The potential of T2 in a WiB planned DTT scenario

THE POTENTIAL OF T2 IN A WIB PLANNED DTT SCENARIO

A. De Vita[1], V. Mignone[1], A. Morello[1], R. Gaffoglio[2]

[1]Rai-RadioTelevisione Italiana, Italy
[2]Dip. di Fisica, Università degli Studi di Torino, Italy

ABSTRACT

WiB (Wideband reuse-1) is a new system concept proposed for DTT (Digital Terrestrial Television), where potentially all UHF channels allocated to broadcasting services are used from all transmitter sites, thus having frequency reuse-1 (even around national borders), instead of frequency reuse 5 to 7 as adopted in “conventional” DTT plans. In WiB, interference from co-channel neighbouring transmitters is handled by a combination of robust transmission modes, wide-band carrier aggregation, directional discrimination of the receiving antenna and, when required, sophisticated interference cancellation methods. All of this requires new standardisation activity and new TV receivers.

The paper describes a planning study that investigates the potential of reuse-1 planning for fixed DTT services, targeting current DVB-T2 receivers, i.e. using the most robust modes, but no interference cancellation techniques in the receiver nor carrier aggregation. Although such configuration promises, in an ideal interference-free environment, dramatic power savings and similar spectrum efficiency compared to current DTT networks, the simulations on a regular hexagonal lattice network including noise and interference produced some surprising outputs which are discussed in this article.

INTRODUCTION

Conventional planning of DTT services is based on international Plans [1] that assign an equal portion of the spectrum to each nation in such a way that each transmitter in a Multi-Frequency Network (MFN) does not cause or receive interference from the neighbouring Countries’ transmitters (a similar approach is adopted inside a MFN-planned country). This results in a frequency reuse *N*, i.e. only one channel out of *N* channels is assigned to each transmitter or service area, with *N* going from 3 (theoretical minimum value for regular hexagonal lattices) to 7 (a typical figure adopted in real networks is N=5), depending on the geography of the country and the network and transmission system ruggedness against noise and interference. The effect is a N-fold reduction of the available capacity (i.e., useful bit-rate) for a given allocated spectrum.

In a traditional High Power High Tower (HPHT) DTT Multi-Frequency Network (MFN) or Single-Frequency Network (SFN) a high capacity is usually transmitted per UHF/VHF channel (8 or 7 MHz in Europe). Table 1 indicates typical frequency reuse factors and spectral efficiency for DVB-T2 networks.

Table 1 – Layer spectrum efficiency of various DVB-T2 scenarios – Typical values - Fixed reception ([2], Table P2-6)

DVB-T2 Network Type	Spectral Efficiency [bit/s/Hz]	Re-use blocking factor	Layer spectrum efficiency [bit/s/Hz]
MFN	5.0	7	0.71
Large SFN	4.2	4	1.05
Medium SFN	4.6	5	0.93

These high DTT capacities (e.g. 33 - 40 Mbit/s for the Digital Video Broadcasting DVB-T2 standard) are obtained using high order modulation schemes, such as 256-QAM (256-points Quadrature Amplitude Modulation) combined with LDPC (Low-Density Parity-Check) coding rate 2/3 ([1]), which require large SINR (Signal-to-Interference plus Noise ratio) values and high-power transmitters. Ideally, if conventional planning at reuse-5 is considered, with DVB-T2 256-QAM rate 2/3 the effective achievable spectral efficiency is in the order of 1 bit/s/Hz, being 5.31 the modulation and coding spectral efficiency ([2]). The corresponding required SINR is of about 18 dB on the Additive White Gaussian Noise (AWGN) channel.

