Planning of Mobile TV service in standalone and cooperative DVB-NGH and LTE networks

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***Abstract*—We study in this paper the planning of DVB-NGH and LTE, both separately and in cooperation, for the offering of mobile TV service. For the case of standalone DVB-NGH, we show the trade-off between coverage and capacity. In the case of standalone LTE, we evaluate the need for expensive infrastructure deployment. In the DVB-NGH/LTE cooperative case, we investigate two scenarios: coverage extension and service extension and show how both DVB-NGH and LTE benefit from the two cooperation schemes: DVB-NGH can extend its coverage and offered services and LTE is able to decrease its infrastructure and hence cost.**

I. Introduction

Although a large number of standards have been developed and even deployed for handheld television, such as Digital Video Broadcasting-Handheld (DVB-H), Terrestrial Digital Multimedia Broadcasting (T-DMB), Multimedia Broadcast Multicast Services (MBMS) [1], the targeted Mobile TV service is not yet a success.

One of the drawbacks of DVB-H is the complicated multiplexing between fixed and mobile services [2]. If an operator chooses to offer DVB-H services in a DVB-Terrestrial (DVB-T)/DVB-H shared network, it would not be able to have the same covered area for both services. In fact, DVB-T/H services are transmitted in the same time slot and have thus the same transmission modes and powers as well. And so, DVB-T signals targeting rooftop receivers will have a large coverage area while DVB-H, targeting mobile terminals with poor receiving antenna gain, will only be able to cover a very small part of this area [3].

Some operators try to overcome this problem with a hierarchical transmission. DVB-T and DVB-H services are transmitted in two independent transport streams in the same radio frequency channel, where one stream known as High priority (HP) is embedded within a Low priority (LP) stream [2]. The HP streams requires less Carrier to Noise ratio (C/N) and can be used to increase DVB-H coverage, but these latter services pay however an increased penalty in their C/N in comparison to the non hierarchical modulation case (please refer to [4] and [5]).

Another configuration option is a DVB-H dedicated network, which is the most flexible way to deliver DVB-H services. But its main disadvantage is that a huge number of DVB-H sites are needed so as to have a good coverage of the service area, including indoor reception [3].

DVB regulators learnt the lessons from DVB-H failures and are now considering Digital Video Broadcasting - Next Generation Handheld (DVB-NGH) [6] [7] as a succor to DVB-H, building on DVB-T2 [8][9], the second generation of digital terrestrial video broadcasting, that targets fixed and portable High Definition (HD) services. DVB-NGH is intended to be broadcast in the same Radio Frequency (RF) channel as the T2-Base signal, but in a flexible time division multiplexing, thanks to the Future Extension Frame (FEF) special frame introduced primarily in the DVB-T2 standard and can carry signals well adopted to the mobile reception with different configuration than the T2 Base frame. DVB-NGH holds the promise of new era of so-called in-band mobile broadcasting.

DVB-NGH is a two phase technology [10]. In the first phase, DVB-NGH is defined as an enhancement of the DVB T2-Lite (the mobile profile in DVB-T2). It inherits many features, such as different input formats, better capacities and performance as compared to DVB-H, as no encapsulation is needed with increased header. Another inherited feature is the Physical Layer Pipe (PLP) that enables a flexible service/regional specific modulations [8], in addition to advanced technologies such as Multiple Input Multiple Output (MIMO), Scalable Video Coding (SVC) and an optional satellite component. These latter features are still under standardization. In the second phase, DVB-NGH is intended to cooperate with the 3GPP standard: Long Term Evolution (LTE).

We study in this work the planning of standalone DVB-NGH and LTE as well as the benefits that can be obtained in the case of cooperation between them for the offering of Mobile TV service. For the case of standalone DVB, we derive link budget curves for diverse receiver devices and reception environments. For the case of LTE, we determine the cost of the extra needed infrastructure to offer such service. As of the cooperative case, we investigate two scenarios and assess the benefits in each case.

The remainder of this paper is organized as follows. In Section II, we investigate the coverage planning of a standalone DVB-NGH network for multi-receiver environments where users have different reception conditions, degradation and robustness requirements, and multi-user devices as well when users with different capacity requirements co-exist in the same network. In Section III, we assess the number of LTE cells needed to serve Mobile TV in a certain area. Section

VI shows the potential DVB-NGH and LTE mutual benefits if they consider cooperation. Eventually, Section V concludes the paper and gives some hints on future work.

