Mixed-Path Trans-Horizon UHF Measurements for P.1546 Propagation Model Verification

B. A. Witvliet[1,2,3] P. W. Wijninga[1] E. van Maanen[1] B. Smith[1]
M. J. Bentum[2] R. Schiphorst[3] C. H. Slump[3]

***Abstract* – An extensive propagation measurement survey was performed between The Netherlands and the United Kingdom. Seven mixed land/sea paths were monitored simultaneously, with path lengths ranging from 55 to 370 km. Eight frequencies between 500 and 700 MHz were used. Over 21 million measurements were collected during 500 days.**

This paper describes the survey and actions taken to assure high data quality. Detailed results are provided and can be used as propagation model test vectors. These results are compared with predictions of the ITU-R Rec. P.1546-4 propagation model. The results are disappointing: differences of up to 20 dB are found. Suggestions are made for improvement of the model.

1 INTRODUCTION

In 2001, the International Telecommunication Union (ITU) published a new radio propagation model, described in ITU-R Recommendation P.1546. It replaces four older models [1]. The current version of the model is P.1546-4 [2]. The P.1546 model uses a new interpolation method for mixed paths and has modified sea-only curves. The model is based on empirical data from measurement surveys, such as [3,4,5]. For distances below 10 km, it uses the Okumura-Hata formulas [6,7].

The P.1546 propagation model is embodied in a number of international frequency planning agreements. With the model, the percentage of time that distant transmitters may cause interference is calculated. As a consequence, the accuracy of the propagation model directly impacts the available frequency spectrum. In smaller countries, such as The Netherlands, this impact could be substantial.

Likewise, the accuracy of the P.1546 model has an impact on the available spectrum for White Space radio, when the model is used to calculate the TV coverage area to be protected. Flaws in the model would either result in unforeseen interference, or in unused frequency space.

Since the introduction of the new model, several parties have conducted measurements to verify the P.1546 model. Australian studies [8,9,10] showed good performance of the model on 900 MHz land-mobile paths up to 20 km, but underestimation of the median field strength by 10 dB in short range rural scenarios. Long-term propagation measurements between the Channel Islands showed a 10-15 dB underestimation of the median field strength, yet good correspondence with the 10% time values. These studies were done on 600 MHz and 2 GHz, over 50 km sea-only paths [11,12]. Mountainous paths were studied in [13].

Little empirical data is available for long-distance mixed paths: paths covering both land and sea. To fill this gap, an extensive trans-horizon UHF propagation survey was undertaken.

This survey is divided in the following sections: (2) Propagation measurement survey; (3) Measurement set-up; (4) Data screening and calibration; (5) Measurement results; (6) A comparison of the empirical data with P.1546-4 predictions; (7) Conclusions.

2 PROPAGATION MEASUREMENT SURVEY

Three TV towers in The Netherlands were chosen as signal sources. They are located in Wieringen, Lopik and Goes, and host 8 high power UHF transmitters. See Figure 1.

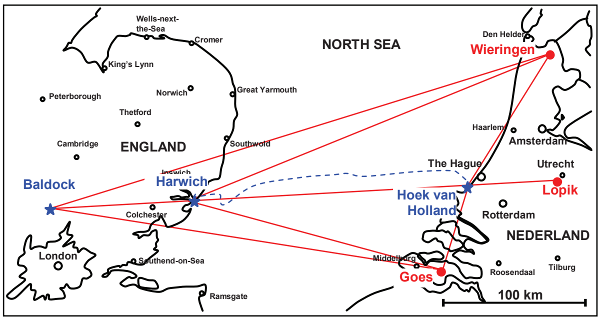

Figure 1: the seven selected propagation paths (blue stars are the receive locations)

Receivers were set-up in Hoek van Holland, Harwich and Baldock, on a straight line from Lopik to the West. Simultaneous measurements were

[1] Radiocommunications Agency Netherlands, Spectrum Management Department, P.O. Box 450, 9700AL Groningen, The Netherlands, email: ben.witvliet@agentschaptelecom.nl, tel: +31 65 124 8341, fax: +31 50 5877 400.

[2] University of Twente, Faculty of Electrical Engineering, Mathematics & Computer Science, Telecommunications Engineering Group, P.O. Box 270, 7500AE Enschede, The Netherlands, email: {m.j.bentum,b.a.witvliet}@utwente.nl, tel: +31 53 489 2108, fax: +31 53 489 5640.

