Handheld receivers coverage by DVB-T2

Muhammad Moiz Anis*, Xavier Lagrange†, Ramesh Pyndiah‡
* †RSM Department, Telecom Bretagne, Rennes, France
‡SC Department, Telecom Bretagne, Brest, France
Tel: (+33) 299127059
{*muhammad.anis, †xavier.lagrange, ‡ramesh.pyndiah}@telecom-bretagne.eu

***Abstract*—It is expected that the upcoming DVB-NGH (Digital Video Broadcasting-Next Generation Handheld) shall be based on the existing DVB-T2 technology. Also DVB-NGH enabled Handheld receivers are going to work with the existing DVB infrastructure. In this paper we model the link budget deficits of the Handheld DVB receivers as additional power losses for a typical fixed roof-top DVB-T2 receiver. Because of those additional losses Handhelds get a reduced coverage. The attrition in coverage is especially dramatic for the indoor Handheld receivers. We analyze coverage for two different models of the Population density, i.e. Clark's and Smeed's.**

***Index Terms*—DVB-T2; Coverage; Handheld Television; Link Budget; Clark's model; Outage probability.**

I. Introduction

The launch of DVB-T2 (Digital Video Broadcasting - Terrestrial 2^{nd} generation) dates back close to 2002 after DVB-S2 (DVB - Satellite 2^{nd} generation). DVB-T2 was first deployed in 2009 in UK and by now has already penetrated in Italy, Sweden, Finland and even outside Europe like Zambia [13]. In countries where DVB-T services are already on air, DVB-T2 is likely to co-exist with DVB-T. Compared to its predecessor DVB-T2 is capable of providing more new services.

In November 2004, the ETSI (European Telecommunications Standards Institute) introduced DVB-H (DVB-Handheld) [5]. DVB-H could not become a success because of the lack of unification in the efforts of the broadcasters and Mobile Network Operators.

According to the design targets laid in [1], DVB-T2 would reuse the transmitters infrastructure of its predecessor system. Also it was supposed to provide services for both fixed and portable receivers, such that it additionally provides a more robust version of the same service for the portable Handheld reception in parallel.

In the DVB-TM study mission report [3], it was concluded that the upcoming DVB-NGH (Digital Video Broadcasting - Next Generation Handheld) is going to be based on the features of DVB-T2 technology along with required modifications. The launch of DVB-NGH is yet awaited. However, in [15] a lighter version of DVB-T2 has been introduced i.e. T2-Lite, which borrows a subset of DVB-T2 parameters ensuring smaller buffer sizes and robust reception. In our work all the considered parameters are compliant with the T2-Lite profile.

DVB infrastructure is designed and optimized for fixed DVB receivers i.e. traditional TV sets with rooftop antenna reception. In our work we try to expose the challenges which the next generation DVB Handheld receivers will have to surmount in order to get proper coverage.

In Section II, we present the basic configuration comprising three cases of Handheld receivers. A typical fixed DVB receivers link budget is presented and compared to the Handheld receiver cases. We also describe the propagation model chosen. Based on the link budget and propagation configuration, we evaluate the total power deficit for Handhelds w.r.t. fixed receivers. In Section III, we present the two population density models and for each we derive and plot the outage probability as a function of the SNR margin. In Section IV, we use the outage probability to find the coverage reductions against the total deficits of the Handheld receivers. In Section V we conclude by summarizing the results and the analytical comments from previous sections. Moreover, we suggest that a solution to the problem shall be a network's infrastructure based.

II. Fundamental Configuration

We consider two types of DVB receivers: a fixed TV set receiving DVB transmission and a Handheld (portable[1]) DVB receiver. There can be several possible cases given the situation around the receiver and the kind of signal it receives. For this work we consider three cases, which are:

1) Fixed DVB receiver (receiving a high data rate service)
2) Handheld Outdoor portable DVB receiver
3) Handheld Indoor portable DVB receiver

A pictorial illustration of the considered cases is given in Figure 1.

