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Research Article

New Method to Determine the Range of DVB-H Networks and the Influence of MPE-FEC Rate and Modulation Scheme

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DVB-H networks allow high data rate broadcast access for hand-held terminals. A new method to determine the range of good reception quality of such a DVB-H network will be investigated in this paper. To this end, a new subjective criterion is proposed, based on the viewing experience of the users. This criterion is related to the percentage of valid reception. A comparison with existing criteria, based on measured signal strengths, is also made. The ranges are determined for mobile reception inside a car. The influence of the MPE-FEC rate and the modulation scheme on the range is also investigated, enabling wireless telecom operators to select optimal settings for future networks.

1. Introduction

The digital broadcasting standard Digital Video Broadcasting-Handheld (DVB-H) enables a high data rate broadcast access for hand-held terminals (e.g., portable, pocket-size, battery-operated phones). It is based on the specifications and guidelines of ETSI [1–4]. The broadband downstream channel features a useful data rate of up to several Mbps and may be used for audio and video streaming applications, file downloads, and many other kinds of services. The standard uses a Coded Orthogonal Frequency Division Multiplexing (COFDM) modulation scheme and builds on Digital Video Broadcasting-Terrestrial (DVB-T) [2]; but is adapted for hand-held devices; it introduces time-slicing to reduce power consumption and includes the possibility to use Multiprotocol Encapsulation-Forward Error Correction (MPE-FEC) at the link layer to improve the performance for mobile reception.

Only very limited data about the calculation of the range of DVB-H systems is available. In [3–7], performance of DVB-H systems is evaluated. A subjective criterion for good viewing reception has also been developed in [8] for Digital Multimedia Broadcasting (DMB). In [9], the performance degradation of OFDM signals due to Doppler spreading in mobile radio applications such as 802.11a and DVB systems is investigated. In [10], a fast prediction method of the coverage area on the uplink of a UMTS network cell is presented by computation of the other cell interferences. The impact on attainable range for an added mobile broadband access element is investigated for systems beyond IMT-2000 in [11, 12]; UMTS cell ranges are calculated based on simulations results. In [13], the influence of different MPE-FEC rates and modulation schemes on the performance of a DVB-H network is analyzed for different reception conditions. In [14], an optimal transmission scheme is proposed for a specific network, maximizing the range for a certain throughput requirement, based on technical trial results. In [15], the benefit and effectiveness of Cyclic Delay Diversity (CDD) in DVB-H networks are investigated through coverage simulations.

The objective of this paper is to investigate the "range" of a DVB-H system. A new method for range calculation is presented, enabling a fast yet accurate prediction of the range of a DVB-H network. The range will be defined as the largest distance from a transmitter, where "good" reception is possible. With "good" reception, we mean a valid reception percentage of at least 95%. This means that the viewer receives valid images on his handheld during at least 95% of the considered time span. In [3], it is stated that a period of 20 seconds during which 5% of the MPE tables or less are erroneous will correspond to a valid reception. In [4], it is stated that it has been agreed that 5% MFER is used to mark the degradation point of the DVB-H service. This corresponds well with our criterion, since we also demand valid MPE tables for 95% of the time. Only, we will use a period of 40 seconds for reasons explained in the paper. The influence of the MPE-FEC rate and the modulation scheme on the range will be analyzed, and a comparison with the existing criteria will be made.

In this paper we investigate the range of a DVB-H system in a suburban environment in Ghent, Belgium. A new subjective criterion to determine the range of a DVB-H system is proposed, based on the viewing experience of the users. It makes use of a new quality criterion, percentage valid reception, which is based on the lock percentage (percentage of the time that the receiver is able to receive frames), and the percentage of correct, corrected, and incorrect tables. Also a second criterion, based on the measured carrier to interference-plus-noise ratio (CINR) and electric-field (E) values along the route, is investigated. The presented methodology can be used to assess the reception quality in wireless DVB-T/H networks. This paper will enable future DVB-H trials and roll-outs to select optimal settings and to define a region, where good reception will be possible.

The presented procedure to calculate the range of a DVB-H network can be used in other networks and for other frequencies, since the proposed method is independent of the terrain characteristics and the frequency. Compared to methods based on path loss measurements, the procedure has several advantages, for example, the possibility for terrain-dependent ranges or the lowered effort to obtain results that are yet reliable. The presented analysis in this paper could be applied in broadband wireless communications or multimedia communications over wireless.

The outline of the paper is as follows: the transmitting network, the measurement method, and the parameters used to calculate the range are described in Section 2. Also the procedure to calculate the range and the investigated schemes is described in this section. Section 3 presents the results for the different range definitions and the different MPE-FEC rates and modulation schemes. Section 4 discusses other work related to this paper, and finally, the conclusions are presented in Section 5.

2. Method

2.1. Transmitting Network. The transmitting network is located in a suburban environment in Ghent, Belgium. The single-frequency network (SFN) contains three base station (BS) antennas. The center frequency is 602 MHz, and the bandwidth is 8 MHz. Time synchronization is achieved by Meinberg GPS receivers with a 10-MHz clock. The absolute accuracy is 1 microsecond. The 10-MHz clock is also used to synchronize the transmitting frequency of the different transmitters in the SFN. In the network no static delay is used, that is, all transmitters transmit at the same time. The locations of the transmitting base stations (Tx) are a tower at the Rooigemlaan-Groendreef (Bemilcom mast, BS1), a building at the Keizer Karelstraat (Belgacom building, BS2), and a building of Ghent University at the Ledeganckstraat (Ledeganck building, BS3). Figure 1 shows a map of Ghent with the location of the three base stations marked with black dots. All transmitting antennas are omnidirectional and vertically polarized. The heights of these Tx are $h_{\mathrm{Tx}} = 57$ m, $h_{\mathrm{Tx}} = 64$ m, and $h_{\mathrm{Tx}} = 63$ m, respectively. The Equivalent Isotropically Radiated Power (EIRP) used for these Tx is 36.62 dBW, 39.93 dBW, and 40.90 dBW, respectively. The measurement environment in Figure 1 is located in a flat terrain, without hills or mountains.

