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MAXIMIZING TV WHITE SPACE IN NIGERIA USING AN OPTIMIZED SFN AND k-SFN NETWORK DESIGN

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Abstract: A proposal for maximizing the available TV white space in Nigeria using a mixture of SFN and k-SFN digital television network design is presented in this paper. First, the current spectrum occupancy of UHF and VHF band by analogue terrestrial television was determined. The spectrum was re-planned for future DTV services by considering the size of the network, the location of the transmitters in each of the geo-political zones of the country, the type of coverage and variation in regional programming. Results from the network plan showed that 8 multiplexes, using 20 UHF channels can be used to broadcast 129 programmes to achieve a spectrum savings of 168MHz which amount to 51.22% of the present analogue television spectrum use. Our optimized SFN and k-SFN network design was further compared on a network design based on a combination of SFN and pure MFN. Results showed that 80.9% increase in savings can be obtained using our proposed optimized network design. Finally, the capacity of TV white space available with the present GE-06 planned entries for digital television services in Nigeria was determined and compared with available TV white space from our proposed reconfigured digital television plan using the SFN and k-SFN design. Results showed that it is possible to improve the average Level of Compactness from 0.401 to 0.561 for the country. This means that, with the optimized network design, it is not only possible to increase the spectrum savings in the country but also possible to improve the level of compactness which translates to a higher level of usefulness of the expected TV White spaces.

Keywords: MFN (Multi-frequency Network), SFN (Single Frequency Network), k-SFN (Hybrid MFN-SFN), TV White Space, Level of Compactness.

1. Introduction

The VHF and especially the UHF bands are highly attractive to newer technologies because lower frequencies are affected more by atmospheric noise and interference from electrical equipment. Higher frequencies are also susceptible to attenuation making the UHF band very competitive and highly desirous for radio communication. Though the radio spectrum is a natural resource which can be reused, it can only accommodate a limited number of simultaneous users. Therefore, if the competition for the UHF band is left unmanaged,

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congestion of the band may result and this can lead to harmful interference that can degrade signals or interrupt communication services. The problem of limited spectrum is further compounded by the development of new technological innovations that must be encouraged through the availability of suitable spectrum.

The VHF and UHF band, sometimes referred to as the television broadcast band, has been primarily used for terrestrial television broadcast services. However, there are several spaces within these spectrum bands that are not used by licensed television services in Nigeria. These holes are often referred to as “Television (TV) White Spaces”. The term “White Space” is used to describe a part of the frequency spectrum which is available for radio communication at a given time, in a given geographical area on a non-interfering and non-protection basis with regard to other services [1].

In Nigeria and Africa as a whole, Band III (174–230 MHz) and Band IV/V (470–862 MHz) is allocated mainly to broadcast services. The use of these bands is regulated by the GE-06 agreement. This agreement for broadcast services contains frequency plans for both analogue television and digital television services. The analogue television plan will cease to exist after full transition to digital television. The mandatory digital switch over date for Nigeria and most African countries is 17th June, 2015. Generally, TV white spaces will be made more available through the transition from analogue television to digital television because digital technology allows more information to be aired using less spectrum space. However, there is the need to quantify the capacity of this TV white space within the country and determine how useful these spaces will be to services competing for its use. The purpose of this paper is to determine the capacity of TV white space available with the present GE-06 planned entries for digital services in Nigeria and compare with a proposed reconfigured digital television plan using an optimized SFN and k-SFN network design that can yield an optimal white space capacity for the country.

In the first phase, this paper makes a first attempt to quantify the capacity of TV white space in Band III and Band IV/V in Nigeria using the current GE-06 planned entries. The results of this quantification was thereafter used to compute the level of compactness that can help determine the usefulness of the available White Space for radio propagation. In the second phase of this paper, we revisited the assignments in the ITU GE-06 plan for Nigeria and optimize the assignments by re-planning the Digital Television (DTV) network using an optimized SFN and k-SFN network design. The available TV white space was then reestimated and the level of compactness re-evaluated. The results from our quantitative analysis were then compared and interesting conclusions deduced from the analysis.