II. PLANNING DVB-NGH NETWORKS

For a fast Mobile TV service enrolment, the DVB operator can consider first a DVB-T2/NGH shared network where the DVB-NGH services (carried by the FEF) are broadcast in the same signal as the rooftop fixed services (carried by the T2 Base Frames) [1].(Fig. 1).

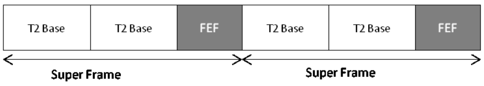

Fig. 1. DVB-NGH/T2 Superframe

So, the DVB-NGH system, offering Mobile TV, uses the existing transmitters and infrastructures originally deployed for fixed TV reception. Given those latter transmitters power and parameters, we start with a link-budget study to plan the DVB-NGH network, taking into account parameters given in [11] for fixed, portable and mobile terminals, as well as indoor, outdoor and vehicular environments, and calculate the maximal permitted path-loss. In other words, we obtain, for the given transmitted power, the maximal permitted power degradation so as to achieve a received power that is not lower than the receiver sensitivity after substituting all other degradation and implementation margins, as shown in Table I.

	Portable Outdoor	Portable Indoor	Mobile	Fixed
Receiver Noise [dBm] (b)	-99.11	-99.11	-99.11	-99.11
required C/N [dB] (c)	$(C/N)_1$	$(C/N)_2$	$(C/N)_3$	$(C/N)_4$
Receiver sensitivity [dBm] (d)	$(b) + (C/N)_i$			
Antenna Gain [dBi] (e)	-7.35	-7.35	0	12.15
Cable Loss [dB] (f)	0	0	0	4
Total Receiver Gain [dBm] (g)	(d)+(e)+(f)			
Location Probability % (h)	95	95	99	95
building/vehicle loss [dB] (i)	0	11	8	0
standard deviation (s.d.)[dB](j)	5.5	5.5	5.5	5.5
s.d. building loss [dB] (k)	0	6	2	0
Total s.d [dB] (l)	$\sqrt{(j)^2 + (k)^2}$			
distribution factor (m)	1.64	1.64	2.33	1.64
Correction factor [dB] (n)	$(l) * (m)$			
Body Losses [dB] (o)	3	3	3	0
Total Margins [dB] (p)	$(i) + (n) + (o)$			
PathLoss [dB]	$ERP - (g) - (p)$			

TABLE I
COVERAGE PLANNING PARAMETERS

The path-loss is the signal degradation due to the transmission trajectory, and thus, by limiting the traversed distance we limit the path-loss. This limited distance defines the coverage of the network. Many propagation models permit to obtain this distance for a given value of the path-loss. We shall use in this paper the Okumura-Hata model and its ITU-R P.529-3 modification, for covered distance > 20 Km [12].

[1]In a DVB-T2/NGH shared network, a Super Frame (SF) can carry the standardized DVB-T2 signal, targeting fixed receivers with high Fast Fourier Transform (FFT) size (i.e., $32K$) in the T2-Base frame, and a totally different signal in the FEF part, targeting mobile services and with lower FFT size ($8K$), guard intervals and suited parameters.

On the other hand, a single frame (T2-Base or FEF), can carry multiple services with different modulations and code rates, thanks to the transparent physical layer, known as Physical Layer Pipe (PLP) [13] [9]. The latter enables service specific robustness and meets thus DVB-NGH requirements [6]. It makes it possible to serve a multi-receiver network composed of large terminals such as tablets and sophisticated smartphones, requiring High Definition (HD) services, coexisting with classical phones. Multi-reception environment is also allowed, where some services, such as mobile, indoor and vehicular, require more robustness than others, typically fixed, outdoor or portable ones.

A. Impact of transmission power on network planning

As stated earlier, thanks to the TDM and the PLP feature with its service specific modulation, it is possible to serve in the same radio frequency signal, users with different reception conditions, for instance rooftop fixed reception in the T2-Base frame and DVB-NGH outdoor, indoor or/and vehicular mobile reception in FEF.

DVB-NGH is still in standardization, especially its MIMO feature, and so we lack many experimental parameters, such as C/N. We hence consider in this paper the parameters of DVB-T2 Lite in Single Input Single Output (SISO) mode in Rayleigh channel for portable indoor/outdoor reception and ITU-6 for the vehicular reception for a bit error rate (BER) of 10^{-4}. The improvement in DVB-NGH signal will certainly improve the C/N ratio and hence the covered area, but the investigation and discussion contained in this paper will still remain the same.