[3] University of Twente, Faculty of Electrical Engineering, Mathematics & Computer Science, Signals and Systems Group, P.O. Box 270, 7500AE Enschede, The Netherlands, email: {r.schiphorst,c.h.slump}@utwente.nl, tel: +31 53 489 2780, fax: +31 53 489 1060.

978-1-4577-0048-4/11/$26.00 ©2011 IEEE

performed on all 8 frequencies on all 3 three locations. This resulted in 7 propagation paths, with a variety of land-sea percentages. Additionally, the Stena Line fast ferry was used to perform 18 path profile measurements between Hoek van Holland and Harwich. The blue dotted line in Figure 1 shows the path of the ferry. Transmitter, receiver and path details can be found in Tables 1, 2 and 3.

	Hoek v Holland		Harwich		Baldock	
Goes	55 km	17% sea	186 km	85% sea	282 km	56% sea
Lopik	64 km	0% sea	258 km	75% sea	356 km	53% sea
Wieringen	121 km	45% sea	277 km	88% sea	367 km	58% sea

Table 1: Path distances and land/sea percentages

	Coordinates		AGL	GL
Wieringen	52° 54' 31" N	005° 03' 30" E	196m	-3m
Lopik	52° 00' 36" N	005° 03' 13" E	363m	2m
Goes	51° 30' 39" N	003° 53' 04" E	137m	0m
Hoek v Holland	51° 59' 03" N	004° 06' 58" E	5m	18m
Harwich	51° 56' 40" N	001° 17' 19" E	18m	0m
Baldock	52° 00' 00" N	000° 07' 45" W	29m	107m

Table 2: Transmitter and receiver coordinates and antenna heights (AGL=Above Ground Level)

	f [MHz]	H v Holland	Harwich	Baldock
Goes 1	535	53 dBW	52 dBW	53 dBW
Goes 2	559	51 dBW	52 dBW	51 dBW
Goes 3	583	51 dBW	52 dBW	52 dBW
Lopik 2	519	59 dBW	59 dBW	59 dBW
Lopik 3	543	59 dBW	59 dBW	59 dBW
Wieringen 1	615	55 dBW	52 dBW	51 dBW
Wieringen 2	663	55 dBW	55 dBW	54 dBW
Wieringen 3	639	55 dBW	54 dBW	53 dBW

Table 3: Luminance carrier frequencies and Effective isotropic Radiated Power

3 MEASUREMENT SET-UP

As the signal had to be measured even during periods of poor propagation, the mean path loss posed a challenge: 170 dB for 250 km, 185 dB for 370 km distance. This challenge was met by using high power analogue TV transmitters, high gain receive antennas and narrowband receivers.

The 7 MHz wide PAL TV-signal has a low average power spectral density, with most power being concentrated in the luminance carrier. Measuring the power of this carrier using a 30 Hz receiver IF filter improves the signal-to-noise ratio by 54 dB. Sub-Hz stability was achieved by locking the R&S FSP3 digital spectrum analyzer to a Quartzlock A10-M Rubidium atomic frequency reference. The analyzer was used in single-frequency mode (zero-span) and was controlled by a LabView program on a laptop.

As the 30 Hz IF filter fails to reproduce all the power contained in the synchronization pulse, a calibration factor was needed. This factor was determined by simultaneous measurement on two receivers with 7 MHz and 30 Hz bandwidth, on a location close to the transmitter.

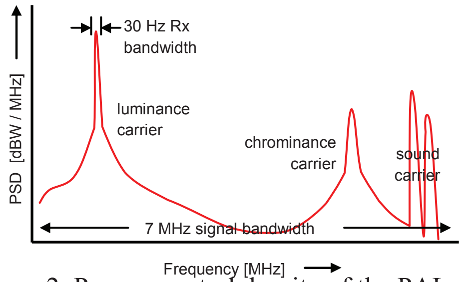

Figure 2. Power spectral density of the PAL-signal

Weak signal reception is quite vulnerable to distant interferers. Luckily, the 30 Hz IF filter provides high selectivity, thereby decreasing the probability of frequency overlap by an interfering carrier. Multiple adjacent 30 Hz bins are stored on each measurement, allowing for transmitter frequency drift (about 30 Hz per month) and interference identification.

4 DATA SCREENING AND CALIBRATION

All measurements were screened thoroughly, using a novel method. First, using data from the Hoek van Holland site, we looked for 'markers' in the transmit signals, such as frequency jumps and short (random) transmitter interruptions. Figure 3 shows an example of such a marker.