A. Link Budget

The link budget for all of the three cases is shown in Table I. The parametric values are referred from Table 3.3.2 of [11]. In principle robust and low bit-rate modulation schemes are chosen for the handheld reception to enable good coverage, while high data rates are preferred for a fixed receiver. Therefore, we choose the highest modulation order for the fixed transmission. According to [15], for the T2-Lite profile, the highest permissible modulation order is 64-QAM, for our analysis we choose QPSK.

A fixed DVB receiver has a high gain receiving antenna at the rooftop level. The signal received is fed to the fixed receiver by the lossy feeder cables. In a link budget, such losses

[1]In [11] the category of portable receiver is defined for stationary or very slow moving (walking speed) DVB receivers.

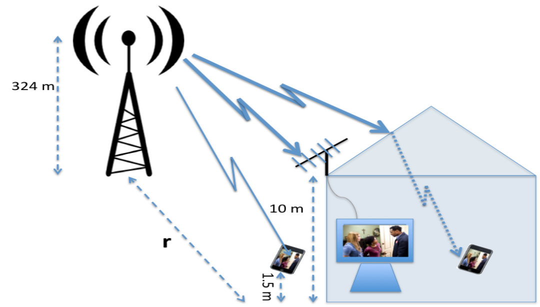

Fig. 1. Three cases considered for the DVB-T2 reception

TABLE I
LINK BUDGET

	Fixed	Portable Handheld			
	Roof-top	Indoor		Outdoor	
Code rate = 1/2	256 QAM	QPSK	64 QAM	QPSK	64 QAM
C/N, dB	16	3.4	12.8	3.4	12.8
Noise Figure	6 dB				
Bandwidth	7.77 MHz				
Noise power	-99.1 dBm				
Min Signal Power, dBm	-82.9	-95.7	-86.4	-95.7	-86.4
Feeder loss, dB	4	0			
Antenna Gain, dBi	13.14	-7.36			
$C_m = P_{sm} + L_f - G_i$, dBm	-92.1	-88.4	-78.9	-88.4	-78.9
Deficit for Handheld, $\Delta C = C_m - C_f$, dB	0	3.8	13.1	3.8	13.1

are accounted as feeder losses. The Handheld receiver has an integrated antenna. As antennae are designed for a reference frequency there is a correction factor which determines the antenna gain value for a given frequency. For the frequency considered in the link budget (i.e. 650 MHz) the Handheld receiver 's antenna gain value calculated is -9.5 dBd (which is -7.36 dBi) [11].

The Carrier to Noise Ratio (CNR) levels taken in Table I are those which correspond to the Quasi Error Free (QEF) level i.e. a Bit Error Rate (BER) = 10^{-11} [1]. To find those we consider BER curve for DVB-T2 in Typical Urban-6 taps (TU-6) channel from [7]. The curves taken had to be extrapolated using a sigmoidal shaped curve-fit till QEF level for BER. The use of sigmoidal curve-fitting is a well-known technique [9], [8]. In the end of Table I the additional signal strength required for the handheld reception w.r.t. the fixed roof top reception is presented.

B. Propagation Model

For DVB networks Okumura Hata is the most commonly used propagation model [10]. According to the Okumura Hata model the average path loss in urban environment is given as,

$$\begin{aligned} L_{dB} &= 69.55 + 26.15\log(f_c) - 13.82\log(h_t) \\ &+ (44.9 - 6.55\log(h_t))\log(r) + 4.97 \\ &- 3.2(\log(11.75h_r))^2, \end{aligned} \qquad (1)$$

where r is the distance (in km) between a DVB receiver and the transmitter, h_t is the height of the DVB transmitter and h_r is the height of the receiver. Using Equation 1, L_{dB} for the fixed receiver is, $L_{dB} = 99.7 + 28.46\log(r)$. For the Handheld receiver, receiver height, $h_r = 1.5$m, therefore, L_{dB} becomes, $L_{dB} = 108.4 + 28.46\log(r)$.

