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CAPEX and OPEX Optimisation in Function of DVB-H Transmitter Power

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Abstract

DVB-H network planning and optimisation are essential tasks for the network operators in order to provide adequate service quality. As DVB-H can be deployed by using Single Frequency Network (SFN), the assumption for building maximum coverage within the SFN area is to use as powerful transmitters and as high antenna locations as possible. Nevertheless, in addition to the technical tuning, the complete network optimisation should take into account also the initial and operating costs of the system. This paper describes DVB-H optimisation methodology which is based on the analysis of the total cost of the network in function of the transmitter power levels.

1. Introduction

DVB-H capacity and coverage can be achieved by many different combinations of the parameter values, including the variation of the transmitter power levels and antenna heights. Taking into account the limitations of SFN interferences, the maximum coverage can be achieved technically by locating the transmitter antennas as high as possible and by using maximum transmitter power levels. Nevertheless, in detailed optimisation, also the cost of different solutions, i.e. parameter settings and site specific installations should be taken into account.

As an example, more output power the transmitter provides, higher the equipment complexity and power consumption are, affecting on the operating expenses (OPEX) of the network. In optimal deployment of the network, it is thus essential to identify the most relevant technical parameters and investigate their impacts on the initial, i.e. capital expenses (CAPEX), and operating expenses. Even in case of relatively small DVB-H network deployment, the proper election of the transmitter types (power levels) might reduce considerably the final costs of the network.

2. Identifying the key parameters

The DVB-H planning is done for both core and radio sub-systems. In each case, the proper capacity is dimensioned taking into account the short-term operation and preferably the prediction for the mid-term evolution.

The capacity of the DVB-H network is calculated by taking into account the modulation scheme (QPSK, 16-QAM or 64-QAM) and error correction scheme (Code Rate of 1/2, 2/3, 3/4, 5/6 or 7/8). As a difference with the DVB-T, there is an enhanced correction method, MPE-FEC (Multi Protocol Encapsulation, Forward Error Correction), defined in DVB-H, which provides additional protection against the effects of multi-path propagation and impulse noise in mobile environment. This parameter can be set with the values of 1/2, 2/3, 3/4 and 5/6. Furthermore, the final design of the network depends on the value for the guard interval, interleaver mode (2k, 4k, 8k), area location probability (typically between 70-95%), shadowing margin and possibly SFN gain. Depending on these settings, the balance between capacity and coverage can be found.
The most important initial network planning input is normally the required capacity in radio interface, which dictates the adequate transmitter power level. The main limitations depend on the general regulations for the RF radiation (including the EMC and human exposure limits) as well as on the practical issues since the cost of different types of transmitters is not linear in function of the power levels. Other significant factor is the antenna height, which does have an impact on the DVB-H coverage.

As the CAPEX and OPEX are considered, there are various other aspects that affects on the final cost of the network. Also the amount of leased or own items, like transmission lines, transmitter sites etc. do have their impact. The cost depends mainly on the transmitter equipment complexity, transmission lines, transmitter sites, towers or roof-tops, antenna feeders and antennas. The detailed cost list might include the material that is needed for the installation of the equipment. In addition, the in-depth cost optimisation should take into account the installation services and other immaterial items like the cost of the planning, preparation of the site drawings, site acquisition, license fees, maintenance costs etc.

3. Description of the methodology

In order to identify the initial optimal parameter values when minimising the CAPEX and OPEX of the DVB-H networks, a systematic methodology can be applied. The process contains the following high-level revision as a basis for the investment decision:

- Identify the main items that affect on CAPEX and OPEX.
- Estimate the cost for each item.
- Calculate the total CAPEX and (yearly) OPEX for single transmitter site.
- Calculate the single cell radius for each case, averaging the investigated area as a uniform type, or selecting a set of separate uniform area types (that are calculated individually), using adequate RF propagation model.
- Select sufficiently large service area and estimate by using e.g. hexagonal model, how many sites there should be obtained in each case in order to cover the area with the uniform quality of service level.
- Calculate the total CAPEX and OPEX for each case for comparison purposes.