2. Available TV White Space From Current GE-06 Plan

In this section, TV white space availability was analyzed on a per channel basis using the current GE-06 DTV planned entries for Nigeria. White space availability was determined for all the states within the country. Figure 1 shows TV white space availability by channel in the VHF and UHF band for all the 36 states of the country. The figure represent availability using distribution of TV transmitters in the present GE-06 planned entries. Frequency channel assigned to a television transmitter within a particular state is considered unavailable for white space devices.

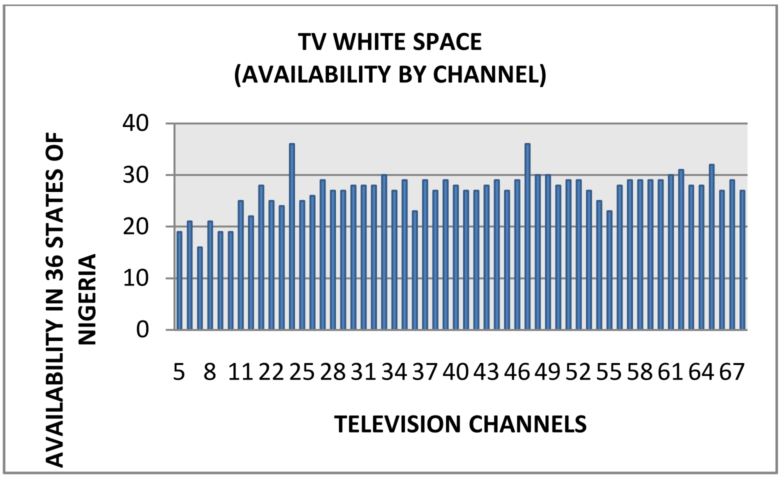

Figure 1: Available TV White Space by Channel

Results from figure 1 shows that 75.1% of the channels in the VHF and UHF bands are available as TV white space in all the states. It must be noted that all adjacent-channels to thel frequencies used within a state are deemed unavailable within that state. The TV white space available in all the states was also quantified using predicted field strength received at various states due to all DTV transmitters. The predicted field strength values could not be verified with actual measured values because DTV is yet to be operational in the country.

The digital television coverage for the country was assessed using the IRT prediction method with the aid of FRANSY; a frequency analysis software tool used in television network planning developed by the Institut für Rundfunktechnik (IRT). Thirty six (36) states have been considered and the transmitter power values used are as contained in the GE-06 agreement. FRANSY employs relevant field strength prediction models in addition to data for terrain and clutter to predict the field strength received from a transmitter and the coverage of a transmitter [2]. The Nigerian land cover data used in this work was collected by

US Geological Survey (USGS) using LANDSAT 7 satellite with a resolution of 1Km. Different attribute data on the transmitter were collected from the Nigerian Broadcasting Commission (NBC) and also from the GE-06 plan for Nigeria. The complete database for the TV network in the states were stored on a digital map and used as an input into FRANSY.

Figure 2 shows the TV white space available in the VHF and UHF band using the predicted received field strength for each channel in all the states. It can be seen from figure 2 that TV white space has now been reduced to 69 % of the available space within the country.

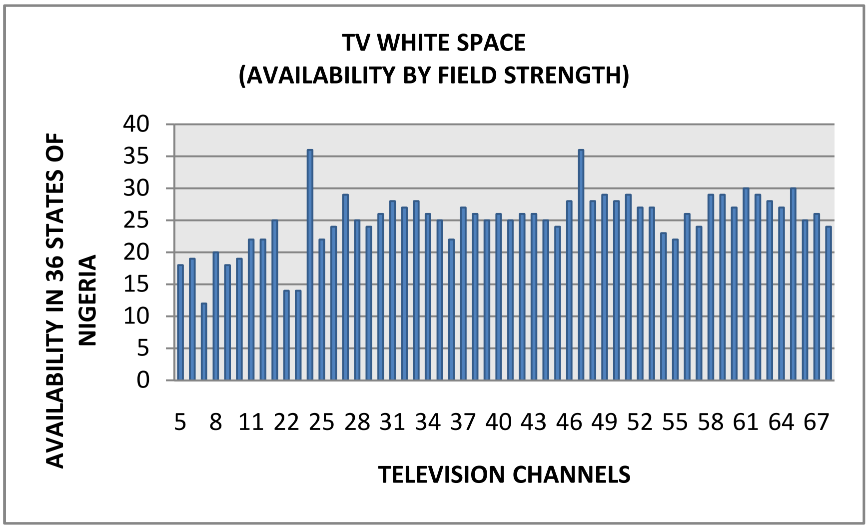

Figure 2: Available TV White Space by Field Strength.