We thus consider a superframe composed of two DVB-T2 frame ($T_{frame} = 250$ ms, $FFT\ size : 32K$, long $64K$ Forward Error Correction (FEC) frame, $256 - QAM2/3$), whose C/N in a Rice channel is equal to 17.8dB [15], and two FEF ($T_{FEF} = 250$ ms, $FFT\ size\ 8K$, short $16K$ FEC frame). For Rayleigh portable services, we present two modulation schemes: $64 - QAM\ 2/3$ and $QPSK\ 3/5$ whose C/N ratios are equal to 15.7 dB and 3.5 dB [15], respectively. And finally, we consider a $16 - QAM\ 3/5$ with a C/N ratio of $12.7dB$ [16] for mobile/vehicular services in ITU-6 channel.

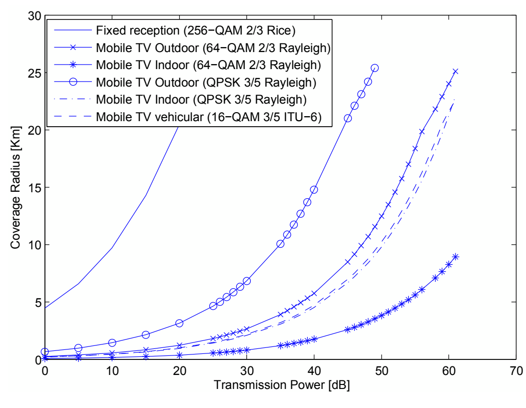

Fig. 2. Coverage Area Vs Transmitter Power

Figure 2 shows the coverage area as a function of transmission power for the previously mentioned services. We can observe that, there is a difference in the rooftop and mobile services coverage area due to many transmission penalties between fixed and mobile services. A transmitter power of 15dBW can cover a fixed reception service area of radius $R_{fixed} = 14.3$ Km, whereas an outdoor mobile receiver served by FEF signal and modulated by QPSK 3/5 needs 40 dBW, and the transmitted power has to be increased to 51.5 dBW if 64-QAM 2/3 is used.

Thanks to Time Division Multiplexing (TDM) of fixed and mobile services, however, the FEF may have a different transmission power than the T2-Base frame, and can cover, by increasing its power, the same area as the T2-Base signal, without affecting the fixed reception. This was not the case in DVB-T/H network, where DVB-T signals targeting fixed receivers impose their FFT size and their transmission power on DVB-H services.

Outdoor, indoor and vehicular coverage cannot be solved as easily, as the multiple PLPs carried by a single frame are Frequency Division Multiplexed (FDM) and share in a complex way the Orthogonal Frequency Division Multiplexing (OFDM) cells allocated for the considered frame with the same transmission power [9]. A possible solution is to have environment specific modulation. Portable indoor services can be modulated with a more robust, lower modulation order than outdoor services. As shown in Figure 2, these two environment specific services (modulated with 64-QAM 2/3 for outdoor services and QPSK 3/5 for indoor ones), will have very similar coverage area until a given transmission power (20 dBW). For higher transmission powers, the outdoor radius begins to slightly exceed the indoor one. Vehicular services modulated with 16-QAM 3/5 will have the same coverage as QPSK 3/5 portable indoor services.

B. Network planning for different mobile user receivers

In the previous section, modulation and coding rate (MODCOD) of PLPs are determined in a way so as to enable a total coverage of radius R in a multiple environment scenario and for a given transmission power. In this section, we check whether the previous planning satisfies the capacity requirements of the offered services and adapt the PLPs modulation and coding rate if this is not the case (the covered area may thus shrink).

Let us consider a network layered into L environment conditions. The latter can be indoor, outdoor, vehicular or any combination of these in more complex networks where the users can be in multi-receiver conditions. As explained in Section (II-A), each layer has its adaptive modulation to cover the total area for a given transmitter power. Moreover, users of each layer may have different devices and therefore different capacity requirements. For example, tablets and smartphones requiring HD services may coexist with other mobile terminals requiring only Single Definition services (SD); HD services will require PLP with higher capacity than SD ones. We define by C_{Req} the set of these required capacities.

Taking both coverage and capacity conditions into account, each TV channel is carried by an independent PLP characterized by its target reception environment $i \in \{L\}$ (and therefore by its MODCOD) and its target receiver capacity requirements $j \in \{C_{req}\}$.The network state is then defined by the set of number n_{ij} of broadcast PLPs of type $\{ij\}$ with $i \in \{L\}$ and $j \in \{C_{req}\}$.