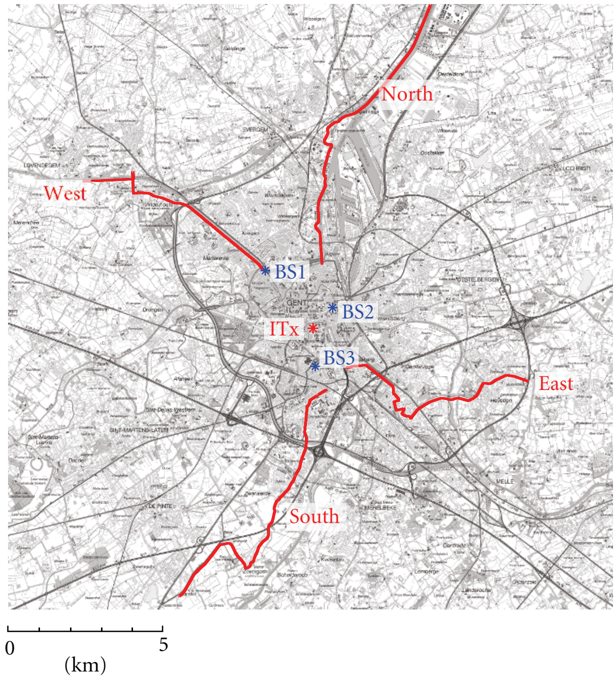

Figure 1: Map of Ghent with the three transmitting DVB-H antennas, the "imaginary transmitter" ITx, and the routes (in red) used to determine the range.

2.2. Measurement Method. The measurements are performed with a DVB-H tool implemented on a PCMCIA card with a small receiver antenna [6, 7, 13]. The antenna is a Pulse DVB-H 470–750 MHz Planar PWB (planar printed wire board) antenna with the following dimensions: length of 50.5 mm, width of 10.5 mm, thickness of 3.0 mm. The gain of the system is −5 dBi. The connector is of type MMCX. The PCMCIA card is plugged into a laptop, which is used to collect and process the measurements later.

Every 0.5 second, a sample is recorded, while the receiver is either locked or unlocked, depending on the signal strength. A locked receiver can receive DVB-H frames, which are either correct or incorrect. Incorrect tables can (sometimes) be corrected by the MPE-FEC code. The tool logs parameters as CINR, Frame Error Rate (FER), Multiprotocol Encapsulation FER (MFER), and electric-field strength. MFER is the ratio of the number of residual erroneous frames (i.e., not recoverable) and the number of received frames [3]. FER is the ratio of the number of erroneous frames before MPE-FEC correction and the number of received frames [3]. Location and speed are recorded with a GPS device. To measure the electric-field value [dBμV/m], the Automatic Gain Control (AGC) value is used. This AGC value corresponds with a certain received power P_r [dBm]. From P_r, the electric field E [dBμV/m] can be calculated as described in [16, 17].

During the measurements, the video channel "één" of VRT (Flemish Radio and Television network) is monitored. All investigated modulation schemes (see Section 2.5) are broadcast in frames with 768 rows, except for 16-QAM 1/2, MPE-FEC 7/8 with 512 rows. Using the right packet identifier, the receiver can stream a channel of the transmitted DVB-H signal. By opening a session description protocol (sdp) file, we can monitor the channel on the laptop with a media player. The observation of the visual and auditive reception quality is related to %Valid reception, defined in Section 2.3. The analysis in this paper will be performed for mobile reception at a height of 1.5 m inside a small van, driving around at a speed of 20 km/h. The reason to select this reception is because firstly, mobile reception is an important scenario for future (DVB-H and other network) deployments [9], secondly, because this low speed is allowed at all locations (speed limits in the city center are sometimes as low as 30 km/h in Belgium), and thirdly, because 20 km/h is low enough to obtain enough samples for the analysis (see Section 2.4).

2.3. Parameters Used to Analyze Performance. This paragraph defines the parameters used to analyze the range of the DVB-H system. First, MpegLock and MpegDataLock are explained. Next, parameters corresponding with MPE tables and signal quality, and finally, parameters related to the range are explained.

(i) Basic Definitions

(1) MpegLock: if MpegLock is "on," the transport stream (TS) synchonization is achieved;

(2) MpegDataLock: if MpegDataLock is "on," the TS synchonization is achieved and the TS packet is valid.

(ii) Parameters Corresponding with MPE Tables

(1) %Lock: the percentage of the time that the logged parameters MpegLock and MpegDataLock are both "on." When both are "on," it is possible to receive tables;

(2) %Incorrect tables = MFER;

(3) %Valid reception: the percentage of the time that the receiver is locked and receives either correct, or corrected tables =

$$100 - \left[\%\text{Not locked} + \left(\frac{\%\text{Lock} \times \%\text{Incorrect tables}}{100}\right)\right]. \quad (1)$$

(iii) Signal Quality Requirements

(1) $\text{CINR}|_{\text{MFER5\%}}$: the minimal value of CINR [dB] for which the MFER is at most 5%;

(2) $\text{E}|_{\text{MFER5\%}}$: the minimal value of E [dBμV/m] for which the MFER is at most 5%. $\text{CINR}|_{\text{MFER5\%}}$ and $\text{E}|_{\text{MFER5\%}}$ correspond with the MFER 5% criterions [3, 4] for the CINR and the electric-field strength, respectively.

