$

Operators use this formula for determining the upper bound of data rate for a given channel and then design the capacity of the overall communication system by making use of multiple access schemes (e.g. TDMA, FDMA, or CDMA).

$$SNR = \frac{\text{Signal Power}}{\text{Noise Power}} = E_b R / N_0 W$$

Signal Power = Energy per bit \* Bit rate

Noise power = Noise power spectral density \* Bandwidth

In our framework the interested operator would bid/request for the average signal power (which incidentally is noise for all other users using this bandwidth) they are interested in over the nominal bandwidth over which this noise would be spread. Hence, the basic unit of trade is Signal Power spread across a certain Bandwidth to achieve a level of capacity.

The basic trading unit for our framework is:

$$BTU = PW$$

This signal power is essentially noise for all other interested users, so the operator essentially gets a permit for polluting the medium with a certain level of noise.

For 1<sup>st</sup> and 2<sup>nd</sup> generation technologies and also narrow bandwidth technologies like public safety network, a high level of power is spread over individual channels of smaller bandwidth (6.25-25 KHz channels for public safety network, ~30 KHz channels for AMPS, ~200KHz channels for GSM). In these cases each channel (or timed slot in channels) represent one user. In contrast, for CDMA based technologies, the bandwidth is large (~1.25-20MHz) but the power levels are low per user. The technology choice is left up to the operator, who can use any technology (given the noise spread) to achieve desired capacity.

#### 4.2. Characterising the spectrum

For our framework, we have assumed that technology for frequency-agnostic application exists. Software defined radio has laid the groundwork for ensuring that various radio access technologies are not bound by a fixed frequency range. There is significant overlap between the frequencies used by applications operating in UHF and part of SHF bands suggesting that a frequency-agnostic scenario isn't entirely impossible to visualise.

Despite this, the basic trading unit discussed above is actually too simplistic to be of practical use. Spectrum frequency bands are different in terms of characteristics and hence operators value bands differently. So the spread of noise should be characterised as follows:

$$BTU = \sum_{i=1}^n P_i W_i$$

$P_i$  is the total signal power spread across bandwidth  $W$  in the  $i^{\text{th}}$  band i.e.  $W_i$ .

Thus even in a frequency-agnostic application scenario, we need to include the individual characteristics of frequency bands themselves. The choice of particular frequency bands in a spectrum has a direct impact on network roll out investment (CapEx) as well as operating cost (OpEx). For instance, a key consideration while designing the network is the number of base stations used. The propagation characteristics of different frequency bands is fundamental to this calculation because this decides the number of cell sites required to provide a specific level of coverage and handle a certain amount of traffic. In general, the number of base stations required to deploy a network per region increases with higher frequency bands. Thus, while different frequency bands in the spectrum are technically fungible, they have a certain interchange cost.

One of the ways to do this is to parameterise spectrum as proposed by Weiss et. al. In their paper, spectrum frequency bands have been assigned fungibility scores based on the following aspects:

- Spatial – Transmission and path loss factors
- Temporal – Availability of band during a fixed interval of time
- Technological – Issues such as duplexing, frequency tenability, and interference
- Regulatory and policy – covering other miscellaneous concepts

(Weiss, Krishnamurthy et al. 2012)

The fungibility scores are then used during secondary spectrum trading in the market (Gomez and Weiss 2013). The operators are free to opt for an alternate technology if the price exceeds what they are willing to pay for it. The approach assumes that the alternate spectrum has similar quality as the preferred frequency.

In our framework, we introduce a simpler concept called the technical application suitability factor (TASF). Operators review the existing frequency channels in terms of their suitability to the current application. This includes factors such as:

- Infrastructure cost required to achieve desired coverage and capacity
- The longest period of availability of the frequency band (same or similar)

The TASF for each available band is expressed on a 0-1 scale.

$$0 \leq TASF \leq 1$$

If a frequency band is not suitable for an operator's network in a given geographical region, its TASF=0. Conversely if a frequency band is considered ideal to an operator in a given geographical region, its TASF=1.