Basically, White Space Devices (WSDs) are of two types: fixed and portable WSDs. Fixed WSDs are allowed transmit power of up to 4W EIRP and therefore can easily operate on the second adjacent (or greater) white space channel. Portable WSDs, which can be mobile, are limited to 40mW EIRP and can operate on the first adjacent channel from channels 21-51 [3]. Figure 3 shows spectrum availability for both fixed and portable WSD in six selected states of the country. It is clear from the figure that there are more channels available to portable WSD compared to fixed WSD. This is because portable WSD are allowed the use of first adjacent white space channels due to their lower EIRP.

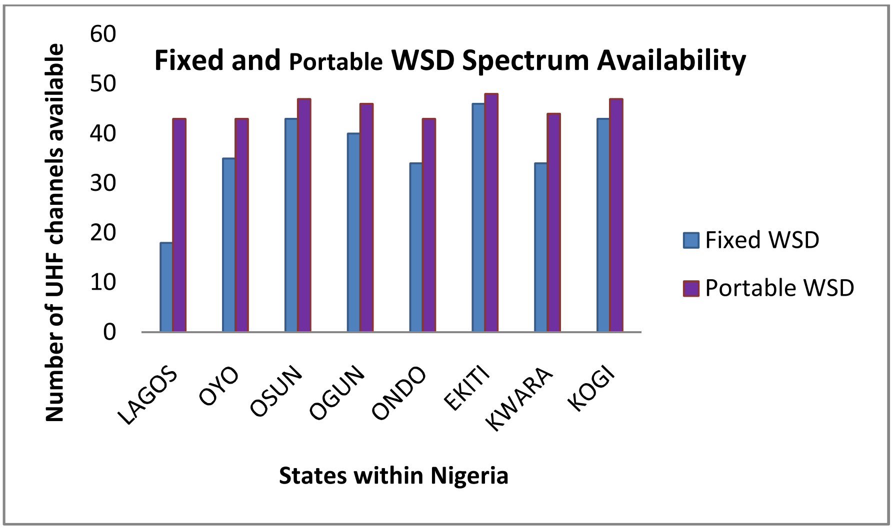

Figure 3: Fixed and Portable WSD Spectrum Availability in Selected States

2.1 Estimation of Contiguous Channel Bandwidth

The total amount of TV white space at a state is usually not enough to describe TV white space availability. Most communication applications competing for the TV white space need more bandwidth, for propagation, than what is available in one TV channel. An example is LTE that needs up to 20 MHz, which is equivalent to 3 contiguous channels, for propagation [4]. Contiguous channels are therefore more attractive as TV white space than fragmented spectrum. There is therefore the need to assess the number of contiguous channels available in order to determine the level of usefulness of the available TV white spaces for communication applications.

To determine how compact and useful the available TV white spaces are, we use a metric known as the Level of Compactness [5]. The Level of Compactness, *C*, is given by;

$$C = \sum_{i=1}^{n} w[b(i)] \tag{1}$$

The weight function $w(b)$ is introduced into equation (1) to be able to weigh the separate blocks of frequencies and sum up all the values and $w(b)$ is defined as;

$$w(b) = \frac{b^2}{sum^2} \tag{2}$$

where sum is as given in equation (3) while $b(i)$ is the width of the block.

$$sum = \sum_{i=1}^{n} b(i) \tag{3}$$

Since all the values lie between $\frac{1}{n}$ and 1, to scale equation 1 to percentage, we therefore use the following transformation:

$$c' = \frac{C - \frac{1}{n}}{1 - \frac{1}{n}} \tag{4}$$

The average Level of Compactness for all the states under consideration is therefore:

$$C_{average} = \frac{1}{x}\sum_{i=1}^{x} C(i) \tag{5}$$

where x is the number of states considered.