(iv) Range

(1) $\text{R}_{\text{CINR}|_5}$: estimated range in a particular direction based on required $\text{CINR}|_{\text{MFER5\%}}$;

(2) $\text{R}_{\text{E}|_5}$: estimated range in a particular direction based on required $\text{E}|_{\text{MFER5\%}}$;

(3) R: estimated range in a particular direction based on %Valid reception;

(4) CINR_R: average CINR value at a distance equal to R;

(5) E_R: average E value at a distance equal to R.

More detailed definitions of the parameters related to the range of the system can be found in Section 2.4.

2.4. Range. The range of the DVB-H network in Ghent will be determined for the four wind directions (North, South, East, and West) for a car driving at 20 km/h. Figure 1 shows the four investigated routes indicated in red. The total length of these routes is 40 km.

The ranges are calculated as the distance from a location noted as the "imaginary transmitter" ITx. The location ((x, y, z)-coordinates) of this imaginary transmitter is chosen as a weighted average of the positions of the three transmitters (see Figure 1):

$$(x, y, z)_{\text{ITx}} = \frac{\text{W1} \cdot (x, y, z)_{\text{Tx1}} + \text{W2} \cdot (x, y, z)_{\text{Tx2}} + \text{W3} \cdot (x, y, z)_{\text{Tx3}}}{\text{W1} + \text{W2} + \text{W3}}, \quad (2)$$

with $(x, y, z)_{\text{ITx}}$ are the Lambert coordinates [18] of the imaginary transmitter, $(x, y, z)_{\text{IT}j}$ are the Lambert coordinates of the base stations in Ghent ($j = 1, 2, 3$). The weights W1, W2, and W3 correspond with their respective EIRP of 4594 W, 9844 W, and 12304 W.

Different criteria can be used to determine the range of the DVB-H system: the required CINR, the required E, or the correctness of the received video stream (%Valid reception; see Section 2.3). In the following, the method to determine the range based on these different criteria will be described and the procedure to calculate R, $\text{R}_{\text{CINR}|_5}$, and $\text{R}_{\text{E}|_5}$ is discussed.

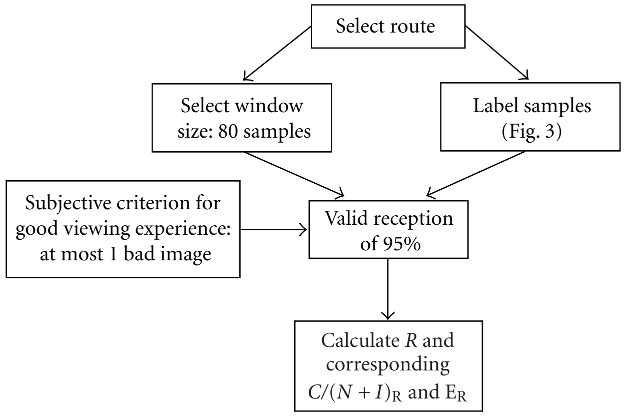

Figure 2: Flow graph illustrating the procedure to calculate R, $\mathrm{CINR_R}$, and $\mathrm{E_R}$.

2.4.1. Criterion 1: Range R for %Valid Reception. Figure 2 shows a flow graph of the new procedure used to calculate the range R (defined in Section 2.3) of the DVB-H system, based on %Valid reception.

The definition of R is based on the definition of %Valid reception (formula (1); see Section 2.3). To calculate R, a window of 80 samples is chosen. This corresponds with at most 20 tables, since tables are received every 2 seconds or slower (sampling occurs every 0.5 seconds). A window of 80 samples corresponds with a window length of 222 metres, when driving at 20 km/h. This length is small enough to obtain sufficient resolution, and large enough to obtain a sufficient number of samples to calculate a certain percentage of valid reception. The range R is calculated for a valid reception of 95% within the window (Figure 2). This percentage corresponds with a subjective criterion based on the viewing experience of the users in the DVB-H network: maximally 1 bad image within the window is allowed for a good experience. A tag is assigned to every sample: 0 or 1, with 0 for invalid reception and 1 for valid reception. The procedure of labeling the samples causes the %Valid reception of 95% to correspond with no more than one incorrect table received within the window, as proposed in our subjective criterion.

Figure 3 shows this procedure of labeling the samples. The tag of a sample is zero if the receiver is not locked or if the receiver is locked but an incorrect table is received. When for a certain sample the receiver is locked, but no table is received, the following rule is used: assign the same tag as the tag of the nearest sample where a table is received. This means, for example, that samples between two consecutive incorrect tables are marked as incorrect as well. The same counts for two consecutive correct tables, where corrected tables are considered to be correct as well. Samples in the middle between a correct and an incorrect table are considered to be correct in order to satisfy our subjective criterion of good reception (Figure 2), that is, maximally one bad image is received within one window. Since the window size is 80 samples, the 95% valid reception range ends when 2 incorrect tables within one window are encountered (2 incorrect tables correspond with at least 6 labels with a tag equal to 0; see Figure 3), or when the receiver is not locked for five samples within the window. This corresponds with the subjective limit for good reception experienced by the viewers when watching the DVB-H stream during the tests. Two consecutive incorrect images or no images at all (when at least 5 successive samples are not locked) observed by the viewer correspond with a valid reception percentage dropping below 95% and is the limiting requirement for a good viewing experience.