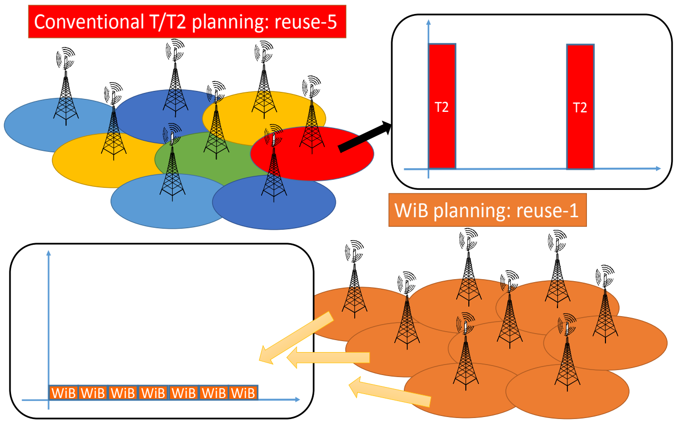

Figure 1 – Conventional vs WiB frequency planning

A new system concept for DTT, called “WiB”, has recently been presented by Erik Stare et al. [3], where potentially all UHF/VHF channels allocated to broadcasting are used from all transmitter sites, thus having frequency reuse-1 (even around national borders), instead of frequency reuse 5 to 7 as adopted in “conventional” DTT plans (Figure 1). Noise and interference from co-channel neighbouring transmitters are handled by a combination of robust transmission modes, directional discrimination of the receiving antenna and, when required, sophisticated interference cancellation methods. While the high order modulation schemes employed in traditional DTT services make the transmitted signals strongly sensitive to interference, using a Quadrature Phase Shift Keying (QPSK) modulation scheme and a low-rate LDPC code increases the robustness of the transmission. Assuming, for example, the adoption of QPSK rate 1/2 and reuse-1, the global spectral efficiency would be similar to that of conventional reuse-5 planning and 256-QAM rate 2/3, but the corresponding required SINR value would reduce from 18 dB to about 1 dB (AWGN channel); taking into account the factor of 5 (5 carriers

[1] The simplified notation “256-QAM rate 2/3” or “QPSK rate 1/2” will be adopted in the following
[2] Spectral efficiency does not take into account signalling / synchronization / sounding / guard interval losses

are active in WiB against 1 carrier in the reuse-5 plan), which corresponds to 7 dB, this results in a potential WiB power gain of about 10 dB in a Gaussian-noise, interference-free, channel.

The authors of [3], in addition to the aforementioned reuse-1 concept, proposed that WiB would include "channel aggregation" over multiple 8 MHz channels ([3]), sophisticated interference cancellation techniques and LDM (Layer Division Multiplexing). They claimed, in addition to the reduction in power consumption of 10 dB, a potential 37-60% capacity increase for the same coverage as current DTT and the possibility to combine fixed and mobile broadcasting and unicasting services.

In this paper we analyse the potential of the WiB concept for fixed DTT services, but renounce everything that would require a new DVB standard and new receivers; thus wideband carrier aggregation, interference cancellation, LDM, mobile reception, bi-directional unicast communications are out of scope. We evaluate the current DVB-T2 system using the most robust available mode (QPSK rate 1/2), roof-top receiving antenna, frequency reuse-1 (for brevity, the T2 with reuse-1 and T2 with reuse-5 schemes will be referred to as T2/R1 and T2/R5, respectively).

A planning study, comparing T2/R1 and T2/R5 approaches in terms of spectrum and power efficiency was conducted using a simulated ideal, regular network, which nevertheless provides an overview of the potential gains that can be encountered in real networks. Since for a simple reuse-1 network implementation the simulation results give unsatisfactory coverages because of the co-channel interference from neighbouring transmitters, successive optimisation steps are described in this paper by introducing, firstly, the transmitter antenna directivity in the vertical plane (and antenna tilt), and then the SFN signal synchronisation inside a country or region. Finally, for the optimised network configuration, the achievable power gains are presented.

THE SIMULATION FRAMEWORK

The simulated network structure is the hexagonal transmitter lattice of Figure 2, where 91 omni-directional transmitters (91 being enough elements to approximate the behaviour of an ideal infinite network) are regularly arranged according to a specified Inter-Site Distance (ISD).

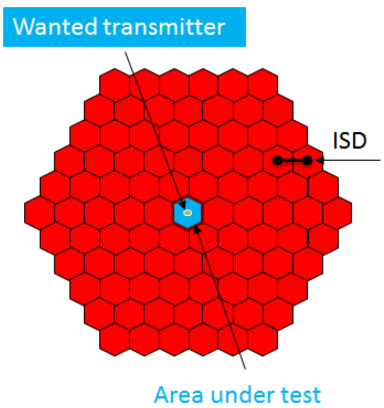

Figure 2 – Ideal hexagonal TX lattice

The reuse-1 network performance has been analyzed by means of a simulation program based on MATLAB® software. This program uses Monte Carlo simulations to calculate the SINR for each receiving point of the testing area. Gaussian demapping is assumed, as in conventional DVB-T2 receivers, so interference is treated as noise.