For the accurate estimation, it is important to select all the major items that has cost impact on the network, and as many minor details as is seen reasonable. In this approach, the transmitter power level is selected as the variable whilst the core network with source signals, capacity, bit rate per channel etc. can be assumed to be the same in each case.

4. CAPEX and OPEX estimation

For the realistic DVB-H CAPEX estimation, the following items can be taken into account:

- Transmitters.
- Antenna systems (with antenna feeders, power splitters, jumpers and connectors).
- Other material, like feeder brackets, tools etc.
- Transmitter site acquisition and preparation work.
- Transmitter, antenna system and other material installation and commissioning work.

For the OPEX, the longer term items include at least the following:

- Transmission (leased lines, satellite transmission etc.).
- Maintenance of the transmitters, other equipment and site.
- Tower and/or site rent.
- Electricity consumption.

The transmission has a key role in the OPEX per site. Depending on the needed capacity, the technical solution can be done by using e.g. sufficient amount of E1/T1 lines, or implementing fibre optics that provides sufficiently wide bit pipe. For the remote areas with relatively large proportion of sites difficult to access, a satellite transmission might provide with optimal solution. The basic cost of the satellite transmission is normally clearly higher than in terrestrial cable solution, but the single satellite link usually covers all the needed sites.

For the electricity consumption, a rough estimation of 6 times the output power level can be used in this analysis unless the practical values are available. For the other items, the costs depends on the equipment and service provider list prices, taking into account the possible volume and other discounts. Furthermore, the prices can be estimated separately for the main transmitter sites and gap-fillers.

In order to simplify the calculation, it is sufficient to take into account the number of main transmitter sites, and possibly estimating a lump cost for the gap-filler sites. The number and transmitting powers of gap-fillers depends on the wanted level of the outdoor and indoor coverage areas.

The CAPEX and OPEX include both common costs
as well as the costs that depend on the type of the transmitter site. The common CAPEX estimation includes the site acquisition and structural analysis whereas the transmitter, antenna system, power splitter, brackets and installation work depends on each site type.

The common OPEX items includes the transmission lease (assuming the same bit pipe is delivered to each site), and average tower or roof-top site rent. The other OPEX items depend on the site type, and include e.g. electricity consumption and maintenance work which both depends on the transmitter type.

For the CAPEX, the transmitter cost plays a key role. As the power level of the equipment gets higher, the relative price of the power (W) gets normally lower. This is logical as the equipment contains common parts, designing, racks etc. that generates equal type of costs regardless of the differences in the power amplifier block. On the other hand, the highest power level transmitters are more complicated with e.g. liquid cooling requirements which cause the rise of the cost as the power level is considered. The following Figure 2 summarises an example of the market prices of the DVB-H transmitters.

The CAPEX estimation for this case study can be seen in the following Figure 3. An estimation of the absolute prices was used in this analysis.

The following Figure 4 shows an example of the OPEX for the same cases as shown previously.

As can be observed form the Figure 4, the OPEX items are basically constant except for the electricity consumption. For the highest power level cases, this might turn out to be an important cost and has thus negative impact if the network is planned with only few high-power sites. For the transmission, the
terrestrial cable solution with sufficiently high bit pipe was used commonly in each case of this analysis.

5. Coverage estimation

In order to estimate the radius for single cell in each transmitter case, an Okumura-Hata propagation model can be used.

In this analysis, a sub-urban area type was used with QPSK modulation, antenna height of 100 m, terminal height of 1.5 m, service level of 90% (area location probability), shadowing margin of 5.5 dB, frequency of 700 MHz and receiver antenna gain of -7 dBi. The code rate of ½ and MPE-FEC of ¾ was selected. The parameter selection yields the minimum received power level of about -87 dBm for the functional service.

