Long-Range Communications In Licence-Exempt TV White Spaces

An Introduction To Soft-Licence Concept

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***Abstract*— Spectrum deregulation in wireless industry along with advancements in Cognitive Radio (CR) technology has opened up opportunities to access under-utilised spectral bands such as TV White Spaces (TVWS). Certain services in TVWS would require access to spectrum which is predictable, measurable and offer a higher degree of certainty currently difficult under the license-exempt model. This paper introduces a novel light-touch regulatory model called as 'Soft-Licence' which sits between the current exclusive-license and license-exempt spectrum models and offers the required service protection from license-exempt secondary systems and provides a fine balance between enabling efficient use of spectrum and encouragement to service providers to deploy infrastructure based on shared TVWS spectrum. To complete the discussion, a commercial model based on separation of White Space connectivity and White Space retail service under the Soft-Licence concept is proposed.**

Keywords-TV White Spaces, TVWS, long range, license-exempt, unlicensed, soft licence, geolocation, spectrum etiquette, coexistence, fairness, QoS, commercial model, business model

I. INTRODUCTION

There is an increasing international interest in using White Space systems as a cost-effective wireless delivery platform. Recent rulings by the FCC in the US [1] and Ofcom in the UK [2] opens up spatially unused portion of TV bands (UHF in UK and VHF, UHF bands in the US), so called TV White Spaces (TVWS) for cognitive radios [3, 4]. The main potential benefit of using TVWS is that signals in TV bands have an excellent propagation characteristic with a low penetration loss, for example compared to the 2.4GHz ISM band, the range is roughly 10 times longer for an equivalent power spectral density in the same receiver bandwidth. The exact amount of TV White Space spectrum availability is subject to the degree of protection afforded to the incumbent licensees which is hotly debated in various countries; initial studies have shown significant amount of White Space availability of about 100MHz on an average for a large percentage of the population [5, 6, 7]. Communication regulators thus wish to stimulate development of new mobile and wireless services for a wide range of services in TV White Spaces such as rural broadband, point-to-point wireless backhaul, home networking, machine-to-machine, etc to name a few [6, 8, 9].

The CR technology works by searching for unused areas of the airwaves or gaps that exist in bands that have been reserved for TV broadcasts and use them on an opportunistic basis. Such secondary use is free, but conditional upon avoiding harmful interference to the license users (also called as primary users) of the Digital Terrestrial Television (DTT) service and wireless microphone service. A brief description of a White Space framework is provided here as illustrated in Figure 1. Spectrum sharing in TV bands is based on the use of White Space database look-up combined with geolocation technology for location determination. The primary systems update the White Space database with their spectral usage patterns. Any changes are notified to the White Space database within a required regulatory timeframe, e.g., a week notice for DTT and a 2 hourly notice for wireless microphones in the UK. The regulator maintains some form of control interface with the White Space database to update regulatory policy/algorithms and to take any corrective actions related to interference. The secondary devices that are permitted to access the White Space database would be certified by appropriate certification body and their device type/class details would be available to the White Space database. The White Space base station/router or "master" device as it is known technically, will search for an authorized White Space database in its respective country and query for TV White Spaces. The request will contain information related to the location of the master device, device type details and height above ground level in fixed outdoor deployments. With the master information and knowledge of primary systems, the White Space database system runs an algorithm to find the TVWS spectrum availability for that location. Appropriate protection criteria set by the regulator is applied to ensure that any secondary usage does not interfere with the existing licensed users of the spectrum. The response to the master device contains details of the available TV channels, associated power levels and validity time for a given location. The master device will use the information to setup a communication session with secondary client devices called "slave" devices. It is important to note that the two-tier database hierarchy shown in the Figure 1 is an artificial one; Tier 1 database layer reflects the mandatory functionality of protecting primary users; while tier 2 layer is functionality related to provisioning of secondary services.