The propagation model used for this analysis is that

[3] The W of WiB means Wideband, offering narrow-band interference suppression, improved diversity in a frequency-selective terrestrial channel, increased statistical multiplexing gain for video broadcasting, improved capacity for 4k UHD programmes.

defined in Recommendation ITU-R P.1546-5 [4], which reports the curves of the field strength exceeded at 50% of the locations within any small area (500 m by 500 m) and for various percentage of the time, as a function of the distance from the transmitter.

The statistical variations of the field strength generated by each transmitter in the small areas (location variability) are assumed to be log-normally distributed with a standard deviation σ of 5.5 dB; statistical independence is assumed between different transmitters.

The target percentages in the small areas have been set at 95% for "good" and 70% for "acceptable" reception.

To guarantee the service coverage for 99% of the time, as suggested by international recommendations and planning studies [5], the useful signals are considered at 50% of the time, while the interfering signals at 1%.

In this study the transmitter height considered is always 200 m (agl, above ground level), omnidirectional in the horizontal plane, while in the vertical plane both omnidirectional and directional antennas, with radiation pattern shown in Figure 3, have been tested. In the simulations, the antenna radiation pattern was tilted downwards to reduce interference at the horizon, to have a 3 dB attenuation at the edge of the coverage area (as a good compromise between high useful field-strength at the service area edge and interference reduction from surrounding transmitters [4]).

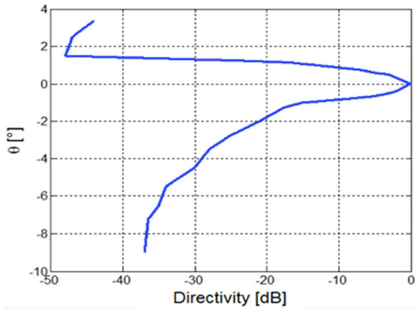

Figure 3 – Transmitter vertical antenna pattern for 0° tilt

The study concentrated on fixed roof-top antenna reception, at 10 m agl, assuming an antenna pattern defined in [6]. This antenna has a gain of 9.15 dB in the range ±20°, falling linearly from 9.15 dB at ±20° to -6.85 dB at ±60°, and a front to back ratio of 16 dB.

Coverage is evaluated in a suburban environment. QPSK rate 1/2 at 2 dB SINR is compared to 256-QAM rate 2/3 at 19 dB (assuming 1 dB for real channel estimation and implementation losses in addition to the theoretical value).

COVERAGE OF T2 WITH REUSE-N

For a 1 kW EIRP single transmitter without interference, Figure 4 reports the percentage of the area covered with “good” quality: for ISD = 40 km the SINR = 19 dB target is guaranteed over the full area, while for ISD = 60 km, coverage of 95% of the area

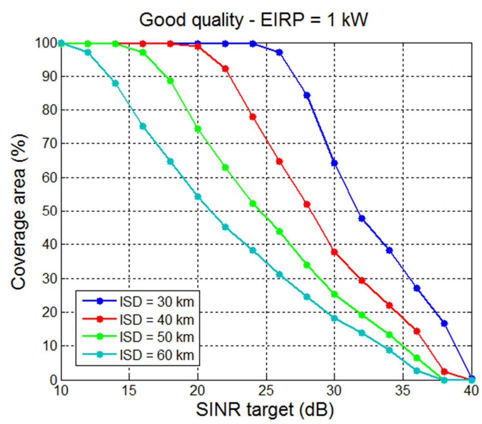

Figure 4 – Reference single transmitter coverage in suburban area

[4] With the TX antenna of Figure 3, near the useful transmitter the field-strength shows a “volcano crater”, but remains sufficiently large not to generate coverage problems. For higher transmitters, such as 500 m agl, the lower lobe of the antenna pattern must be widened to avoid coverage problems near the transmitter.

requires about 7 dB EIRP increase (thus about EIRP = 5 kW).

This noise-limited reference case well represents the simulated performance with noise and interference and reuse-7 (i.e. T2-R7, where in the regular hexagonal lattice co-channel interfering transmitters are separated by two “rings” of non interfering transmitters), while for T2-R4 (where co-channel interfering transmitters are separated by one “ring” of non-interfering transmitters) simulations indicated an EIRP penalty due to interferences of 7 dB (for ISD=60 km and SINR=19 dB). T2-R5, a configuration not allowed in regular hexagonal networks, should have a MFN performance between T2-R7 and T2-R4.