Results showed an average Level of Compactness of 0.401 for the country with the present GE-06 agreement. This shows a relatively high Level of Compactness and therefore a high level of usefulness for the expected TV white spaces. However, we show in the next section that by re-planning the DTV network using our proposed optimized SFN and k-SFN network design, it is possible to achieve a higher level of compactness and therefore improve the usefulness of the national TV White spaces.

3. Network Re-Planning and Optimization

There are some major elements that need to be considered in drawing up a plan for digital terrestrial television network. They are as follows [6], [7].

- **Compression Technique**: MPEG-2 or MPEG-4.
- **Required Quality**: SD or HD television
- **Network Architecture**: MFN, SFN or Hybrid MFN-SFN (k-SFN)
- **Reception Mode**: Fixed Antenna, Portable Indoor or Mobile reception.
- **DVB-T Variant:** DVB-T or DVB-T2

The required data rate for one television programme for MPEG-2 and MPEG-4 is shown in Table 1. The table shows that H.264/MPEG-4 variant is approximately twice as efficient compared to MPEG-2, [7].

Table 1: Data Rate required for one Television Programming Channel [7]

Compression Technology	SD Programming Channel	HD Programming Channel
MPEG-2	3.2 Mbit/s	16 Mbit/s
H.264/MPEG-4 AVC(HIP)	1.6 Mbit/s	8 Mbit/s

The net data capacity of DVB-T2 configuration depends on a number of technical characteristics such as the FFT size, guard interval fraction, pilot pattern and the modulation scheme [8]. These parameters when selected for SFN implementation, affect the performance of the network. Table 2 gives the guard interval fraction and corresponding distance for SFN. The guard interval limits the physical size of an SFN and is normally chosen to be as large as the most separated transmitter in the network.

Table 2: Choices of Guard Interval and corresponding distance for SFN [9]

		1⁄128	**1⁄32**	**1⁄16**	**19⁄256**	**1⁄8**	**19⁄128**	**1⁄4**
FFT	$T_U(ms)$	$l_{max}(km)$						
32k	3.584	8.4	33.6	67.2	79.8	134.4	159.6	N/A
16k	1,792	4.2	16.8	33.6	39.9	67.2	79.8	134.4
8k	0.896	2.1	8.4	16.8	19.95	33.6	39.9	67.2
4k	0.448	N/A	4.2	28	N/A	16.8	N/A	33.6
2k	0.224	N/A	2.1	4.2	N/A	8.4	N/A	16.8
1k	0.112	N/A	N/A	2.1	N/A	4.2	N/A	8.4

DTT networks can be implemented using multi-frequency (MFN) or single frequency (SFN) or a combination of both. Multi-frequency Network consists of transmitters with independent programme signals and with individual radio frequencies. Although MFN requires a large amount of spectrum, it is an effective way of maximizing coverage and supporting regional variations in programming. On the other hand, with SFN, all the transmitters in a given area use the same spectrum channel and must broadcast exactly the same content everywhere. All transmitters are synchronized and radiate on the same frequency over the whole coverage area. SFNs allow more efficient utilization of the spectrum and it also power efficient compared with MFN. However, it may give rise to self-interference of the network in which the signals from far distant transmitters are delayed more than allowed by the guard interval, so they behave as noise-like interfering signals rather the wanted signals. The SFN approach can also be combined with the MFN concept. This is implemented such that within an MFN using high power main station, if such station does not provide complete coverage, lower power relay stations may complete the coverage using the same frequency as the associated main station. This configuration could also be called hybrid MFN – SFN, also called the k-SFN configuration [6][7]..

The digital terrestrial television network in Nigeria was designed by assuming that the analogue television transmission will be completely switched off before commencement of DTV transmission. Planning was done by deploying the existing analogue infrastructures within the six geopolitical zones in Nigeria with 87 main transmitters and 42 relay stations to achieve the same level of coverage as the analogue service. Owing to the ethnic and cultural diversities in Nigeria implementing a national SFN is not practicable instead a mixture of MFN and SFN was used. A mixture of SFN and hybrid MFN-SFN (also known as k-SFN) design is deployed in this paper using a minimum of 4 multiplexes with nation-wide coverage in the band 470-694MHz (UHF channels 21 to 48). This is done in order to meet requirement for DTV planning according to the ATU frequency coordination meeting in Bamako 2012 [10]..