These PLPs are organized into Forward Error Correction (FEC) blocks of $16K$ bits and have to share the maximal number of useful active OFDM cells given by:

$$C_{max}(T_{FEF}, n_{PLP}) = \frac{N_{FEF} \cdot C_u(T_{FEF}, n_{PLP})}{T_{SF}} \; [cells/s] \qquad (1)$$

Where T_{SF} is the duration of the superframe, N_{FEF} is the number of FEF in this superframe (fig. 1), $C_u(T_{FEF}, n_{PLP})$ is the useful OFDM cells in a FEF that depends on T_{FEF} the FEF duration, n_{PLP} the number of served PLP in the system and the signal FFT size [9][7].

The useful data bits in a FEC block is given by $(Kbch - BB_{Header})$ (see fig 3). Where K_{bch} is the number of bits processed by the FEC coding subsystem, to generate a FEC block. It depends on the PLP Code rate. Finally BB_{Header} is a 3, 5, 6 or 8-byte header [7].

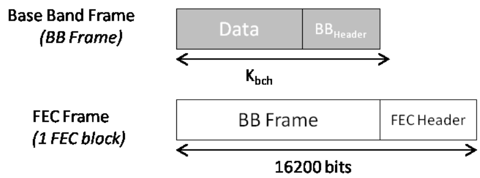

Fig. 3. DVB-NGH Baseband and FEC frames

So, the number of FEC blocks per second needed by a PLP of type$\{ij\}$ ($i \in \{L\}$ and $j \in \{C_{req}\}$) is:

$$N_{FEC}^{ij} = \frac{C_{req}(j) \cdot T_{SF} + I_B}{T_{SF} \cdot (Kbch_i - BB_{Header})} \; [block/s] \qquad (2)$$

where $C_{req}(j) \in C_{req}$ is the TV channel required bitrate, T_{SF} is the superframe duration, $C_{req}(j) \cdot T_{SF} + I_B$ are the required bits to be carried formed by $C_{req}(j) \cdot T_{SF}$ bits representing the total data bits of a TV stream in a superframe and I_B bits for in-band signalling and $Kbch_i - BB_{Header}$ are the total useful bits carried by a FEC block.

However, the number of OFDM cells N_{cell} in a FEC block, depends on the PLP modulation. So, finally the admission control of served TV channels is:

$$\sum_{i=1}^{L} \sum_{j=1}^{|C_{Req}|} n_{ij} \cdot N_{FEC}^{ij} \cdot N_{cell}^{i} \leq C_{max}(T_{FEF}, \sum_{i=1}^{L} \sum_{j=1}^{|C_{Req}|} n_{ij}) \qquad (3)$$

Where L is the maximal number of network environment conditions, $|C_{Req}|$ is the maximal number of different capacity requirements in the network and n_{ij} the number of TV channels targeting users {ij}.

When a Mobile TV operator aims to serve X TV channels in a defined area of radius R, it is intended that all users can access these X TV channels. And so, X PLPs of each type, defined by the couple (reception environment condition, capacity requirements), have to be broadcast. This is however not always possible since the number of served PLPs is limited by the admission condition. In this case, the operator should prioritize some services over the others and choose between the following two scenarios, shown in Figure 4. the operator can choose to cover the whole area and reach the maximum number of users and does not broadcast services that are less integrated among users (Figure 4-a). The other option is to broadcast all the target services, although they cannot cover all the area (Figure 4-b). The latter scenario is preferred when a higher percentage of users is near the broadcast transmitter and increasing the coverage will not increase so much the operator interest.

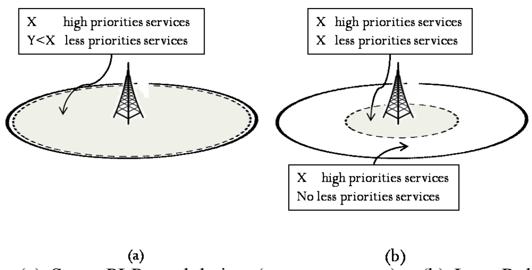

Fig. 4. (a) Same PLP modulation (same coverage) ; (b) Less Robust PLP for less priority services (same capacity)

To illustrate the above statement, we consider the simplest case of one layer network, supporting for instance only indoor portable reception, with coverage area radius 7 Km, where coexist two types of terminals requiring HD (512Kbps) and SD (250Kbps) services. We aim to serve 8 TV channels. SD services are chosen to have higher priority and need thus to be always diffused in the whole area. For a transmission power P_T of 45 dBW, PLPs modulated by QPSK 3/5 in Rayleigh channel will be able to cover the area (Figure 2).