COVERAGE OF T2 WITH REUSE-1

The first investigation analysed, assuming an isotropic transmitted EIRP, the percentage of the area covered with “good” quality, as a function of the achievable SINR, for different ISD values and 1 kW transmitted EIRP. The high interference level from adjacent transmitters allowed “good” quality only over 70 - 75% of the area (target SINR = 2 dB), independently of the ISD ([5]). To be noted that isotropic transmitter antennas produce a large interference effect from distant transmitters, and the coverage performance gets worse for shorter ISD, with reversed behaviour compared to a noise-limited network (see Figure 4).

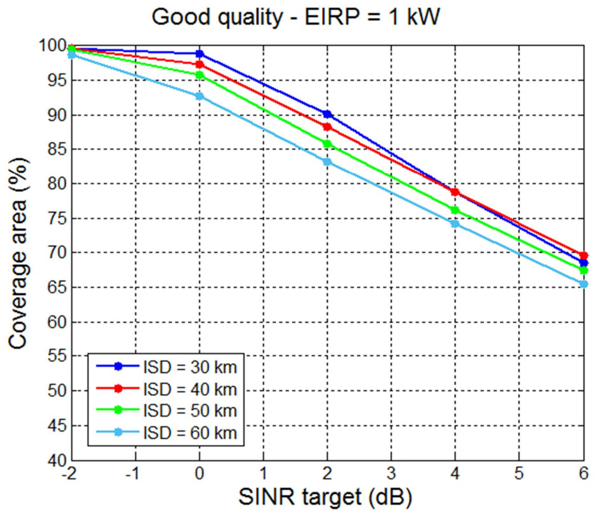

Figure 5 – T2-R1 coverage results in suburban area - Tilted TX antenna in the vertical plane

The benefits introduced by using the vertically directive (see Figure 3) and tilted transmitter antenna are shown in Figure 5. The “good” quality coverage (target SINR = 2 dB) significantly improved with respect to the isotropic EIRP, but even with a high transmitted EIRP (thus no power gain of T2-R1 in comparison with conventional T2-R5 planning) 95% of coverage area was not reachable.

COVERAGE OF T2 WITH REUSE-1 AND SFN

Under the restriction of keeping the DVB-T2 specification and receivers unchanged, the only perspective of improving the surrounding transmitters’ interference is to operate in SFN (synchronized transmitters broadcasting the same signal/content) at national or regional level, while neighbouring nations or regions are not synchronised and interfere: in such condition, the number of interfering signals drastically reduces, even in the “border” service areas.

---

[5] In the simulations, the receiving antennas have been pointed to the nearest transmitter, assuming that neighboring transmitters can broadcast a different content.

Figure 6 shows ([6]) the percentage of area covered with "good" quality in the central violet cell of the drawing, placed on the Country border, assuming a T2 guard interval of 224 µs. The figure shows the significant coverage improvement, with respect to the previously examined case, allowing the approach to "good" quality for 95% of the area. Using a high transmitted power (i.e. 1 kW) all over the Country or Region just to better serve a "critical stripe" at the Country border is of course not the best strategy (T2-R1 would not give any power gain over T2-R5 for the same transmitted capacity). Let's assume instead a more pragmatic approach, where the full EIRP gain offered by reuse-1 is adopted (i.e. 17 dB, corresponding to 100 W versus 5 kW for ISD = 60 km, see section "The simulation Framework").

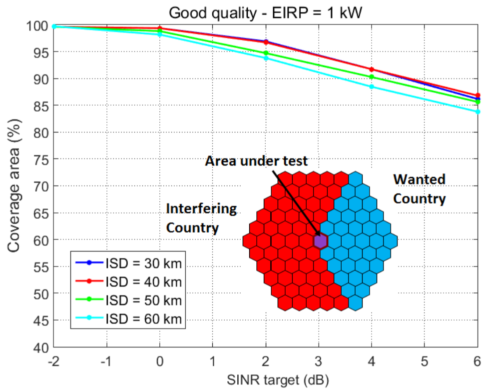

Figure 6 – T2-R1 coverage results in suburban area. Border of the SFN. Tilted TX antenna

Simulation results shown in Figure 7 (internal transmitter) and in Figure 8 (border transmitter), demonstrate 100% "good" coverage in the first case, and "acceptable" coverage in the second case.