Finally, the range R characterizing the distances for valid reception of the system is defined as

$$\mathrm{R} = \sqrt{(x_{95} - x_{\mathrm{ITx}})^2 + (y_{95} - y_{\mathrm{ITx}})^2}, \tag{3}$$

with $(x, y)_{\mathrm{ITx}}$ defined as in formula (2). x_{95} and y_{95} are the coordinates of the point that is located the furthest from ITx in the last window before %Valid reception reduces to values lower than 95%. The difference in height between this point and ITx (z-coordinates) will be neglected in the range calculation, because the influence of the height difference on the range is negligible compared to the influence of the x, y-coordinates. $\mathrm{CINR_R}$ and $\mathrm{E_R}$ are the average values of CINR and E, respectively, over the samples in this last window before %Valid reception drops below 95%.

2.4.2. Criterions 2 and 3: $R_{CINR|_5}$ and $R_{E|_5}$. To determine $\mathrm{R}_{\mathrm{CINR}|_5}$ (defined in Section 2.3), a window of 80 samples is slid along the route. For each position of the window, the average CINR of the samples inside the window is determined. The window stops sliding when the average CINR within the window drops below the required $\mathrm{CINR}|_{\mathrm{MFER5\%}}$ value. These $\mathrm{CINR}|_{\mathrm{MFER5\%}}$ values have been determined in [6, 7, 13]. $\mathrm{R}_{\mathrm{CINR}|_5}$ is then defined as the distance between ITx and the location of the sample in the window that is the furthest away from the transmitter ITx. An analogous definition is used for $\mathrm{R}_{\mathrm{E}|_5}$.

A comparison of the values of R, $\mathrm{R}_{\mathrm{CINR}|_5}$ and $\mathrm{R}_{\mathrm{E}|_5}$ will be presented in Sections 3.1 and 3.2.

When comparing the different methods to calculate the range, we prefer our subjective criterion based on %Valid reception (criterion 1), because, unlike the criterion based on the MFER values (criterions 2 and 3), this criterion is based on the instantaneous viewing experience. The criterion based on the MFER values makes use of precalculated MFER values, which are based on an *average* calculation of the percentage of correct(ed) tables over a large region. For example, for the range calculation in the North direction, the $\mathrm{CINR}|_{\mathrm{MFER5\%}}$ requirement is lower than that for other directions, because the receiver suffers less from multipath reception in the North direction as the environment is more open there. To allow a correct use of the criterion based on the MFER 5% values, one should have $\mathrm{CINR}|_{\mathrm{MFER5\%}}$ values for each specific environment for which the measurements are executed, in constrast to our criterion which is valid for all situations. The $\mathrm{CINR}|_{\mathrm{MFER5\%}}$ value also differs for different speeds, whereas using our subjective criterion, the velocity is of no importance because no precalculated ($\mathrm{CINR}|_{\mathrm{MFER5\%}}$) values are used to define the range. For measurements inside

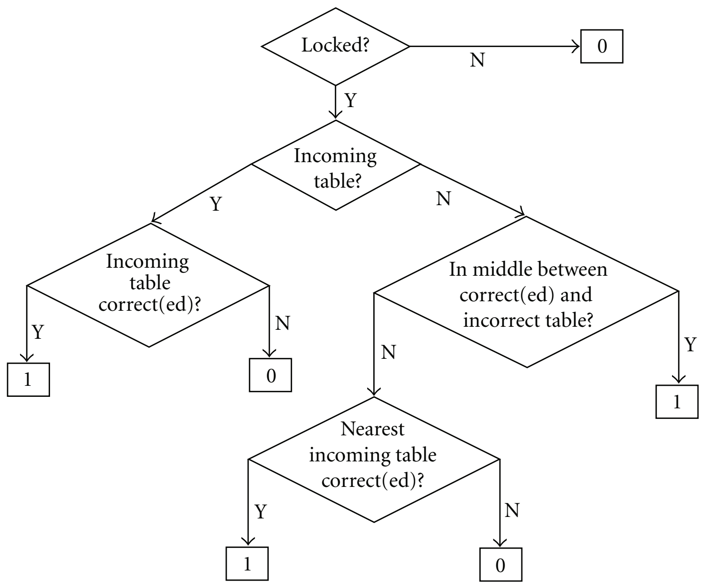

Figure 3: Flow graph illustrating the labeling of the samples (0 or 1) (Y = yes, N = no).

Table 1: Parameter sets investigated to determine the influence of MPE-FEC and modulation scheme.

	Parameter set	PHY bit rate [Mbps]
Variation MPE-FEC	4 K, 1/8, 16-QAM 1/2 **MPE-FEC 67/68**	10.90
	4 K, 1/8, 16-QAM 1/2 **MPE-FEC 7/8**	9.68
	4 K, 1/8, 16-QAM 1/2 **MPE-FEC 5/6**	9.22
	4 K, 1/8, 16-QAM 1/2 **MPE-FEC 3/4**	8.30
	4 K, 1/8, 16-QAM 1/2 **MPE-FEC 2/3**	7.37
	4 K, 1/8, 16-QAM 1/2 **MPE-FEC 1/2**	5.53
Variation modulation scheme and inner code rate	4 K, 1/8, **QPSK 1/2** MPE-FEC 7/8	4.84
	4 K, 1/8, **QPSK 2/3** MPE-FEC 7/8	6.45
	4 K, 1/8, **16-QAM 1/2** MPE-FEC 7/8	9.68
	4 K, 1/8, **16-QAM 2/3** MPE-FEC 7/8	12.91
	4 K, 1/8, **64-QAM 1/2** MPE-FEC 7/8	14.52
	4 K, 1/8, **64-QAM 2/3** MPE-FEC 7/8	19.36

a vehicle, the vehicle penetration loss has an influence on the $CINR|_{MFER5\%}$ values. Also, a statistically relevant number of samples needs to be investigated to obtain these MFER values. So, a measurement campaign has to be executed before the actual range measurements can even start.