For a received power level P the generalized dB form of Okumura Hata model can be given as,

$$P = P_t - L_o - 10\gamma\log(r). \qquad (2)$$

The linear version[2] of the generalized form of Okumura Hata model in Equation 2 is, $p = \frac{p_t}{l_o r^\gamma}$. The received power level p has variations due to shadowing. This shadowing effect is modeled by taking a standard normal distribution. Hence, p can be modified as,

$$p = \frac{p_t}{l_o r^\gamma} 10^{\frac{\xi\sigma}{10}}, \qquad (3)$$

where ξ is a random variable defined by the standard normal distribution and σ is the overall standard deviation of the power variation due to shadowing. We represent the standard deviation due to outdoor shadowing by σ_o and the one due to indoor by σ_i. Both of the shadowing effects are uncorrelated therefore the overall standard deviation can be given as, $\sigma = \sqrt{\sigma_o^2 + \sigma_i^2}$.

We take $P_t = 73.01$dBm (20kW) and Frequency, $f_c = 650$MHz. For the fixed receiver the signal is received at rooftop level i.e. $h_r = 10$m. The standard deviation of outdoor shadowing variation is typically $\sigma_o = 5.5$dB. By comparing the coefficients of $\log(r)$ in Equations 1 and 2 the value for γ is 2.85, for a Transmitter height, $h_t = 324$m. For indoor coverage signal experiences some penetration loss, which is normally modeled as a constant penetration loss, l_p. We take the indoor standard deviation to be $\sigma_i = 5$dB, for which the overall Standard deviation for the indoor coverage becomes $\sigma = 7.43$dB.

1) Evaluation of Total deficit: The distance independent part of the average path loss, L_o, for the case of rooftop reception is less due to its configurational advantages over the one for Handheld receivers i.e. line of sight condition and higher receiver antenna height. We call it the configurational deficit, ΔL_T for the Handheld receivers. Moreover, in Table I we present the additional signal strength needed in the handheld scenario w.r.t. the case of rooftop signal reception for a fixed user i.e. ΔC. In Table II we give the total deficit in terms of power loss for a Handheld receiver with respect to a fixed Receiver i.e. $\Delta L_T + \Delta C$, for all the cases considered in Table I.

[2] We choose small letter symbols for all linear values.

TABLE II
TOTAL DEFICIT IN POWER LOSS FOR THE HANDHELDS

	Fixed	Portable Handheld			
	Roof-top	Indoor		Outdoor	
Code rate = 1/2	256 QAM	QPSK	64 QAM	QPSK	64 QAM
L_o, dB	99.7	108.4		108.4	
Penetration, l_p, dB	0	11		0	
$L_T = L_o + l_p$	99.7	119.4		108.4	
ΔL_T	0	19.7		8.7	
ΔC	0	3.8	13.1	3.8	13.1
$\Delta C + \Delta L_T$	0	23.5	32.8	12.5	21.8

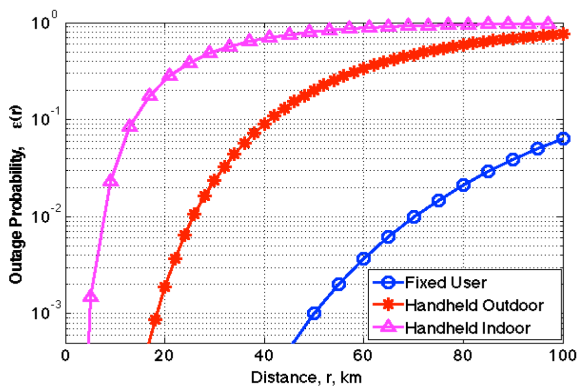

Fig. 2. Outage comparison between a Handheld and a fixed DVB-T2 receivers

III. OUTAGE IN THE CELL AREA

Because of the presence of shadowing phenomenon the power level received is a random value. Using Equation 3 the probability of a signal being less than a required minimum Signal power, c_{min} can be given as,

$$\Pr(p \leq c_{min}) = \Pr\left(\frac{p_t}{l_T r^{\gamma}} 10^{\frac{\xi\sigma}{10}} \leq c_{min}\right) \tag{4}$$