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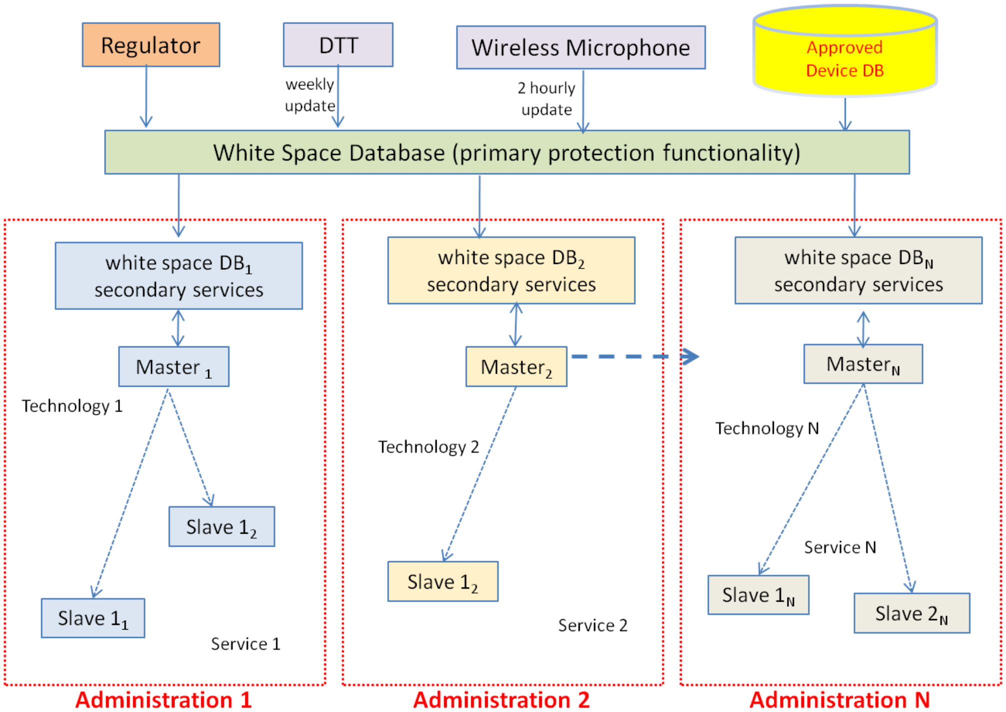

Figure 1. Simplistic view of the proposed White Space framework

The two are shown as separate layers to emphasise FCC's and Ofcom's decision to allow multiple third-party providers to develop databases, to create a competitive marketplace and to incentivise operators to provide the best database service to end consumers. It is expected that multiple database administrations will operate independently and provide services with the wireless interface technology of their choice. However, this does not preclude that it may be necessary for the White Space databases to share certain information.

The focus of the TVVWS regulatory rulings [1,2] is on primary system protection, and the question as to how the White Space spectrum will be shared amongst secondary users is left to the industry and standardisation bodies. Under this context, FCC and Ofcom have decided to make White Spaces devices license-exempt. As White Space systems are expected to support a wide range of service scenarios under the license-exempt model certain aspects related to QoS, fairness, coexistence and spectrum usage efficiency need to be carefully understood. This paper aims to focus on the challenges associated with one such secondary system scenario aimed at providing long-range communication services. The rest of this paper is organized as follows. Section II provides the discussion about problems in long-range communication context; Section III describes the spectrum etiquette approach currently proposed to address the problem; section IV presents solution proposed by the author called as 'Soft-Licence' and 'Protected Service' concepts; section V presents the commercial model for Soft-Licence concept and finally Section VI gives the overall conclusion.

II. Problem Definition

TV White Spaces operate in frequencies below 1GHz band and have excellent propagation characteristics; so a natural tendency of service providers would be to consider it for long-range communications [10, 11]. Service providers deploying such services in White Spaces would require access to spectrum which is predictable and is measurable and offers a higher degree of certainty of service parameters related to availability, priority, guarantees, etc. Currently, there exists no mechanism to ascertain the quantity or the quality of the TVWS spectrum available for such a secondary service. This is primarily due to the following two reasons.

The first reason is due to the nature of White Space availability. There is a fundamental uncertainty regarding availability of TV White Spaces as Primary systems may occupy the entire TV spectrum none available for a secondary service at a given location or in a given time-periods. The problem is exacerbated due to relatively higher EIRP and antenna height requirements in case of long-range outdoor secondary services. Recent geolocation database pilot trials in the US show no or very limited spectrum availability in certain US areas for an EIRP of 100mW requirement [12]. Long-range services would typically need a relatively higher EIRP, of about 4W with an antenna height of about 12 to 15m in outdoor settings to achieve a coverage range of 8 to 10km. When the primary protection criterion is applied under such secondary context, the amount of TV spectrum available for the secondary system either disappears or is drastically reduced due to interference protection requirements [13].