Frequencies suitable for a given application are usually common across operators offering similar services. This introduces competition for the particular band, which is then used to

determine the demand levels (and hence market cost) for different frequency bands. In general, it is expected that radio frequencies with TASF closer to 1 would have higher contention and the operators would have to be open to pay a higher price to win the competition. The utility of a particular set of frequency can then be determined as:

$$Utility = TASF \cdot Cost\ of\ acquisition$$

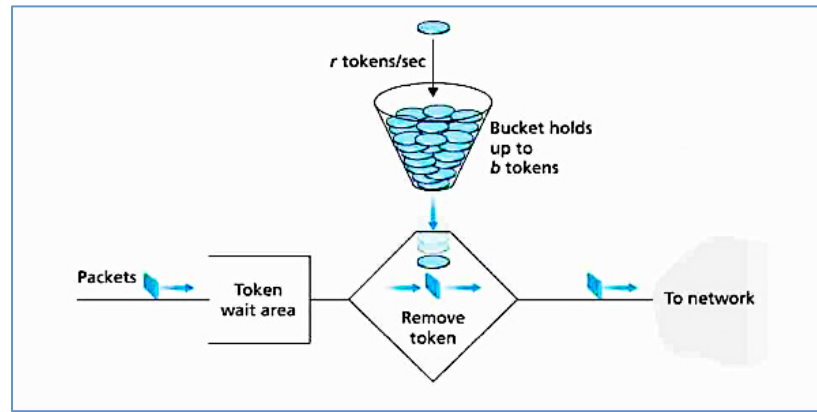
Operators thus have an optimization problem, where they balance the cost of network and probability of availability with the cost of acquiring the band in the market.

TASF is internal to the operators, which means that operators are free to change the parameters of the TASF. Newer generations of mobile technology have generally achieved higher frequency agility, making more frequency bands fungible. Data rates (bits/second) per Hz of frequency has also gone up as a result of better coding efficiencies, leading to a reduction in the bandwidth required for the transmission of same amount of data. It builds a strong case for technology innovation in frequency bands that have historically been 'earmarked' for different purposes and have lower access cost.

## 5. Tokens for spectrum sharing

The framework proposed above is a potential solution to the issue of spectrum lying unused. It also has the potential to improve innovation, reduce the undue cost of spectrum access and reduce spectrum fragmentation. However, the issues of hoarding and other anti-competitive measures still remain. Government regulators have historically managed such issue by keeping the allocation under their control and maintaining strict, though arbitrary, decisions as a reactive measure to manage spectrum control. Such solutions might solve the anti-competitive behaviour but pay a price in terms of spectrum remaining unused. Even while auctioning spectrum, the focus has been to progressively build complicated strategy-proof auction mechanisms. The increased level of complexity has actually reduced the interest in adopting these methods.

In our work, we have proposed a unique measure to manage competition by making use of the network traffic shaping idea of tokens. By the original definition used in the token bucket algorithm – a token is an authorization to send one packet of data. In the network traffic shaping environment, tokens are used to regulate the bandwidth usage by limiting the amount of traffic sent. For sending data of  $s$  packets,  $s$  tokens are required. If there is no token available, the particular data packet is either delayed or discarded. Tokens are generated at a fixed rate and stored in a token bucket. If the bucket is full, any extra tokens generated are discarded. The size of bucket determines the maximum size of data burst that can be sent. This is shown in Figure 7.



*Figure 7: Traffic management using token bucket*

### 5.1. System definition

In our system, tokens are defined in terms of total available frequency bands in the market. Let this be  $F$ . Each of the available bands is divided equally into bandwidth of  $x$  Mhz. So total available bandwidth is  $Fx$ .

Representative numbers are used to illustrate the system in the following description. Each bandwidth has a maximum level of occupation (based on max. noise emission) defined as 100. Minimum occupation is 1.

1 token represents right to emit noise equivalent to 10% of maximum noise level in  $x$  MHz bandwidth. The  $x$  MHz bandwidth is the smallest practically divisible unit of frequency band. A possible value could be 6.25MHz, which is said to be the narrowest possible channel for UHF transmission. Choosing this division would mean that each 1 MHz bandwidth is divided into 160 distinct channels. Not all these channels will have the same level of usability, but percentage noise level (discussed next) would define the level of usage.

Each token gives an operator a potential right to pollute the channel to 10% of its total noise capacity every hour. The maximum and minimum levels are calculated for each band and available in a central database. For the sake of simplicity, noise levels are linearly additive. This gives the maximum possible number of tokens, which is equal to the maximum noise level permitted every hour

$$\text{Number of tokens per hour} = 10 Fx$$

Tokens are replenished only when one of the medium term spectrum allocation periods expires e.g. every 1 or 2 years. Thus the maximum token bucket size is

$$\text{Token bucket size} = (365 \times 24) \times 10 Fx$$

$$\text{Token bucket size} = 87600 Fx$$

Regulators pre-decide the tokens allocated for each individual operator as a percentage point between 1 and 10. This number is reviewed annually and internally calculated on factors such as:

- Total spectrum already owned by the operator in the region
- Interest/contention in various frequency bands
- Past usage factor

On the expiry at the end of the year, regulators decide whether the token bucket limit should be increased. This might happen if the available frequencies change –new frequencies may be introduced or reserved.