The classical method to calculate the range for a network is to formulate a path loss model based on a path loss measurement campaign within the network. The range is then calculated as the radius of the circle around the transmitter for which the probability to meet the CINR requirement on the edge is, for example, equal to 95%, hereby taking into account the predicted average path loss at a certain distance from the transmitter and the standard deviation of the path loss values around the predicted value. When comparing our method to this classical method, there are several advantages. Firstly, our method is much faster executable since there is no need for a large measurement campaign to obtain a statistically relevant number of samples on different distances from the transmitter for formulating a path loss model (even at small distances from the transmitter, where coverage is mostly excellent and does not need much investigation). Secondly, models for networks with multiple transmitters are not yet available, we only have knowledge of path loss models for one transmitter. Thirdly, unlike range calculations based on a path loss model, our method provides the possibility to have different ranges in different directions, which can be useful when the investigated terrain is heterogeneous.

2.5. Investigated Schemes. The parameters that have been tuned are modulation, inner code rate, and MPE-FEC coding rate level. A list of the different investigated parameter sets together with the corresponding bit rate [Mbps] is provided

Table 2: Range R, corresponding $CINR_R$ and E_R values for 95% valid reception, and MFER 5% values for routes along different wind directions and for different MPE-FEC rates (modulation scheme 16-QAM 1/2).

MPE-FEC rate		North	West	South	East	Average	$CINR\|_{MFER5\%}$ and $E\|_{MFER5\%}$
67/68	Range R [m]	6589	6035	4149	3955	5182	
	$CINR_R$ [dB]	12	13.97	15.58	14.53	14.02	14.42
	E_R [dBμV/m]	74.8	77.59	83.07	77.52	78.25	78.89
7/8	Range R [m]	6469	4607	4072	4012	4790	
	$CINR_R$ [dB]	12.72	15.27	13.48	12.89	13.59	12.94
	E_R [dBμV/m]	79.93	83.75	81.27	75.89	80.21	79.65
5/6	Range R [m]	5665	6281	5188	3965	5275	
	$CINR_R$ [dB]	12.73	16.44	14.91	12.52	14.15	13.27
	E_R [dBμV/m]	76.29	80.8	77.14	77.85	78.02	78.91
3/4	Range R [m]	6637	6245	5117	3956	5489	
	$CINR_R$ [dB]	12.02	15.7	13.21	12.973	13.48	13.12
	E_R [dBμV/m]	76.65	81.39	77.69	77.5	78.31	77.73
2/3	Range R [m]	6975	6285	5402	4007	5667	
	$CINR_R$ [dB]	11.69	15.01	13.38	12.83	13.23	12.34
	E_R [dBμV/m]	73.3	77.02	75.76	77.05	75.78	74.88
1/2	Range R [m]	6676	6608	5498	4399	5795	
	$CINR_R$ [dB]	13.03	11.44	13.98	13.85	13.08	11.53
	E_R [dBμV/m]	76.05	72.67	74.93	78.95	75.65	75.00

in Table 1. The influence of the MPE-FEC rate and the modulation on the range is investigated. For the MPE-FEC study, 16-QAM 1/2 has been selected as modulation scheme [6, 7, 13]. For the variation of the modulation scheme, MPE-FEC 7/8 has been chosen [6, 7, 13]. The FFT size [2–4] is 4 K, and a guard interval of 1/8 has been selected for all tests [6, 13].

3. Results

3.1. Influence of MPE-FEC Coding Rate on R, $R_{CINR|_5}$, and $R_{E|_5}$. In this section, the influence of the MPE-FEC rate on the range of the DVB-H network is analyzed.

3.1.1. Range R for Different MPE-FEC Modes. The range R based on 95% valid reception and our subjective criterion of Section 2.4 has been determined for the different wind directions (North, South, East, and West (Figure 1)) and the different MPE-FEC rates. Table 2 shows the ranges for the different MPE-FEC rates for the different directions, as well as the average range over the four directions. For the considered DVB-H system, in a suburban environment (Ghent) a range R of 5 to 6 km is possible for good viewing reception in a car.

Table 2 shows that the average range increases for higher MPE-FEC rates (average values from 5182 m (67/68) to 5795 m (1/2)). Thus a gain in range of about 600 m is possible. One has to make a compromise between lower bit rate (more MPE-FEC) and higher possible ranges. Because of the higher MPE-FEC coding, lower CINR values are required and invalid reception occurs further from ITx than for lower MPE-FEC coding rates. Table 2 thus shows that higher MPE-FEC rates require lower $CINR_R$ and E_R values (CINR and E values at range R; see Section 2.4), resulting in a higher range. $CINR_R$ varies from 14.02 dB for MPE-FEC 67/68 to 13.08 dB for MPE-FEC 1/2.