3.1 Optimized SFN and K-SFN Network Design

The scope for implementing SFN mainly includes the physical size of the service area and the possibility of providing regional content (same programming channel, advertising and data services). Single frequency network can be implemented easily in the southwest zone (which includes Lagos, Ogun, Oyo, Osun, Ekiti and Ondo states) and southeast zones (Abia, Enugu, Anambra, Ebonyi and Imo states). SFN is deployed in these areas because there is common language, thus SFN can be used to broadcast same content.

To implement the SFN, the existing analogue transmitter networks in these areas were examined and the services areas were also assessed in order to define and extract the useful sites. The useful sites were classified according to geopolitical zones and then grouped into SFNs. A regional SFN design was implemented in the south east zone with 16 transmitter sites and diameter of 158.84Km. The largest inter-transmitter distance in the south west zone far exceeds the maximum distance equivalent to the guard interval length provided by DVB-T2 system variant (see Table 2). Therefore, in order to prevent self-interference, the zone was grouped into 3 SFNs made up of 6, 14 and 16 transmitters with the diameters 138.25Km, 183.46Km and 157.07Km respectively.

Due to the vast language diversities in south-south region of Nigeria, it would not be practically viable to implement a regional SFN because there will be no variation in the programming content. It would also be difficult to deploy SFN in part of the north-central, north-east, north-west zones because of the large geographical size of the states in these regions, although they share a common language. Transmitter sites in each state are located very far apart and so the effects of self-interference would be pronounced. A Multi-frequency network configuration can be used in this case, where individual transmitter provide its own coverage but will require several channels almost in the range of that used in analogue services. For these reasons, a k-SFN, also known as a hybrid MFN-SFN network which requires fewer frequencies than in pure MFN was deployed in these areas, in our design, to provide local content in the states. The k-SFN topology is made of high power main station for the MFN configuration and at least two gap-fillers (that is, k > 1) as lower power relay stations to complete the coverage.

Table 3 gives a summary of the DVB-T2 parameters for the multiplexes for fixed roof-top reception. It can be seen from the table that a total of 5 HD (High definition) and 124 SD (Standard Definition) programmes is possible using the existing 129 programmes.

Table 3: Summary Proposed DVB-T2 Multiplex Parameters in Nigeria

Parameters	**Multiplex 1**	**Multiplex 2**	**Multiplex 3**	**Multiplex 4**	**Multiplex 5**	**Multiplex 6**	**Multiplex 7**	**Multiplex 8**
Number of Programmes	6	14	16	16	21	20	16	20
Guard Interval	19/128	19/128	19/128	19/128	1/128	1/128	1/128	1/128
Modulation Scheme	64-QAM	256-QAM	256-QAM	256-QAM	256-QAM	256-QAM	256-QAM	256-QAM
FFT Size	32k Extended mode	32k Extended mode	32k Extended mode	32k Extended mode	32k Extended mode	32k Extended mode	32k Extended mode	32k Extended mode
Code Rate	2/3	3/5	3/5	3/5	3/5	3/5	3/5	3/5
Pilot Pattern	PP8	PP8	PP8	PP8	PP7	PP7	PP7	PP7
Data Rate (Mbps)	26.5	35.3	35.3	35.3	36.2	36.2	36.2	36.2
Compression	MPEG-4	MPEG-4	MPEG-4	MPEG-4	MPEG-4	MPEG-4	MPEG-4	MPEG-4
Programme content with existing broadcast stations	1 HD + 5 SD Channels	1HD + 13 SD Channels	1 HD +15 SD Channels	1 HD + 15 SD Channels	21 SD Channels	20 SD Channels	1 HD + 15 SD Channels	20 SD Channels

4. Estimation of Contiguous Bandwidth Using SFN and k-SFN Network Design

In accordance with the Bamako 2012 ATU Frequency coordination meeting, UHF channels 21 to 48 (471.25-695.25MHz), that is 28 channels, will be used to provide frequency allocation for nationwide coverage. The allocation of frequencies used in specific sites is reused in other transmission sites under consideration of harmful adjacent and co-channel interference by allowing sufficient geographical separation distance before frequency re-use. All multiplexes will transmit from all transmitter sites. Table 4 shows the UHF channels used for each of the multiplexes.