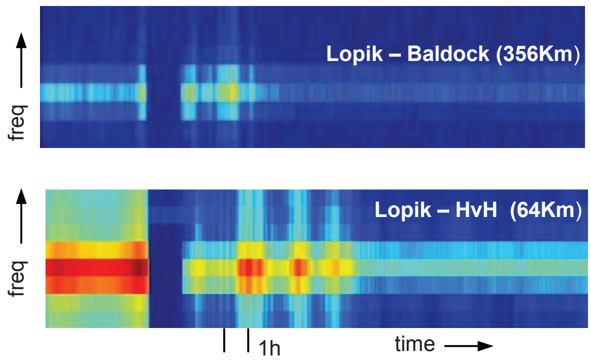

Figure 3. Two simultaneous waterfall displays with a transmitter outage 'marker'.

Subsequently, we looked for the same marker at the same timestamp, but now in the measurement data of the more distant receive sites. Presence of the same marker proves that the right transmitter is observed. Between two markers the slow frequency drift of the transmitter could be followed, as all receive sites had high frequency accuracy. Interferers could then be identified easily in the waterfall display. If they would compromise the intended signal, those measurement samples would be discarded. About 11% of the measurements were discarded, leaving 20.874.000 measurements for further processing.

The measurement values were converted to absolute field strength values. Therefore all measurement equipment was calibrated externally. The loss and mismatch of all other components was measured. From these figures the measurement uncertainty was calculated, in conformance with EA-4/02 [14]. With the uncertainty in EiRP included, the measurement uncertainty was better than 2.3 dB (2σ).

5 MEASUREMENT RESULTS

From every radio path or path section a histogram has been made, by sorting the measurements in 0.25 dB bins and counting their occurrence. For the 56 km path the histogram approaches log-normal distribution, as can be seen in Figure 4.

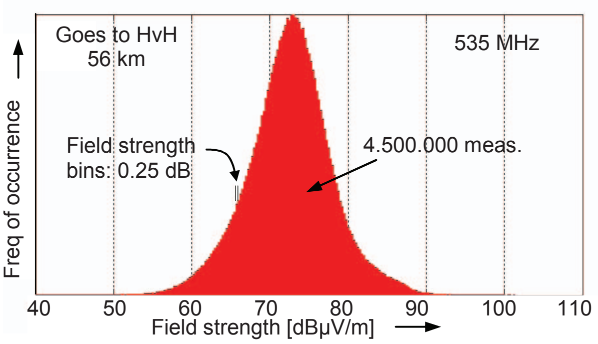

Figure 4. Histogram for the 56 km path.

For the longer distances, the histograms have a long upward tail, caused by signal enhancement during tropospheric propagation events. (See Figure 5 for an example.)

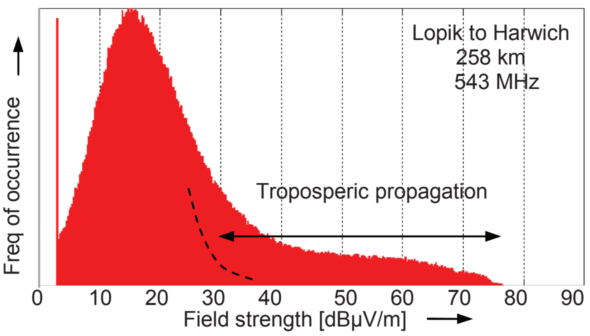

Figure 5. Histogram for a 258 km path.

The field strength values which are exceeded 50%, 10% or 1% of the total time are summarized in Table 4. Where the signal was too weak for an accurate measurement or where a strong interferer was present (Baldock) the corresponding values are omitted.

	Hoek v Holland			Harwich			Baldock		
	50%	10%	1%	50%	10%	1%	50%	10%	1%
Goes 1	73	79	87	28	61	76		18	44
Goes 2	73	80	85	27	62	76			40
Goes 3	73	81	87	25	60	76			34
Lopik 2	90	92	95	19	46	68		21	45
Lopik 3	88	91	93	20	47	69		21	44
Wieringen 1	46	69	84		32	57		22	47
Wieringen 2	41	68	83		38	60			
Wieringen 3	41	67	82		32	57			

Table 4. Measured field strength [dBμV/m].

6 COMPARING EMPIRICAL DATA WITH THE P.1546 PROPAGATION MODEL

Next step was the comparison of the acquired empirical data with the predictions using the ITU-R Rec. P.1546-4 propagation model. For that purpose, the field strength was calculated, using the detailed information of the transmitters and of the receiver locations. Percentages sea were determined using a detailed map. The terrain height profile near Baldock was derived from the height data set "DTM 50m-NL +Western Europe". The predicted field strengths are given in Table 5.