The probability considered in Equation 4 is basically the outage of the service, denoted by ϵ. As shadow fading is defined by the standard normal distribution, ξ, therefore Equation 4 can also be given as,

$$\epsilon(r) = \frac{1}{2}\left(1 + \text{erf}\left(\frac{C_{min} - P_t + L_T + 10\gamma\log(r)}{\sigma\sqrt{2}}\right)\right), \tag{5}$$

where $C_{min} = 10\log c_{min}$.

In Figure 2, using Equation 5 the outage probability as a function of the distance is plotted for a single user. For the outdoor and ordinary indoor cases QPSK modulated format is plotted. It can be observed that a possible cell radius for a 95% coverage is 96 km for the fixed receiver, whereas it is one-third of it for an Outdoor Handheld. For the case of indoor it is under one tenth value of the fixed receiver coverage.

For a cell radius, R there is an average power level, $c_{plan} = \frac{p_t}{l_o R^{\gamma}}$, which operators plan for the edge of the cell. Solving this average power level with Equation 3 we get,

$$p = \frac{R^{\gamma}}{r^{\gamma}} c_{plan} 10^{\xi\sigma}. \tag{6}$$

Using Equation 6 the probability of a signal p being less than c_{min} (i.e. the outage probability) can be given as,

$$\Pr(p \leq c_{min}) = \Pr\left(\xi \leq \frac{10}{\sigma}\log\left(\frac{c_{min}}{c_{plan}}\right) + \frac{10\gamma}{\sigma}\log\left(\frac{r}{R}\right)\right). \tag{7}$$

Using Equation 7, Equation 5 can be rewritten as,

$$\epsilon(r) = \frac{1}{2}\left(1 - \text{erf}\left(b_1(C_{plan} - C_{min}) - b_2\ln\left(\frac{r}{R}\right)\right)\right), \tag{8}$$

where $b_1 = \frac{1}{\sigma\sqrt{2}}$, $b_2 = \frac{10\gamma}{\sigma ln(10)\sqrt{2}}$ and $C_{plan} = 10\log(c_{plan})$.

The average outage probability over a surface area, $s = \pi r^2$, of a disk-like shaped cell can be evaluated as,

$$\epsilon_s = \frac{\int\int_s \epsilon(r)\rho(r,\theta) r dr d\theta}{\int\int_s \rho(r,\theta) r dr d\theta}, \tag{9}$$

where $\rho(r,\theta)$ is the population density function of the cell and θ is the azimuth angular position of a user in the cell.

A. Smeed's Urban Population density

R.J. Smeed used Urban population density as a direct function of distance [14], in his analysis of the routing systems for the traffic in downtown areas. We take a similar mathematical form to define the population density of a disk-like shaped DVB-T2 cell, with R being the cell radius.

The basic mathematical form of the Population density function $\rho(r)$ is,

$$\rho(r,\theta) = \frac{(i+2)N}{2\pi R^{i+2}} r^i, \tag{10}$$

where θ is the azimuth angular position of a user with respect to the direction of the DVB transmitter in the cell, N is the total number of users in the cell and i is an integer number, such that, always $i > -2$. For all negative values of integer, i, it will have more users close to the cell center than the cell edges, whereas for the positive i, it is vice versa.

By solving Equations 8, 10 and 9, the cell outage probability derived for the Smeed's population density can be given as,

$$\begin{aligned}\epsilon_s &= \frac{1}{2}(1 - \text{erf}(b_1 M)) \\ &- \frac{1}{2}e^{\frac{(i+2)^2 + 4b_1 b_2 M(i+2)}{4b_2^2}}\left(1 - \text{erf}\left(b_1 M + \frac{i+2}{2b_2}\right)\right),\end{aligned} \tag{11}$$

where, $M = C_{plan} - C_{min}$, is the coverage margin.