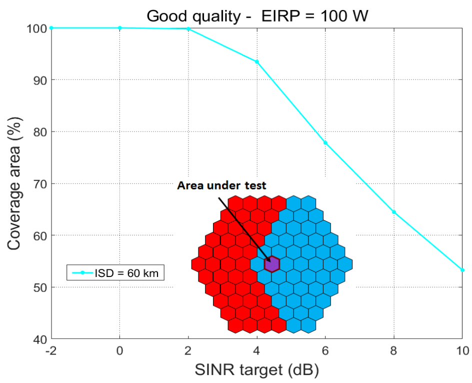

Figure 7 – T2-R1 coverage results in suburban area. In-country SFN. Tilted TX antenna

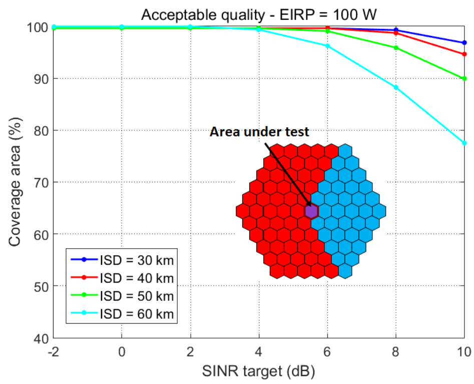

Figure 8 – T2-R1 coverage results in suburban area. Border of the SFN. Tilted TX antenna

Let's investigate, for EIRP = 100 W, the extension of the "critical stripe" at the Country border. For ISD = 60 km and EIRP = 100 W, Figure 9 represents, in different colours, the available SINR for "good" quality, where the grey part is below the 2 dB target: thus the extension of the "critical stripe" can be estimated at around 4 km. In such small (compared to the full country extension) areas, receiving antennas with improved front/back discrimination may be adopted. For example with a front/back ratio FTB=26 dB (commonly available in commercial UHF antennas) simulations showed "good" coverage in 95% of the border areas.

---

[6] In the simulations, for simplicity, all signals having a delay within the guard interval are considered as useful, while those exceeding the guard interval as interference (this is a pessimistic assumption, since these latter contributions are partly useful, partly interference according to [5]). Furthermore, the receiving antenna is pointed to the nearest transmitter, while the SFN network gain could be further optimized by pointing to the "best" transmitter.

A further analysis has been carried out to maximise the spectrum efficiency, adopting QPSK rate 2/3 (requiring a SNIR=2,9 dB on AWGN, rounded to 4 dB in the following to take into account the implementation margin) instead of QPSK rate 1/2, spectrum efficiency 1,33 bit/s/Hz. The simulations, for ISD=60 km and EIRP=150 W (i.e. about 2 dB increase over 100 W previously adopted), gave "*good*" quality coverage over more than 99% of the area for the internal SFN transmitter as in Figure 7, and "*acceptable*" quality coverage for the border transmitter as in Figure 8. As for QPSK rate 1/2, the use of an improved receiving antenna (FTB=26 dB) solves the problems on the border areas.

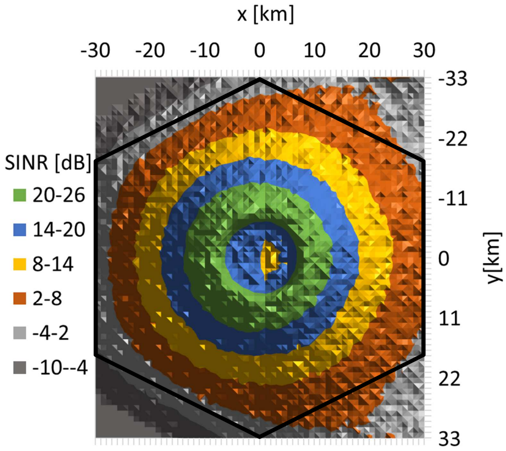

Figure 9 – Evaluation of the width of the "critical stripe" at the country/ region border (grey area inside the hexagon)