Secondly, FCC and Ofcom have decided to make White Spaces license-exempt, i.e., White Space devices will be allowed to operate without a need for a license. Benefits and limitations of license-exempt spectrum model are well known; to name a few benefits: it promotes spectrum sharing among diverse applications, results in a faster rollout and lowers the barrier to entry thereby fostering innovation in wireless industry.

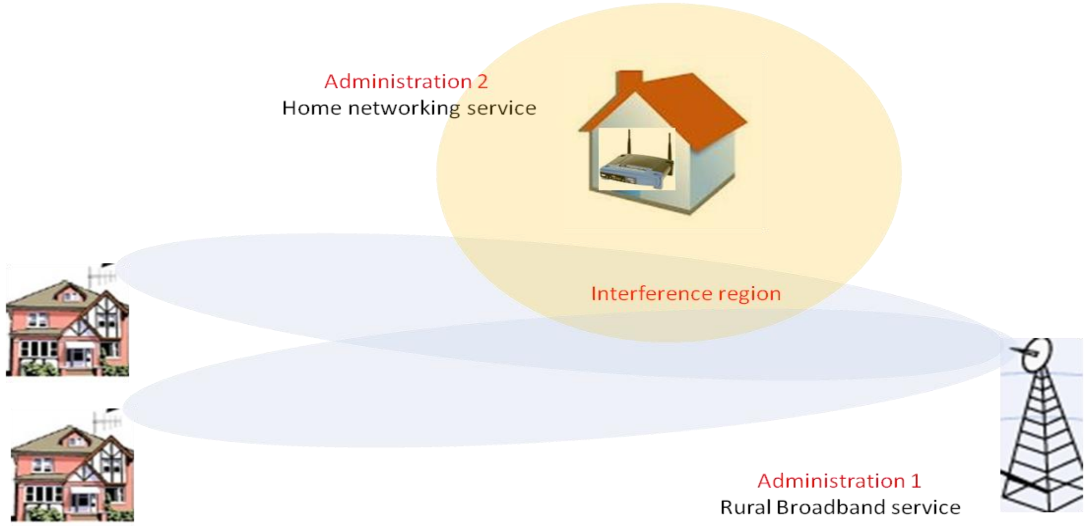

Figure 2. Two co-located systems belonging to different administrations sharing license-exempt White Space channel

However interference between neighbouring license-exempt systems resulting in service disruptions is a major limitation of the license-exempt model. There is nothing that prevents secondary White Space infrastructure being deployed by different operators in same location and in the same frequency band. This aspect worsens in TV White Spaces as the cell size could be much larger unlike the smaller WiFi cell sizes. Long-range communications imply a larger interference range as the probability of capturing contending users goes up as a function of coverage area. This is illustrated in Figure 2 where a rural broadband service is deployed in a region based on White Spaces and provides a service to tens of houses over a range of few kilometres. If within this coverage area any other secondary service is operating on the same channel, it would significantly affect performance rural broadband service. At best, the license-exempt mode in this case would guarantee everyone a share of the available bandwidth, but there is no guarantee of how much each will receive and the delay performance will almost certainly become more variable and hence less predictable. This becomes increasingly more problematic as usage volumes increase because the associated delay variability will eventually become unacceptable for the rural broadband service.

It could be rightly argued that an obvious way to resolve the interference problem would be to assign such secondary systems non-interfering channels. This however assumes a cooperation interface amongst secondary administrations and an adequate White Space spectrum availability which may not necessarily remain true with an evolving White Space device density. The next section provides an approach proposed by the industry and standard bodies address this problem.

III. Protection Of Long-Range Service: Spectrum Etiquettes & Associated Issues

The current approach proposed to address the stated problem i.e., protection of long-range services is via adoption of spectrum etiquette rules. Spectrum etiquette is a set of rules adopted by systems operating in the shared spectrum for a mix of deployment scenarios. All secondary administrations would adopt a technical solution within the constraints of the defined spectrum etiquettes. This is similar to the existing etiquette rules like listen-before-talk, use of spread-spectrum technology, spectral masks, etc adopted by IEEE-802.11 standard. Standards currently developing spectrum etiquette rules for the various TVWS deployment scenarios [14, 15, 16] discuss proposals such as super-frame concept, max transmission time and min pause time after transmission, inter-technology coordination interface such as cognitive pilot channel, adaptive duty cycle concept for low data-rate delay-tolerant telemetry service, etc.