Table 2 further shows the MFER 5% values ($CINR|_{MFER5\%}$ and $E|_{MFER5\%}$) for the different MPE-FEC rates, as measured in [6, 7, 13]. These values correspond well with the $CINR_R$ and E_R values, respectively (e.g., differences lower than 1.6 dB for CINR for all MPE-FEC rates). The MFER 5% values tend to be slightly lower than the $CINR_R$ and E_R values though. Our subjective criterion (two consecutive bad images are considered to be intolerable) is thus somewhat more restrictive than the MFER 5% requirement of [3, 4]. A first reason for this is that the $CINR_R$ and E_R values are determined in the first window, where %Valid reception drops below 95%. As it concerns the first drop under 95%, the window is likely to be located relatively close to the transmitters. This window is probably situated in a zone with relatively higher CINR and E values than the MFER 5% values obtained in [6, 7, 13]. A second reason is that our criterion also takes %Lock into account, in contrast with the MFER 5% criterion. This could slightly increase the signal strength requirements, since 95% valid tables (or MFER 5%) correspond with *maximally* 95% valid reception.

The differences between the E_R values (up to 4.56 dB) for the different MPE-FEC rates are larger than the differences between the $CINR_R$ values (up to 1.07 dB), because of the nonlinear relation between CINR and E: the measured range for the CINR values is about 30 dB (0–30 dB), while the range for E is about 50 dB (70–120 dBμV/m).

The $CINR_R$ and E_R requirement is lower for route North than for the other directions due to the less dense environment (more rural): the receiver suffers less from multipath reception in the North direction, lowering the CINR requirement. The range is also higher for North, because the more open environment attenuates the signal less than the denser environments in the other directions. Another reason is the selection of the location of ITx: the relatively higher weights of the two most southern BS pull the location of ITx southwards, resulting in higher distances in the North (and West) direction. The low-power BS1 in the North is still very useful, because it extends the range in that direction. It must also be noted that the differences between the ranges for the different parameter sets are more important than the absolute values to draw conclusions. These results will enable future DVB-H trials to select optimal settings and to define a region where good reception will be possible.

3.1.2. Comparison of R, $R_{CINR|_5}$, and $R_{E|_5}$. Table 3 compares the ranges R, $R_{CINR|_5}$, and $R_{E|_5}$ for the different MPE-FEC rates for the different directions as well as the average range over the four directions. Again, the highest ranges are obtained for more MPE-FEC coding (67/68 : 4.7 km versus 1/2 : 5.8 km). The differences between the three ranges are rather limited. The values for $R_{CINR|_5}$ and $R_{E|_5}$ tend to be slightly lower than the values for R, because of the method of the subjective criterion (Section 2.4): samples in the middle between a correct(ed) table and an incorrect table are *always* marked as good, while on average only half of those samples may be correct. The lower ranges R and $R_{CINR|_5}$ for route West for MPE-FEC 7/8 (see Table 3) may be caused by the fact that all range calculations are the result of one single investigated route.

3.2. Influence of Modulation Scheme on R, $R_{CINR|_5}$, and $R_{E|_5}$. In this section, the influence of the modulation scheme on the range of the DVB-H network is analyzed.

3.2.1. Range for Different Modulation Schemes. The range R based on 95% valid reception and our subjective criterion of Section 2.4 has again been determined for the different wind directions (Figure 1) for the modulation schemes (Table 1). Figure 4 shows the range R for the different wind directions as a function of the modulation scheme. Table 4 shows the ranges for the different modulation schemes and for the different directions as well as the average range over the four directions. Figure 4 and Table 4 show that the range increases for lower modulation schemes (average values from 3473 m (64-QAM 2/3) to 6427 m (QPSK 1/2)). Because of the lower modulation, lower CINR values are required, and invalid reception occurs further from ITx than for higher modulation schemes.

Table 4 shows that lower modulation schemes require lower $CINR_R$ and E_R values, resulting in a higher range. $CINR_R$ varies from 8.02 dB for QPSK 1/2 to 20.34 dB for 64-QAM 2/3. Table 4 shows that more inner coding results in higher ranges on average: 6427 m versus 5002 m for QPSK,

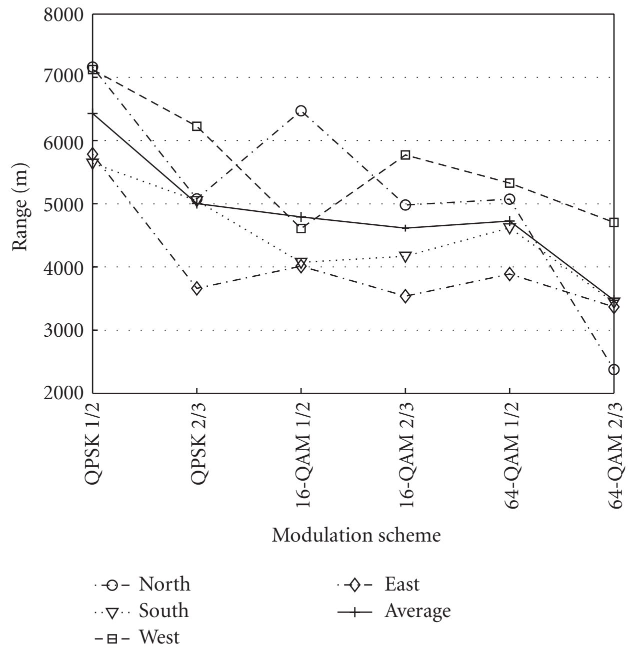

Figure 4: Range R for the different modulation schemes and for different directions.