As earlier stated, the total size of the analogue television is 328MHz. With the use of the combination of SFN and k-SFN network implementation, a total 20 UHF channels is used to broadcast 129 programmes giving a spectrum savings of up to 51.22% of the present analogue television spectrum usage. This implies the size of the digital dividend in Nigeria amounts to 168MHz. This savings can be compared with a total of 37 UHF channels needed when a mixture of SFN and pure MFN design is used which produces a savings of just 9.76%. This implies that there is 80.9% increase in the amount of spectrum freed when mixture SFN and pure k-SFN architecture is implemented as compared to the a mixture of SFN and pure MFN design. With the DVB-T2 parameters chosen for each of the multiplex (see Table 3), there is a possibility of having a total of 27 more SD channels in addition to the 129 programmes used in the planning.

Table 4: UHF Channels used for each Multiplexes

	Multiplex	1	2	3	4	5	6	7	8
Channel									
21		**D**	**D**	**D**	**D**	**D**	**D**	**D**	
22		**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**
23		**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**
24			**D**	**D**	**D**		**D**	**D**	**D**
25		**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**
26		**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**
27		**D**	**D**		**D**	**D**	**D**	**D**	**D**
28		**D**	**D**	**D**	**D**	**D**			**D**
29		**D**			**D**		**D**	**D**	
30		**D**	**D**		**D**	**D**	**D**	**D**	**D**
31		**D**	**D**	**D**		**D**	**D**	**D**	**D**
32				**D**	**D**	**D**	**D**	**D**	**D**
33		**D**		**D**		**D**	**D**	**D**	**D**
34		**D**						**D**	**D**

35		D	D	D	D	D	D		D
36		D	D	D	D	D	D		D
37		D	D	D			D	D	D
38		D	D	D	D	D	D		D
39		D	D	D		D	D	D	D
40			D	D		D	D	D	D

☐ Unused Channel D Used Channel

The south-west SFN was divided into 3 sub-regions because the service area diameter is greater than can be accommodated by the guard interval. In order to prevent self-interference, the SFNs were grouped into manageable sizes with respect to reducing the effects of internal network interference. SFN cannot be deployed in most parts of the northern states because of the large geographical size and the huge separation between adjacent transmitters which cannot be allowed by the longest guard interval. A hybrid MFN-SFN is implemented with MFN as main transmitters and SFN as gap-fillers to complete the coverage. Also, due to the vast language diversion in the south-south, it is possible to provide local content using a hybrid MFN-SFN.

Estimating the level of compactness with the results from our optimized DTV network design, it can be showed that it is possible to improve the average Level of Compactness from 0.401 to 0.561 for the country. This means that, with the optimized SFN and k-SFN DTV network design, it is not only possible to increase the spectrum savings in the country but also improve the level of compactness which translates to a more promising use of the expected TV White spaces.

5. Conclusion and Recommendation

A DTV network plan is developed using a combination of an optimized SFN and k-SFN network design to determine the amount of spectrum that can be saved from analogue to digital transition and determine the usefulness of this spectrum to competing digital services. Result reveals that 51.22% of the spectrum is saved after the digital switch-over which implies the size of the digital dividend amounts to 168MHz. This translates to 80.9% increase in savings compared to what is possible if a combination of SFN and pure MFN is implemented. We therefore conclude that combining a k-SFN with SFN topology is more spectrum efficient than a mixture of SFN and a pure MFN configuration and recommend this as the digital television network design to be used in Nigeria.

From the plan, it is possible to implement a hybrid MFN-SFN configuration in the North and South-South zones in Nigeria instead of a pure MFN configuration. This will help to reduce the number of channels used and also provide local content in the states. Furthermore, Single Frequency Networks should be implemented across the South-West and South-East zones because the inhabitants of these regions share a common language thus SFN can be used to broadcast the same content and using SFN will also increase the spectral efficiency. The paper further estimated the Level of Compactness of the expected TV White space from the released spectrum in order to determine how useful these spaces are to new digital services. Results showed that it possible to achieve a Level of Compactness of up to 0.561 with the SFN and k-SFN network design. This means that is possible to release half of the present frequency spectrum used by analogue television as a contiguous band and this can be shared among competing digital services as required.

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