B. Clark's Urban population density

According to Colin Clark's work on urbanization [2], an urban population density is an exponentially decaying function of the distance from the metropolitan center. For example if ρ_0 is the population density in the city center, b is the decay parameter and r is the distance then population density at a given distance as given in [12] is, $\rho(r) = \rho_0 e^{-br}$, where $\rho(r)$ is the resident population density in per surface area unit. We assume a disk-like circular shape for the cell and in our example the DVB transmitter is in the center of the city, like in [10] , therefore r is the radial distance of a DVB-T2 receiver from the transmitter. At $r = R$ we have a cell edge density, ρ_e, which can be related to R as,

$$bR = \ln\left(\frac{\rho_0}{\rho_e}\right). \tag{12}$$

For our analysis of a Clark 's population density based cell, the model we consider is,

$$\rho(r,\theta) = \frac{Nb^2}{2\pi\left(1 - e^{-bR}(1+bR)\right)} e^{-br}, \tag{13}$$

where N is the total number of users inside the cell. To find average cell outage probability we solve the integrals of Equation 9 with Equations 13 and 8. The exponential function of Equation 13 was expanded using Taylor series i.e. $e^{-br} = \sum_{j=0}^{\infty} \frac{(-br)^j}{j!}$. The outage probability obtained for the Clark's Urban Population density model is,

$$\epsilon_s = \frac{1}{2}\left(1 - A\sum_{j=0}^{\infty} B\left(\text{erf}(b_1 M) + C\right)\right), \tag{14}$$

where,

$$A = \frac{\left(\ln\left(\frac{\rho_o}{\rho_e}\right)\right)^2}{1 - \frac{\rho_e}{\rho_o}\left(1 + \ln\left(\frac{\rho_o}{\rho_e}\right)\right)},$$

$$B = \frac{\left(\ln\left(\frac{\rho_e}{\rho_o}\right)\right)^j}{(j+2)j!},$$

$$C = e^{\frac{(j+2)^2 + 4b_1 b_2 M(j+2)}{4b_2^2}}\left(1 - \text{erf}\left(b_1 M + \frac{j+2}{2b_2}\right)\right).$$

The above form is obtained after parametrization of the results with Equation 12 to have an intuitively more understandable form. The summation in Equation 14 does not change significantly beyond the seventh term of Taylor series expansion.

In Figure 3 we present the Outage probability curves for Clark's Population density on ground, for different values of $\frac{\rho_o}{\rho_e}$. We take the summation in Equation 14 up to twenty terms to plot the curves corresponding to Clark's model in Figure 3. We also consider the uniform population density case from Smeed 's model i.e. $i = 0$, which coincides with the Clark' s model curve for $\frac{\rho_o}{\rho_e} = 1.01$. For a higher density ratio a reduction in the outage can be observed.

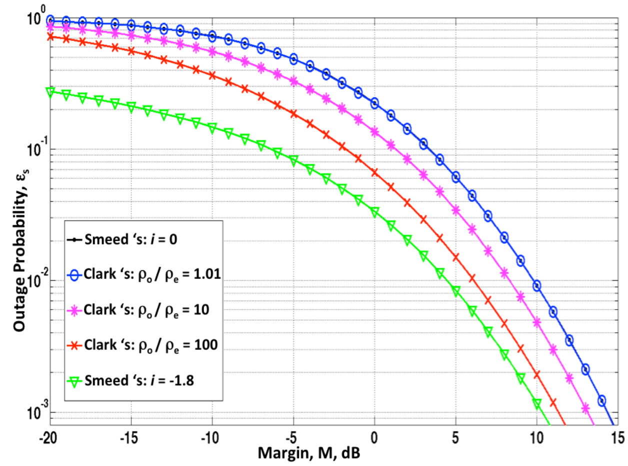

Fig. 3. Outage probability curves

IV. Coverage Analysis of the Models

Clark's model is a close-to-reality population density model widely used and applied in wireless communications e.g. in [12]. For Clark's model we have taken a density function for $\frac{\rho_o}{\rho_e} = 10$, which is very optimistic. For an analysis of the Smeed's model we take $i = 0$ i.e. the uniform population density and $i = -1.8$ i.e. an ideal case (as for $i = -2$, $\epsilon_s = 0$ Equation 11).