Figure 5 shows that by serving 8 SD TV channels, only 2 HD TV channels can be served if we keep the same modulation as that needed to cover all the area (QPSK 3/5).

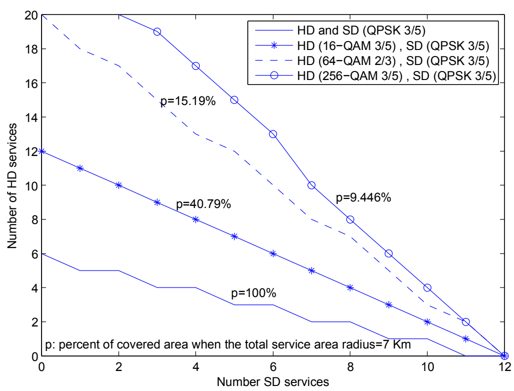

Fig. 5. Number of served low priority HD TV channels in accordance to the number high priority SD channels for indoor reception with $P_T = 45$ dBW

If we increase the modulation order of PLPs carrying HD services to 256-QAM 3/5 (C/N: 16.9 dB), we will be able to serve 8 TV channels, but only 9.4% of the area will be served by HD services.

III. Planning LTE networks for TV services

Mobile operators started to provide video services for their customers by point to point bearer. This streaming solution was not so efficient and rapidly congested the network. Mobile TV has then been provided by the Enhanced-MBMS (e-MBMS) bearers. The content is transmitted over a single channel from the source to multiple users.

E-MBMS can operate in a multiple or single frequency networks (MFN or SFN). In the MFN case, each cell broadcasts independently its services using its own radio frequency. In SFN, several cells coordinate to carry the same information at the same time over the same frequency. This improves capacity and coverage especially at cells edge, since the interfering signals from neighbour cells are now constructive and contribute with their transmission power weighted by the function defined below [17][18]:

$$w(\tau) = \begin{cases} 1 & 0 \leq \tau < T_{Cp} \\ 1 - \dfrac{\tau - T_{CP}}{T_u} & T_{CP} \leq \tau < T_{Cp} + T_u \\ 0 & otherwise \end{cases} \quad (4)$$

Where T_u is frame useful signal length, T_{CP} is the cyclic prefix length and τ is the propagation delay of the received signal.

An analytical method to calculate the Signal to Noise Ratio (SNR) in each point in the Multicast-Broadcast over Single Frequency Network (MBSFN) network has been derived in [17][18]. The authors considered every possible Modulation and Code rate Scheme (MCS) in the LTE standard and used link level performance curves to obtain the Spectral Efficiency (SE, in bps/Hz) of the MCS at each network location. We make use of the methodology of [17][18] in order to obtain, for each MCS, the SE reached by 95% of the users in the whole network for different Inter-Site Distance (ISD), and use these values, presented in Figure 6, as inputs to our analysis.

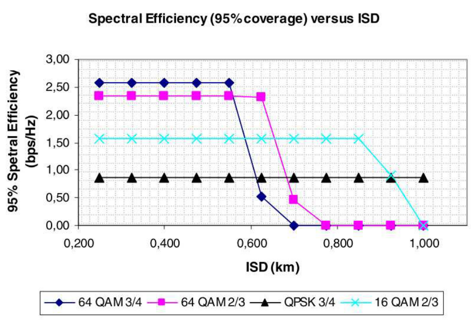

Fig. 6. The spectral Efficiency reached by 95 % of users for different MCS and ISD

We consider that the LTE operator aims to serve X Mobile TV channels. In MBMS, the same signal is transmitted to all the users (broadcast), and so, adaptive modulation cannot be used. Instead, a unique modulation and coding rate serve all the users regardless of their reception conditions. The best suited MCS is the lowest order MCS whose capacity C_{MCS} is at least equal to the total required capacity to serve all X TV channels: $C_{MCS} \geq \sum_i^X d_i$ where d_i is the required bitrate of TV channel i. This strategy satisfies the capacity requirements and decreases the number of LTE cells as well since it gives the maximum radius an LTE cell can reach and still hs the required capacity. The number of required LTE cells of radius $r_{cell} = \frac{ISD}{2 \cdot \cos(30)}$ and serving an area of radius R is given by $n_{cell} = (\frac{R}{r_{cell}})^2$.