4790 m versus 4614 m for 16-QAM, and 4726 m versus 3473 m for 64-QAM, corresponding with an increase of the range of 1425 m, 176 m, and 1253 m, respectively. The lower increase of the range for 16-QAM may be caused by the fact that all range calculations are the result of only a few investigated routes.

Table 4 compares the MFER 5% values ($CINR|_{MFER5\%}$ and $E|_{MFER5\%}$) with the $CINR_R$ and E_R values for the different modulation schemes. These values correspond again well with the $CINR_R$ and E_R values, respectively (e.g., differences lower than 0.74 dB for CINR). The MFER 5% values tend to be slightly lower than the $CINR_R$ and E_R values though, for the same reason as mentioned in Section 3.1. Section 3.1 also explains why the differences between the E_R values (up to 15.75 dB) for the different modulation schemes are larger than the differences between the $CINR_R$ values (up to 12.32 dB).

Comparison between Tables 3 and 5 shows that the gain in range is higher when changing the modulation scheme from QPSK 1/2 to 64-QAM 2/3 than when changing the MPE-FEC rate from 67/68 to 1/2 (3000 m versus 600 m). A first reason for this is of course the large influence of the difference between modulation schemes QPSK and 64-QAM. A second reason is the following. When changing the MPE-FEC rate from 67/68 to 1/2, the inner code rate is constant and equals 1/2. This code rate is relatively high, so that the relative influence of the MPE-FEC rate on the range is rather limited. When changing the modulation scheme from QPSK 1/2 to 64-QAM 2/3, the MPE-FEC rate is always 7/8. This low rate MPE-FEC code causes the influence of the modulation scheme on the range to be higher than when changing the MPE-FEC rate, while keeping an inner code rate of 1/2. The range is again higher for route North, and the $CINR_R$ and E_R

Table 3: 95%-range R, $R_{CINR|_5}$, and $R_{E|_5}$ for the different MPE-FEC rates and for the different directions.

MPE-FEC rate		North	West	South	East	Average
67/68	Range R [m]	6589	6035	4149	3955	5182
	$R_{CINR|_5}$ [m]	4907	5975	4194	3957	4758
	$R_{E|_5}$ [m]	5175	5854	4270	3647	4737
7/8	Range R [m]	6469	4607	4072	4012	4790
	$R_{CINR|_5}$ [m]	6462	4695	4129	4009	4824
	$R_{E|_5}$ [m]	5171	6163	4132	3678	4786
5/6	Range R [m]	5665	6281	5188	3965	5275
	$R_{CINR|_5}$ [m]	5093	6354	5301	3948	5174
	$R_{E|_5}$ [m]	5028	6331	4282	3939	4895
3/4	Range R [m]	6637	6245	5117	3956	5489
	$R_{CINR|_5}$ [m]	5766	6331	5129	3954	5295
	$R_{E|_5}$ [m]	5299	6339	5117	3951	5177
2/3	Range R [m]	6975	6285	5402	4007	5667
	$R_{CINR|_5}$ [m]	6923	6382	5455	4607	5842
	$R_{E|_5}$ [m]	6700	6352	5446	4048	5637
1/2	Range R [m]	6676	6608	5498	4399	5795
	$R_{CINR|_5}$ [m]	6709	6443	5604	4826	5896
	$R_{E|_5}$ [m]	6715	6339	5498	4837	5847

Table 4: Range R, corresponding $CINR_R$ and E_R values for 95% valid reception, and MFER 5% values for routes along different wind directions and for different modulation schemes.

Modulation scheme		North	West	South	East	Average	$CINR|_{MFER5\%}$
QPSK 1/2	Range R [m]	7162	7122	5641	5784	6427	
	$CINR_R$ [dB]	8.57	6.16	8.5	8.83	8.02	7.28
	E_R [dBμV/m]	74.7	71.02	71.59	70.81	72.03	72.30
QPSK 2/3	Range R [m]	5076	6224	5048	3660	5002	
	$CINR_R$ [dB]	8.93	11.17	10.41	10.42	10.23	10.23
	E_R [dBμV/m]	78.44	79.23	77.74	78.29	78.43	79.01
16-QAM 1/2	Range R [m]	6469	4607	4072	4012	4790	
	$CINR_R$ [dB]	12.72	15.27	13.48	12.89	13.59	12.94
	E_R [dBμV/m]	79.93	83.75	81.27	75.89	80.21	79.65
16-QAM 2/3	Range R [m]	4979	5771	4168	3537	4614	
	$CINR_R$ [dB]	15.06	16.22	16.58	17.15	16.25	16.11
	E_R [dBμV/m]	80.78	83.16	83.53	83.77	82.81	81.21
64-QAM 1/2	Range R [m]	5071	5327	4619	3887	4726	
	$CINR_R$ [dB]	15.95	18.35	17.88	18.41	17.65	17.45
	E_R [dBμV/m]	79.42	82.64	80.65	79.01	80.43	80.08
64-QAM 2/3	Range R [m]	2376	4704	3443	3368	3473	
	$CINR_R$ [dB]	20	20.12	20.54	20.7	20.34	20.28
	E_R [dBμV/m]	88.58	86.52	89.38	86.65	87.78	86.49

requirement is lower for that direction for the same reasons mentioned in Section 3.1.

3.2.2. Comparison of R, $R_{CINR|_5}$, and $R_{E|_5}$. Table 5 compares the ranges R, $R_{CINR|_5}$, and $R_{E|_5}$ for the different modulation schemes and for the different directions as well as the average range over the four directions. The differences between the three ranges are rather limited. The values for $R_{CINR|_5}$ and $R_{E|_5}$ tend to be slightly lower than the values for R, because of the method of the subjective criterion. This reason is explained in Section 3.1. The lower ranges R and $R_{CINR|_5}$ for route West for 16-QAM 1/2 (see Table 5 and Figure 4) may again be caused by the fact that all range calculations are the result of one single investigated route.