Graphically, against a target outage (e.g. 0.01, 0.001) planned for the roof-top mounted antenna fixed DVB users in the cell, the dB Margin, $M = C_{plan} - C_{min}$ can be taken from Figure 3. In Table II total deficit of Handheld receiver link budget can be found with respect to the fixed roof-top DVB receiver. The value of M for Handheld DVB user is lower because of that deficit, which gives a higher outage in Figure 3 i.e. a reduction in the coverage.

In Tables III and IV we have listed several fixed users' percentage coverages. Against each fixed user coverage the graphically obtained reduction in the coverage for Handheld users is tabulated. From Table II we have taken the cases of QPSK Outdoor ≈ 12 dB, QPSK Indoor/ 64-QAM Outdoor ≈ 24 dB and 64-QAM Indoor ≈ 36 dB.

In Tables III and IV, we can see that the coverage for the Indoor users is reduced by 80-90% even for the strongest modulation and code rate i.e. 1/2-QPSK. In Table II the deficit for Outdoor 64QAM is 22 dB, which is almost the same as the Indoor QPSK i.e. 24 dB. Hence, for the case of Higher order modulation the coverage for Outdoor Handheld is as bad as for the Indoor case.

One possible solution is to add a separate antenna receiving DVB-T2 transmission, which would reduce losses by 9 dB [11], by avoiding the loss due to negative gain of the integrated antenna considered in our analysis. But there are still going to be cases like, 64-QAM in indoor, for which the reduced $\Delta L_T + \Delta C = 33 - 9 = 24$dB, which is the same as having QPSK indoor e.g. it gives a 71 % coverage reduction in Clark's model in Table IV.

In [4], it is mentioned that some advanced techniques like

TABLE III
COVERAGE REDUCTION FOR HANDHELD RECEIVERS IN SMEED 'S POPULATION DENSITY

Sigma, σ, dB	i	fixed Cov. ,%	$\Delta L_T + \Delta C$, dB	Handhelds Cov.,%	Handhelds Uncovrd,%
5.5 (Out-door Handheld)	-1.8	95	12	80	15
		99	12	88	11
	0	95	12	50	45
		99	12	72	27
7.43 (Indoor Handheld)	-1.8	99	24	74	25
			36	61	38
		99.9	24	80	19.9
			36	67	32.9
	0	99	24	15	84
			36	2	97
		99.9	24	30	69.9
			36	7	92.9

TABLE IV
COVERAGE REDUCTION FOR HANDHELD RECEIVERS IN CLARK'S POPULATION DENSITY FOR $\frac{\rho_o}{\rho_e} = 10$

Sigma, σ, dB	fixed Cov. ,%	$\Delta L_T + \Delta C$, dB	Handhelds Cov.,%	Handhelds Uncovrd,%
5.5 (Outdoor Handheld)	95	12	53	42
	99		74	17
	99.9		88	11.9
7.43 (Indoor Handheld)	99	24	28	71
		36	6	93
	99.9	24	44	55.9
		36	9	90.9

MIMO and TFS (Time Frequency Slicing) are going to be employed in the upcoming DVB-NGH profile to improve Time, frequency and space diversity. In [6] a 4x2 MIMO has been applied over DVB-T2, which shows some improvement of around 5 dB.

We choose a very special case of having a several hundreds meter high tower in the city center. Normally, it is hard to have such a tall tower in a congested downtown. Since the radius of a DVB cell, covering the fixed users only, is very long to give good coverage till the heart of the city (refer to Figure 2). Therefore it is more likely to find such towers erected at the outskirts of cities for the conventional DVB networks. Now if we apply the theory of urbanization [2] to a DVB transmitter based in the outskirts, it suggests long distances for most of the Handhelds from the transmitter, as the most of the handhelds are cluttered in the city center.