For numerical illustration, we consider for the sake of simplicity, an LTE network allocating a dedicated bandwidth of 5 MHz to offer Mobile TV. The required number of LTE cells, when it aims to serve 8 TV channels in a service area of radius $R = 7\ Km$, is given in Table II for three cases: SD services (250Kbps) only, HD services (512 Kbps) only and when multi-user devices co-exist and LTE has to serve both HD and SD services. The number of cells increases with the total capacity of offered services.

	Required Capacity [Kbps]	Best MCS	Cell radius [Km]	Number of cells
Only SD	2000	QPSK 3/4	0.58	146
Only HD	4096	QPSK 3/4	0.58	146
SD and HD	6096	16-QAM 2/3	0.5	196

TABLE II
REQUIRED NUMBER OF LTE CELLS TO SERVE 8 TV CHANNEL IN A MBSFN NETWORK OF RADIUS 7 KM

IV. PLANNING COOPERATIVE DVB-NGH/LTE NETWORK

The second phase of DVB-NGH standard envisages co-operation with LTE in different scenarios. In case of Live Mobile TV service, DVB-NGH operator can benefit from the cooperation with LTE to overcome the trade-off between coverage and capacity, as discussed in Section II. Cooperation is possible in two ways:

1) *Service extension:* DVB-NGH chooses to cover the whole area and cooperates with LTE to increase the number of served channels (Figure 4-a).
2) *Coverage extension:* DVB-NGH cooperates with LTE to serve users in the area not covered by DVB-NGH (for instance indoor HD services - Figure 4-b). In this case, the LTE service area is $A_{LTE}^{scenario2} = ((1-p) * S)$, where S is the total service area and p is the percentage of area where DVB-NGH can serve all the target services.

On the other hand, LTE benefits from this cooperation to offload a part of its services on the DVB-NGH bearer, and saves thus some capacity to serve other unicast services, or if no other services are needed, it decreases the number of required sites in the coverage area.

The cooperation scenario, service or coverage extension, is chosen so as to bring targeted benefits for both DVB-NGH and LTE networks. To illustrate the benefits of this cooperation, we choose the minimal number of LTE cells as the decision parameter of the best cooperation scenario.

We consider that both LTE and DVB-NGH aim to offer 8 indoor TV channels in a multi-user device network (i.e., users requiring SD and HD services co-exist). If we choose the service extension scenario (scenario 1), and referring to Figures 5, DVB-NGH is able to cover the whole network and serve all 8 SD TV channels and only 2 HD channel. In this case, LTE relies on DVB-NGH to offer all the 8 SD services and 2 HD channel and has to broadcast only 6 HD TV channels instead of 8 SD TV channels and 8 HD channels as well. In accordance with Figure 6, the best MCS in this case is QPSK 3/4, and we need $n_{cell}^{scenari\ 1} = 146$ LTE cells instead of 196 cells.

If coverage extension (scenario 2) is chosen, DVB-NGH is able to serve all the 8 SD services in the total service area, and 8 HD TV channels in only 9.4 % of the service area, as obtained from Figure 5. And so, LTE has to serve 8 HD TV channels in 90.6% of the service area. The required number of LTE cells in this case is thus $n_{cell}^{scenario\ 2} = 0.906 * 146 = 132$.

For these particular input parameters and decision parameter for the cooperation, $n_{cell}^{scenario\ 2} < n_{cell}^{scenario\ 1}$, the coverage extension scenario is the best for DVB-NGH/LTE cooperation.

V. CONCLUSION

We investigated in this paper planning of DVB-NGH and LTE, separately and in cooperation, for the offering of Mobile TV service. We first started with the planning of standalone DVB-NGH and showed the trade-off between coverage and capacity in such a network. We also discussed the planning of standalone LTE and assessed the need for expensive infrastructure in this case. Finally, we examined DVB-NGH/LTE cooperative scenarios network and showed that cooperation is beneficial to both as it allows DVB-NGH to extend its coverage and offered services and it enables LTE to decrease its infrastructure and hence cost. The general planning model we developed in work can be used in accordance with different operators needs and targets. Our further works will explore the economical issues of DVB-NGH/LTE cooperation and the QoS of Mobile TV achieved in such a hybrid network.

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