CONCLUSIONS

This study has analysed the applicability of frequency reuse-1 planning to DVB-T2 (without modification to the current specification, collective master antenna systems and receivers) to provide television broadcasting to TV receivers connected to roof-top directive antennas. The main results of the study is that reuse-1 planning can be applied to DVB-T2 (using QPSK rate 1/2 or 2/3), achieving an overall spectrum efficiency of 1 to 1,3 bit/s/Hz, matching and even improving what is today obtained with conventional planning (e.g., DVB-T2 256-QAM rate 2/3 and reuse-5 [7]). In such conditions, an overall power gain of 10 to 8 dB was achieved for the same transmitted bit-rate, fully matching the interference-free theoretical WiB gain ([8]). This huge power reduction (i.e., 90%) would positively reflect in new broadcast network implementation and maintenance costs, in the electrical power consumption and in the electromagnetic pollution. From the simulation results it can be deduced that DVB-T2 and reuse-1 (T2-R1) could even be introduced at different times in neighbouring countries (i.e. by keeping conventional reuse-5 plans in some countries and new reuse-1 plans in others). The 17-15 dB per-multiplex power reduction allowed by reuse-1 implies high interference levels from reuse-N neighbour countries (1 multiplex over N, since the other N-1 multiplexes would be interference-free on the border), but this could be mitigated by assigning vertical polarization to reuse-1 countries, and leaving horizontal polarization to reuse-N countries ([9]). Even the addition, in a conventionally-planned country, of T2-R1 multiplexes in channels reserved to neighbouring countries seems feasible. Therefore a flexible introduction of reuse-1 planning, although requiring some further analysis at an international planning and coordination level, and implying a massive intervention on reuse-1 antenna orientation, seems feasible.

---

[7] See also Table 1, showing the results of Rep. ITU BT.2386-0 for real MFN, large SFN and medium SFN

[8] This result required careful network design to control neighboring transmitter interferences, as described in this article: shaped and tilted transmitter antenna diagrams in the vertical plane, SFN transmitter synchronization, replacement of few old receiving antennas in a 4 km critical stripe at the country border.

[9] The cross-polar discrimination of UHF antennas being of about 16 dB, thus matching the 17-15 dB power unbalance

However, such very promising results come with significant drawbacks, some of which are listed in the following. To move to T2-R1, international frequency plans are to be modified, and this may require decades, or bi-lateral national co-ordinations have to be carried-out. Although the total capacity of T2-R1 is larger, five "small" 10 Mbit/s multiplexes are less flexible in terms of transported services than a single "large" 37,5 Mbit/s multiplex. In addition, small multiplexes can lose about 10% - 15% statistical multiplexing gain for video services compared to large multiplexers. Using HEVC video coding, the introduction of 4k-UHD/HDR (Ultra High Definition, High Dynamic Range) services would be limited by the 10 Mbit/s capacity, although high quality UHD services would not be precluded ([10]). For already existing conventional DTT networks, the savings on electrical power consumption and network maintenance may not be sufficient to pay-back in few years the required investments to migrate to T2-R1. For countries characterised by a favourable geography (i.e. like Italy, protected by neighbouring countries interferences by sea and mountains), the adopted reuse factor may be lower than 5, thus T2-R1 may be considered only as an addition to traditionally planned services (exploiting channels allocated to foreign countries), not as a replacement.

In a longer term perspective, a next generation DTT system based on WiB, under evaluation in DVB Technical and Commercial Modules, could allow (in addition to reuse-1 planning) channel aggregation, sophisticated interference cancellation, LDM and other technical improvements. Since the 10-8 dB power gain is already achievable by T2-R1 as demonstrated in this article, significant additional advantages have to be proven. The deployment of a next generation system would be even more complex than the case considered in this paper, because of the needs of new specifications, new receivers ([11]) and new wideband collective antenna systems.

All those use-cases must be carefully evaluated against the strategic and economical drivers, under the pressure of on-demand video services distributed over optical-fibres and of TV services distributed by satellites.

REFERENCES

[1] International Telecommunication Union-Radiocommunication Sector [ITU-R]. Final Acts of the Regional Radiocommunication Conference 2006 (RRC-06). Geneva, 2006

[2] Report ITU-R BT.2386-0, Digital terrestrial broadcasting: Design and implementation of single frequency networks (SFN) (07/2015)

[3] E.Stare, J.J. Giménez, P. Klenner, WiB – A new System Concept for Digital Terrestrial Television (DTT), Best IBC Conference Paper 2016

[4] Recommendation ITU-R P.1546-5; Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz, Geneva, 2013

[5] Rep. ITU-R BT.2254-2, Frequency and network planning aspects of T2, Geneva, 2014

[6] Recommendation ITU-R BT.419-3, Directivity and polarization discrimination of antennas in the reception of television broadcasting, Geneva, 1992

[10] Which viewer could distinguish a 1440-lines from a 2160-lines UHD service on a 50"-60" screen?

[11] As well established in DVB history, to maximise the benefits and concentrate in time the migration processes, a new physical layer standard should be launched together with a new generation of video coding (i.e., the successor of HEVC)