Various secondary systems would have differing service requirements related to bandwidth, delay-tolerance, etc. Defining spectrum etiquette rules to satisfy competing goals often needs trading off one objective over the other. Therefore agreeing on an appropriate set of spectrum etiquette rules across the administrations that use different technologies is very challenging. To manage interference between systems sharing a common White Space channel would require some form of synchronisation/orthogonality as explained below

- Achieving orthogonality using time-frames in a single relatively wide channel requires synchronisation between the various users, probably on a packet time-scale
- Achieving orthogonality using spreading in a single relatively wide channel requires synchronisation such that different spreading codes are used by the various users, probably on a session time-scale
- Achieving orthogonality using space requires synchronisation such that spatial overlap of wireless signals is avoided at a receiver.
- Achieving orthogonality using relatively narrow frequency sub-channels in a relatively wide single channel requires no synchronisation but needs sufficient guard bands to protect from adjacent sub-channel interference.

Under certain scenarios, the centralised global knowledge in the White Space database is of limited to manage interference due to the rapidly changing dynamics as a result of propagation characteristics, traffic profiles and mobility attributes. Moving to the infrastructure level, the administrations would have to cooperate with each other under some form of etiquette or code-of-conduct. The technical requirements would require a close cooperation amongst the White Space master base stations/routers via a coordination interface. Similar interfaces have been proposed in LTE standard with X2 interface [17], CoMP in LTE-Advanced standard [18] or the Hyper Receiver concept [19] as part of spectrum sharing concepts discussed/adopted in low-power concurrent spectrum sharing in the 1800MHz [20] and in 2.6GHz [21] UK auctions. There are technical challenges associated in developing this type of interface especially across technologies and administrations such as the need for high speed optical links and high computational processing. Based on the operating contexts, the spectrum etiquette rules may not be needed and for cases where it would be useful the overheads of achieving what's needed may be impractical. Further more, individual technology would have to be adapted to enforce the agreed spectrum etiquette rules or suitable new technologies would have to be developed. Finally any benefits to cooperate across administrations should outweigh competition reasons. The next section provides a far simpler alternative approach to resolve the problem avoiding the complexities of spectrum etiquette approach.

IV. Protection Of Long-Range TVWS Service: Soft-Licence Proposal

This section proposes a novel light-touch regulatory model called as 'Soft-Licence' along with Protected Service category to address the protection of long-range service problem. To aid understanding and lead into the discussion of Soft-Licence concept, following functional structure is proposed.

A. Spectrum Access Control (SAC) and Spectrum Usage Control (SUC)

Spectrum Access Control layer – The SAC functionality resides in the geolocation White Space database and informs whether or not White Space channel is available for use at a particular location. The decision to allow spectrum to be used on secondary basis is based on an assurance from the secondary systems not to interfere with the primary system by a certain interference protection ratio. The protection criterion serves a form of conventional connection admission control; however there is no such mechanism to protect secondary systems due to the license-exempt ruling i.e., all devices would be admitted into the network irrespective of the congestion level leading to possible degradation to others. Proposal includes extending the SAC functionality as discussed ahead.

Spectrum Usage Control layer - The SUC functionality aims to enforce the spectrum etiquette rules for those given permission to use the spectrum, i.e., control usage of the White Spaces by minimising the probability of packet collision when multiple users are transmitting simultaneously. Due to the traffic dynamics it would be difficult to manage spectrum usage at the geolocation database layer; but where the SUC functionality resides will be ultimately decided by overall system performance/cost considerations which is a design choice.

B. 'Protected Service' Category

Currently there are two service categories identified in the White Space context, the 'Primary Service' category which comprises of the DTT and wireless microphone service and the 'Unprotected Secondary Service' category comprising of all license-exempt secondary services. As illustrated in Figure 3, a new service category called 'Protected Secondary Service' is proposed to provide protection for certain secondary services operating in White Spaces. As shown in the figure, the Primary Service is at the highest level while Unprotected Secondary Service is at lowest level of the SAC service hierarchy. The SAC functionality in the White Space database is extended to ensure protection of the Primary and Protected Secondary Services from the Unprotected Secondary Service in following way. A Protected Secondary Service is protected by the SAC functionality in the same way as a Primary Service is currently protected; i.e., all Unprotected Secondary Services (the current license-exempt systems) in the coverage area of a Protected Secondary Service would have to operate at a power level that is no higher than some specified value below that used by the Protected Secondary Service. Basic SAC algorithm follows as below:

1. Primary service(s) – these are licensed users of the spectrum and will be given exclusive access to the spectrum and full transmission rights. No conditions or checks applied. Examples - DTT, Wireless microphone
2. Protected Secondary Service(s) – these are Soft-Licence users, protect the Primary service and are granted restricted spectrum usage rights under the rules defined by the Soft-Licence. Examples –rural broadband, delay-sensitive telemetry service, etc.
3. Unprotected Secondary Services(s) - these are licence-exempt users and are not provided any service guarantees but only connectivity, all conditions and checks applied for protecting primary and protected service category. Example –Home networking WiFi.

Services that need protection are identified by the regulators under a Soft-Licence licence type as discussed next.

C. Soft-Licence concept

Soft-Licence concept is a new flexible licensing mode that sits between the two current licence types i.e., exclusive licence spectrum and license-exempt spectrum. Soft-Licence reflects a light-touch regulatory approach and provides the fine balance between how best to enable efficient use of spectrum while at the same time encourage service providers to deploy infrastructure based on spectrum shared amongst multiple systems. It is a pseudo license category i.e., when viewed by Unprotected Secondary Service it makes the Protected Service appear as Primary Service while when viewed from the Primary Service perspective it makes the Protected Service appear as any other Unprotected Secondary Service via the SAC functionality. An example of a Soft-Licence could be issuing a licence for rural-broadband service for rural geo-types only. Some of the properties/constraints of a Soft-Licence Protected Service could be

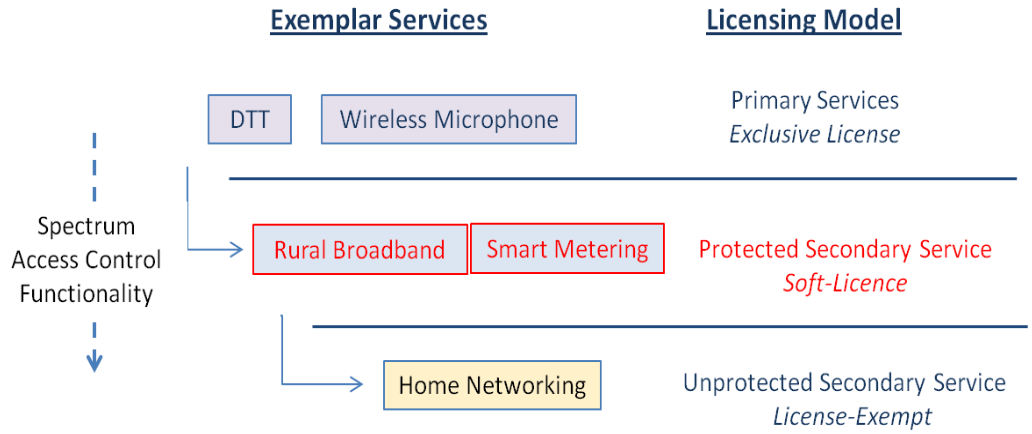

Figure 3. Spectrum Access Control as a function of service type category

- it is not a national or 24x7 service, but a limited one - specified for certain geo-types only (regional basis) or specified for certain time of the day only (temporal basis).
- there may be different frequency channels reserved in different regions/different times due to the constraints of the primary systems
- a certain amount of channel bandwidth would be reserved for the protected secondary service category
- duration of a Soft-Licence would be shorter unlike an exclusive licence.

D. Potential issues with Soft-Licence

Some potential issues regarding the Soft-Licence concept are discussed here. Firstly, there is an element of statistics regarding the amount of White Space spectrum availability as to whether or not a Protected Service Category can be accommodated and operated in the same coverage area. In certain areas identifying spectrum for Protected Service may not be possible. Further the Primary Service could still cause service disruption to the protected services. It should be noted and enforced that protection is only offered from other Unprotected Secondary license-exempt users rather than from a Primary Service. Secondly, there may be competition concerns if a Soft-Licence is granted to only one service provider. If more than one service providers wish to operate a Protected Secondary Service under the Soft-Licence model in the same location/time, there is a danger of reinventing a flavor of etiquette rules at a different level. To prevent this and to address competition concerns, commercial model using Soft-Licence is proposed in the next section.