The presented procedure to calculate the range of a DVB-H network can also be used in other networks and for other frequencies, since the method is independent of the terrain characteristics and the frequency.

TABLE 5: 95%-range R, $R_{CINR|5}$, and $R_{E|5}$ for the different modulation schemes and the different directions.

Modulation scheme		North	West	South	East	Average
QPSK 1/2	Range R [m]	7162	7122	5641	5784	6427
	$R_{CINR\|5}$ [m]	7185	6635	7340	5827	6747
	$R_{E\|5}$ [m]	6999	6592	5583	5746	6230
QPSK 2/3	Range R [m]	5076	6224	5048	3660	5002
	$R_{CINR\|5}$ [m]	4674	6273	4222	3696	4716
	$R_{E\|5}$ [m]	4929	5488	4217	3607	4560
16-QAM 1/2	Range R [m]	6469	4607	4072	4012	4790
	$R_{CINR\|5}$ [m]	6462	4695	4129	4009	4824
	$R_{E\|5}$ [m]	5171	6163	4132	3678	4786
16-QAM 2/3	Range R [m]	4979	5771	4168	3537	4614
	$R_{CINR\|5}$ [m]	3374	5776	4193	3638	4245
	$R_{E\|5}$ [m]	4743	5912	4237	3695	4647
64-QAM 1/2	Range R [m]	5071	5327	4619	3887	4726
	$R_{CINR\|5}$ [m]	4896	5365	4224	3946	4608
	$R_{E\|5}$ [m]	4912	5487	4192	3433	4506
64-QAM 2/3	Range R [m]	2376	4704	3443	3368	3473
	$R_{CINR\|5}$ [m]	2376	4697	2747	1821	2910
	$R_{E\|5}$ [m]	3060	4707	3977	1808	3388

4. Related Work

A subjective criterion for good viewing reception has also been developed in [8] for DMB: 7% freeze frames in 20 seconds were considered the maximum rate, while in our paper, the maximum was 5% in 40 seconds (or 80 samples). Our criterion can be considered somewhat more restrictive. It was shown in Section 3 that our criterion corresponds well with the MFER 5% criterion [3, 4]. Work performed in [3, 19] revealed that the MFER5 (5%) objective criteria corresponded to a "good/fair" recovery of audiovisual programmes subjectively reported by two observers in [3]. It has been also revealed that an MFER10 (10%) corresponds to annoying recovery [3]. According to [4], MFER5 marks the degradation point of the DVB-H service.

In [9], the performance degradation of OFDM signals due to Doppler spreading in mobile radio applications such as 802.11a and DVB systems is investigated. In [10], a fast prediction method of the coverage area on the uplink of a UMTS network cell is presented by computation of the other cell interferences. The impact on attainable range for a new mobile broadband access element is investigated for systems beyond IMT-2000 in [11, 12]; UMTS cell ranges are calculated based on simulations results. All these papers however do not present actual range calculations for active networks.

In [13], the influence of different MPE-FEC rates and modulation schemes on the performance of a DVB-H network is analyzed for different reception conditions. The percentage of valid reception, MPE-FEC gains, carrier to interference-plus-noise ratios, and minimal signal strengths for the different reception conditions and modulation schemes are presented. The values obtained from this paper can be used for range calculations based on CINR and E (see Section 2.4.2). In [14], an optimal transmission scheme is proposed for a specific network, maximizing the range for a certain throughput requirement, based on technical trial results. Ranges are calculated for one active transmitter (BS2 in our paper), based on the ITU model and a self-developed model. In [15], coverage simulations are presented for antennas with different transmitting powers and at different heights, but with a predefined CINR requirement and with use of CDD. CDD is not used in our network and moreover, in our paper the range is defined as the range for an imaginary transmitter which is a combination of the *three* active transmitters in the network, each with different heights and transmitting powers. This makes a comparison between [14, 15] and this paper difficult or at least unfair.

5. Conclusions

In this paper, a new method to determine the range of DVB-H networks is proposed. A new subjective criterion related to the percentage valid reception is used, based on the viewing experience of the users. The proposed method provides reliable range predictions for which less measurement effort is needed than the classical methods, and it provides the possibility to have different ranges for different terrains. Measurements are performed with a DVB-H tool implemented on a PCMCIA card in a laptop in a suburban environment in Ghent, Belgium, for a DVB-H network operating at 602 MHz and with a bandwidth of 8 MHz. The measurements are executed at a height of 1.5 m inside a vehicle for different modulation schemes and MPE-FEC rates.

Modulation schemes with more MPE-FEC result in higher ranges (up to 600 m): from 5182 m (67/68) to 5795 m (1/2) for the considered system. Lower modulation schemes also have higher ranges (up to 3000 m): from 3473 m (64-QAM 2/3) to 6427 m (QPSK 1/2). The range can increase by up to about 1400 m when changing the inner code rate from 2/3 to 1/2. One has to make a compromise between higher ranges (more MPE-FEC, more inner coding, lower constellations) and the resulting lower data rates. The MFER 5% values ($CINR|_{MFER5\%}$ and $E|_{MFER5\%}$) correspond well with the $CINR_R$ and E_R values. Future research could include the formulation of a mathematical model, of which the results can be compared with those presented in this paper.

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