In terms of the Smeed's model, this scenario is close to the case of $i > 0$ and for the Clark's model it would be a case of $0 < \frac{\rho_o}{\rho_e} < 1$. The cell area coverage observed for the uniform density model is already very low for indoor and outdoor Handhelds. For positive values of i or for a fractional value of $\frac{\rho_o}{\rho_e}$, it is going to be even lower. Hence keeping in view a very bad coverage even with very optimistic assumptions, it can be said that Handheld coverage with the existing DVB-T2 infrastructure is going to be worse.

V. CONCLUSION

In this work we have estimated the extent of the coverage problems for a DVB-T2 infrastructure covering Handheld receivers. We modeled Handheld receivers as the fixed ones with additional power losses to translate the link budget deficits for the Handheld receivers into the expected coverage reductions. The magnitude of coverage reductions is not ignorable, specifically for the indoor Handhelds the outage is as large as 90%. Based on the analytical results obtained from this work and the concepts of urbanization, we suggest some smart modifications to the existing DVB infrastructure. A convenient solution would be to have some pre-existing infrastructure in a complementary role for a proper DVB transmission to the Handhelds. In this regard the cellular network is the best candidate, especially after the incurrence of LTE (Long Term Evolution) and the up-coming LTE-advanced like more capacious technologies.

REFERENCES

[1] DVB Document A133. *"Implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2)"*, 2010.

[2] C. Clark. Urban Population Densities. *Journal of the IRoyal Society*, 114:490–496, 1951.

[3] Digital Video Broadcasting (DVB). *TM 4026r1: TM-H NGH Study mission report*, 2008.

[4] C. Gallard. *D21.1 - Analysis on 3GPP E-MBMS/DVB-NGH Physical layer convergence*, 2011.

[5] E. Aaltonen J. T. J. Penttinen, P. Jolma and J. Vare. *The DVB-H handbook: The Functioning and Planning of Mobile TV*. John Wiley and Sons, Ltd, Publication, first edition, 2009.

[6] T. Jokela, C. Hollanti, J. Lahtonen, R. Vehkalahti, and J. Paavola. Performance evaluation of 4x2 mimo schemes for mobile broadcasting. In *Broadband Multimedia Systems and Broadcasting (BMSB), 2011 IEEE International Symposium on*, pages 1 –6, june 2011.

[7] T. Jokela, M. Tupala, and J. Paavola. Analysis of Physical Layer Signaling Transmission in DVB-T2 Systems. *IEEE TRANSACTIONS ON BROADCASTING*, 56:410–417, 2010.

[8] S. Lembo, K. Ruttik, and O. Tirkkonen. Modelling of convolutional code performance. *WPMC Symposium, IEEE*, 11, 2008.

[9] S. Lembo, K. Ruttik, and O. Tirkkonen. Modelling BLER performance of puncture turbo codes. *WPMC Symposium, IEEE*, 2009.

[10] G. Pousset, Y. Lostanlen, and Y. Corre. Mobile TV Standards: DVB-T vs DVB-H. *EBU technical Reveiw*, 2008.

[11] EBU UER Technical Report. *EBU - TECH 3348: Frequency and Network Planning aspects of DVB-T2*, 2011.

[12] M.Q. Sharif, R. Ghazizadeh, and P. Fan. Spatial Dynamic Spectrum Allocation and Population Density. *Wireless Communications, Networking and Mobile Computing (WiCom)*, 2007.

[13] DVB-T2 Fact Sheet. 2^{nd} *Generation Terrestrial: The World 's Most Advanced Digital Terrestrial TV System*, 2011.

[14] R. J. Smeed. The effect of kinds of routing systems on the amount of traffic in the central areas of towns. *Journal of the Institution of Highway Engineers*, 10:5–26, 1963.

[15] ETSI EN 302 755 V1.3.1. *"Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system"*, 2012.