V. Soft-Licence Commercial Model

If multiple service providers wish to run a Protected Service using Soft-Licence in same area/or same time – there will be a requirement on their interfaces to cooperate and access each other's network on rapid timescales, which suggests that ultimately it would make more sense if they were all served by a single administration ideally using a single technology. This suggests a new business model [22] [23] has to evolve to decouple the service layer from the underlying infrastructure network as shown in Figure 4.

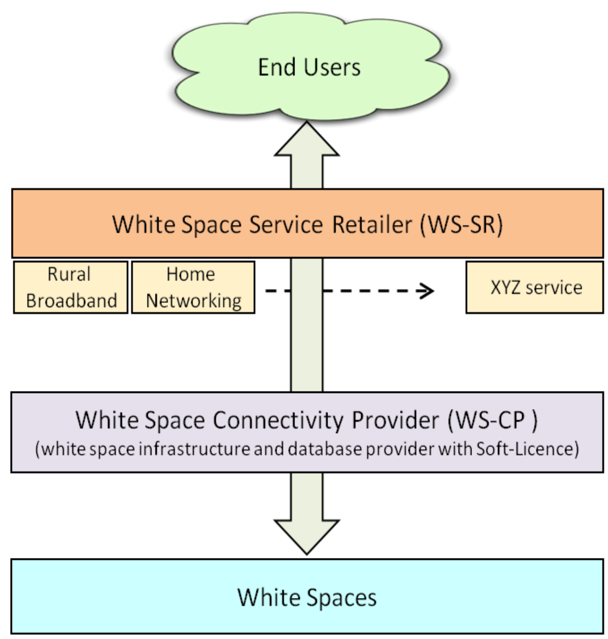

Figure 4. Single White Space administration based on Soft-Licence proposal

The basic idea proposes that types-of-services and types-of-connectivity are conceptually independent and cleaner separation of connectivity and service provisioning should be made. This would result in White Space spectrum being more open and flexible and avoid future White Space access networks to be stove-piped due to lack of separation of technology, infrastructure and services; as discussed below.

A. White Space Connectivity Provider (WS-CP)

The underlying connectivity layer known as White Space Connectivity Provider (WS-CP) will be responsible for providing connectivity and deploying White Space infrastructure. It will keep the White Space database up to date in accordance with the spectrum rules and associated dynamics. The WS-CP is granted a Soft-Licence; i.e., certain the White

Space spectrum reserved under certain constraints to provide White Space services. The WS-CP hides the underlying complexity and is responsible providing QoS, service level agreements, etc as agreed with White Space Service Retailers (WS-SRs discussed ahead). It treats all the service retailers in an equivalent way i.e., without any bias towards a particular service provider, which the regulator would police and may be restricted from providing retail services directly to end users. Conceptually, the single WS-CP administrator could be a consortium of interested parties sharing White Space spectrum.

B. White Space Service Retailer (WS-SR)

The current White Space service providers of rural broadband, smart metering, home networking, etc would become pure WS-SR and would not deploy any White Space infrastructure. They would negotiate access to a certain amount of network capacity in terms of bandwidth and latency based on their service requirements and leave the network infrastructure build to the WS-CP.

Service specific aspects of a Soft-Licence mandated by regulator would be taken into account by the WS-CP whilst managing the network on behalf of all of the service providers. Under this proposed commercial model, competition is shifted from the network layer to the service layer and competition at the network layer is replaced with cooperation. Similar analogy in other industries could be cited, for example – the Local Loop Unbundling (LLU) concept in fixed-line infrastructure or Mobile Virtual Network Operator (MVNO) concept in cellular industry. Migrating to the proposed commercial model is a political/business decision that the regulator and industry would have to make. Further research is needed to provide insights into the impact migrating to the proposed model is likely to have on overall aspects such as operating costs, regulation, technology, operators, users, etc.

VI. CONCLUSION

This paper discusses fundamental problem associated with providing long-range communication services in license-exempt TV White Spaces, namely spectrum assurance needed by service providers to invest in White Space infrastructure. It highlights the limitations and complexities of the current spectrum etiquette proposal. The paper proposes a far simpler and flexible alternative based on a novel regulatory approach of 'Soft-License' and 'Protected Service' concepts. It is claimed that a Soft-Licence along with proposed commercial model would result in White Space spectrum being more open and flexible and avoid future White Space access networks being stove-piped.

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