The cell radius was calculated for the transmitter output power levels of 100-9,000 W. Antenna gain of 13 dBi was used in each case, which is the result of directional antennas (or antenna arrays, depending on the power level) installed in 3 sectors without down-tilting.

The calculation takes into account the jumper, connector, power splitter and feeder losses. A feeder of 1 5/8’’ with the loss of 1.9 dB/100m was selected for the power levels of 100-3400 W, and a 3’’ cable with the loss of 1.5 dB/100m was used for the power levels of 4,700-9,000 W. An estimation of 10% for transmitter filter loss was used in each case. The assumption was to use the antenna in tower, which means that the same antenna feeder length (133 m) was used in each case.

The cell range that was obtained by taking into account the above mentioned values can be seen in Table I.

The next step of this methodology includes the selection of a physical service area. The cells are then placed in the planned area in order to estimate the total cost of the network for each power level case. The area is thus filled with cells as tightly as possible, using the hexagonal model.

The cell coverage area is represented with a circle that touches the edges of the hexagonal element. The circles overlap partially in the cell edges resulting relatively realistic presentation of the coverage areas. In practice, this provides the service continuity as well as SFN gain due to the multiple path of the radio signal. The overlapping area presented in this analysis can be calculated geometrically by comparing the surface of the circle with the hexagonal area.

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![Fig. 5. The overlapping area of the individual cell can be calculated by the difference between the surface of the circle and hexagonal element.](image)

When the radius of the cell (circle) is $r$, the surface of the hexagonal inside of the circle is:

$$Ah = 6\pi \frac{r^2}{2} = 3r^2 \cos(30)$$

In this analysis, the overlapping area is taken into account as a reduction factor $R_f$ when estimating the total cell number in given service area. It means that the overlapping area exists in the investigated area, but the reduction factor gives the possibility to calculate the single cell areas and the number of the cells by using the formula of the surface of the circles. The reduction factor can be obtained be the following formula:

$$R_f = \frac{Ah}{Ac} = \frac{3r^2 \cos(30)}{\pi} = \frac{3 \cos(30)}{\pi} \approx 82.7\%$$

With the reduction factor, it is thus possible to estimate, how many partially overlapping omni-cells ($N_{cells}$) with a form of the circle and the radius of $r$ fits into the planned service area. The formula is the following:

$$N_{cells} = \frac{A_{tot}}{A_{cell}} R_f = \frac{A_{tot}}{\pi r^2} R_f$$

### Table 1. The calculated cell range for each case.

<table>
<thead>
<tr>
<th>TX power</th>
<th>EIRP / W</th>
<th>Range $r$ / km</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>576</td>
<td>6.4</td>
</tr>
<tr>
<td>200</td>
<td>1152</td>
<td>8.0</td>
</tr>
<tr>
<td>500</td>
<td>2880</td>
<td>10.7</td>
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<tr>
<td>750</td>
<td>4321</td>
<td>12.1</td>
</tr>
<tr>
<td>1500</td>
<td>8641</td>
<td>15.1</td>
</tr>
<tr>
<td>2800</td>
<td>16130</td>
<td>18.4</td>
</tr>
<tr>
<td>3400</td>
<td>19857</td>
<td>19.5</td>
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<tr>
<td>4700</td>
<td>31019</td>
<td>20.7</td>
</tr>
<tr>
<td>9000</td>
<td>59398</td>
<td>22.6</td>
</tr>
</tbody>
</table>
6. Results

When observing the results calculated for the total service area (in this analysis an area of 100 km · 100 km was selected), the following CAPEX and OPEX relation can be obtained depending on the power level of the site.

As can be seen from Figure 7, there exists an optimal point for both CAPEX and OPEX (when observing the 4th year of operation costs) curves. In this specific case, the optimal power level is found in 3.4 kW category.