Each time operators bid for and win spectrum, the tokens are removed from the bucket in proportion to the spectrum acquired. If operators fail in an auction type trade, a set number of tokens are removed as administrative cost. Operators are also allowed to trade/bid for spectrum speculatively for future periods. The risk is the availability of spectrum and low or minimum cost, when it is not under use. Speculative access attracts a futures exchange rate and auction appearance charge.

## **6. Distributed system using smart contracts**

An additional purpose of the BYOS framework is to move away from the traditional bureaucratic register, replacing it with an autonomous transactional database system that can track ownership of assets (converted in their digital form) over a distributed system comprising of a secure registration and transaction process. The advantage of this method is that the framework is decentralized allowing multiple parties to trade simultaneously without going through a central clearance authority that extends rigid control over the allocation process.

A popular example of a distributed ledger system is Blockchain. Blockchain, by definition, is a means to provide a ‘trust-less’ environment, where users do not have to rely on central authorities – the hallmark of standard commercial landscape with regulatory authorities holding significant power to control and manipulate the system. Applications using blockchains make use of the advantages the scheme provides such as transparency/visibility, data immutability, distributed consensus and integrity to make their systems inherently trustworthy over a distributed environment, without a central integration point.

The division of tokens by the central regulator makes the system distributed. This means that each transaction does not need to be centrally cleared to be validated. There is sufficient information available in the chain to ensure transparency and fairness. The property of immutability creates records that can be used to audit the process by the central authority and alter the tokens in the market, if required.

A smart contract is essentially a piece of code that allows two parties to enter a legally binding agreement under mutually agreeable terms. The contract process is automated i.e. executes by itself when conditions are met/not-met and leaves a clear follow-up trail for review by parties or regulators. The contract also allows the parties to remain anonymous, while the contract itself is available on the public ledger allowing interested parties to review the agreement.

Not all applications are a fit for the distributed ledger system in their proposed way of operation. The combination of transparency-visibility-immutability becomes a direct challenge to privacy, which is a necessary prerequisite for many commercial applications. These very challenges are however a key requirement for our BYOS framework. This is because our system relies on the consensus aspect of a distributed ledger to ensure the system’s transparency and fairness. As our spectrum allocation framework requires hands-off oversight, transparency and fairness in the spectrum management process is important. This type of application of blockchain differs from standard regulatory applications, where

the goal of the distributed ledger is to ensure transparency of the operation for ensuring only trustworthiness or identity of the participant.

We are currently in the process of building this part of our framework

## **7. Conclusion**

In this paper we have presented a framework that solves existing policy limitations with current technical advancements to bring an 'as-a-service (aaS)' model to the spectrum allocation landscape either in the form of Spectrum as a Service (Saas) or using a combination of spectrum and infrastructure to offer Capacity/Data as a service (CaaS/DaaS) to the end users. With BYOS we envisage an allocation framework in which spectrum can be traded in near real-time, but one that also allows long-term spectrum acquisition. The framework is decentralized, which means multiple parties can trade simultaneously without going through a central clearance authority that controls the allocation process and assigns spectrum based on preset winning criteria.

The BYOS framework makes use of quasi-static allocation to build a tiered architecture of spectrum ownership. The architecture would help reduce entry barriers in the market. Operators would be able to gain access to unused and reserved part of spectrum faster. The potential to access newer bands would foster innovation both in terms of increasing coverage/capacity and novel application areas for frequency bands. The categorization between the different types of users would allow incumbents to still retain their customer base and build stable network over longer time periods. To manage competition in the architecture, we have introduced the concept of token bucket from network traffic management. This mechanism leaves the operators free to access spectrum as they desire without active intervention from regulation. However, the regulator still retains control over participants by controlling the size of token bucket and penalizing operators who engage in anti-competitive behavior. At the initial stage this process can be centrally managed, but the advent to public ledger would introduce automation and transparency to the process. Using blockchain-based smart controls would make it possible move away from a traditional bureaucratic register, replacing it with an autonomous transactional database that can track ownership of assets (converted to a digital form) over a distributed system comprising a secure registration and transaction process. This would be the next stage of our work

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