It is interesting to notice that the OPEX and CAPEX curves follows the general trend of the power unit price for different transmitter types, but nevertheless, the final relative CAPEX and combined CAPEX / OPEX grows faster for the highest power level cases that takes into account all the relevant cost items for each power level case.

For the OPEX, a more specific analysis can be done. The Figure 8 shows the development of the cumulative operating costs during 4 years form the initial deployment of the network. The yearly OPEX is constant for each transmitter case, producing lines with certain angular coefficient.

The following Figure 9 shows an amplified view of the OPEX development in order to observe the detailed behaviour of different power levels.

It can be seen that e.g. for the power level of 750 W, the initial cost is lower than in average with the small-power levels, but the operating cost of 750 W case is considerably higher than could perhaps be expected. In this very case, it can also be seen that the highest power level, i.e. 9 kW, is relatively expensive solution as the CAPEX is considered, and regardless of the considerably lower amount of the sites compared to the lower power level cases, the cumulative OPEX development (angular coefficient of the line) is only slightly lower than that of the mid-power transmitters, mainly because of the higher power consumption.

When observing the angular coefficients of each case and taking into account the development of the network for 4 years of time period, the optimal power level is thus found in the mid-level power range, i.e. the respective transmitters provides with the lowest CAPEX and OPEX of the DVB-H network in this specific case.

In generic situation, the coefficients can be calculated by the formula:

$$k = \frac{y - y_0}{x - x_0}$$

The term $y_0$ represents the CAPEX (the cost in initial year), and $x_0$ can be marked as 0 as it represents the beginning of the operation, i.e. the year 0. It is thus straightforward to calculate the total cost of the network after $x$ years:

$$y = kx + y_0$$

The coefficients of this specific analysis are shown in Table 2. It can be seen that the coefficient lowers when the transmitter power level is higher. The task would thus be to find the case that yields lowest total cost (CAPEX and cumulated OPEX) within $x$ years.
In this specific analysis, the 3,400 W transmitter would provide the lowest total cost for the time scale of 0-6 years of operation. The 4,700 W turns out to be more attractive if the network would operate during 7-45 years, and theoretically, the 9,000 W transmitter would yield the lowest costs if the network would operate in the very same setup at least 46 years.

### 7. Conclusions

The method presented in this paper shows the possibility to estimate the costs of the network, both the initial as well as the operating ones, by observing the angular coefficient of the CAPEX and OPEX as presented in Figures 8 and 9. It is obvious that in infinite scale, the solution with lowest angular coefficient does have the lowest final cost regardless of the initial investments. In practice, though, the DVB-H network does have a limited life time. This should be used as one of the parameters in the analysis of the final cost of the network in function of the power level of the transmitter.

It is interesting to note that the behaviour of the OPEX depends strongly on the power level. This means that cost-wise, it is not same to build the coverage area with a big amount of low-power transmitters as with lower amount of mid-power transmitters. It is also worth noting that the optimal CAPEX and OPEX of the network is not necessarily achieved by using the highest power levels.

In detailed optimisation of the DVB-H network, it is thus essential to obtain all the relevant CAPEX and OPEX related items and carry out the combined cost and technical analysis for different transmitter types, i.e. varying the power level, in the very same total coverage area for each case and observing the effect of the power levels on the cost of the network.

The models presented in this paper are theoretical, and the final sites cannot be obtained from the ideal locations shown by the hexagonal cell distribution. In practice, there is thus need for cell-based adjustments of the power levels, and probably a combination of different power levels in different area types is needed with variable antenna heights, different antenna elements and down-tilting in selected locations. In addition, there might be need to limit the power levels in order to avoid the interferences outside a single SFN area, i.e. the theoretical limitations of SFN could possibly be avoided by using low power levels.

Nevertheless, the method presented in this paper gives means to investigate the logical combinations as a basis for the initial network planning. It is thus probable that the use of the presented method yields savings in the DVB-H network deployment and operation.

### 8. References