	Hoek v Holland			Harwich			Baldock		
	50%	10%	1%	50%	10%	1%	50%	10%	1%
Goes 1	68	70	76	30	48	65	20	33	44
Goes 2	66	68	74	29	47	64	19	31	43
Goes 3	66	68	74	29	48	64	20	32	44
Lopik 2	77	79	84	30	46	61	22	34	46
Lopik 3	77	79	84	30	46	61	22	34	46
Wieringen 1	47	56	63	18	37	58	10	23	36
Wieringen 2	47	56	63	21	40	61	13	26	38
Wieringen 3	47	56	63	20	39	60	12	25	38

Table 5. P.1546-4 predicted field strength [dBμV/m].

The difference between the predictions and the empirical data can be found in Table 6. Positive values indicate that P.1546-4 predicts a field strength that is higher than the measured value.

	Hoek v Holland			Harwich			Baldock		
	50%	10%	1%	50%	10%	1%	50%	10%	1%
Goes 1	-5	-9	-11	3	-13	-11		15	0
Goes 2	-7	-12	-12	2	-14	-12			3
Goes 3	-7	-13	-13	5	-12	-12			10
Lopik 2	-13	-14	-11	12	0	-7		13	1
Lopik 3	-11	-12	-9	11	-1	-9		13	2
Wieringen 1	1	-13	-21		5	1		1	-11
Wieringen 2	6	-12	-20		2	1			
Wieringen 3	6	-11	-19		7	3			

Table 6. Ratio of P.1546-4 predictions to the measured field strength [dB].

The P.1546-4 predictions correlate poorly with the empirical data: differences of up to 20 dB occur. At distances of 50-70 km, the median field strength is underestimated, as in [9,11]. As in [11], we see an unbalance in the model performance for the median values and the lower percentiles, although the pattern is dissimilar.

As will be shown below, P.1546-4 performs worse than its predecessor P.370-7 [15]. This could be explained by the flat terrain in The Netherlands. P.1546 uses the land-only curves that were used in P.370-7 for a terrain roughness of 50 meters. Calculations show that introducing the Δh correction of P.370-7 in P.1546 would reduce the peak prediction errors by 5 to 8 dB.

Approximately the same improvement could be achieved by reintroducing the TCA correction factor at the receiver that was used in P.370-7 and P.1546-1. The RMS Deviation (RMSD) of the four models show this improvement. See Table 7.

	RMSD
P.370-7	8,2 dB
P.1546-4	10,0 dB
P.1546-4 mod dh	8,4 dB
P.1546-4 mod TCA	8,7 dB

Table 7. Comparison of RMS Deviation

However, these modifications do not correct the unbalance between the error in the median value and the lower percentile estimates. The ratio between the median and the lower percentiles is embedded in the curves in P.1546. An investigation into the changed sea-only curves is needed to solve this.

7 CONCLUSIONS

The calculations using the P.1546-4 model correspond poorly with the collected measurements: random errors of up to 20 dB occur.

The peak prediction errors can be reduced by 5 to 8 dB by reinstating the TCA correction of P1546-1. Alternatively, the Δh correction factor from P.370-7 could be introduced in the P.1546 model.

Even with these changes, the overall prediction accuracy of the new propagation model remains below expectations. The ratio between the median and the lower percentiles shows an unbalance. To improve this, further study into the sea-only curves is needed.

Acknowledgments

Thanks go to Tony O'Neill of the High Lighthouse in Harwich, Ron Stanley and John Sullivan of the Ofcom RF monitoring station at Baldock, and Bob Brouwer of Stena Line for their assistance and hospitality.

References

[1] "Approval of 1 new and suppression of 4 existing ITU-R Recommendations of Radiocommunication Study Group 3", ITU-R, CACE/233, 2001.

[2] "Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz", ITU-R Rec. P.1546-4, ITU, 2009.

[3] J.W. Stark, "Simultaneous Long Distance Tropospheric Propagation Measurements at 560 Mc/s and 774 Mc/s over the North Sea", Radio and Electronic Engineer, 1965.

[4] E. Sofaer, J.W. Stark, "Tropospheric radio-wave propagation over mixed land and sea paths", Proc. of the IEE, 1966.

[5] U. Kühn, and S. Ogulewics, "Propagation measurements at 500MHz over sea for varying meteorological parameters", Proc. of the IEE, 1970.

[6] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, "Field Strength and Its Variability in VHF and UHF Land-Mobile Radio Service," Review of the Electrical Communication Laboratory, 1968.

[7] M. Hata, "Empirical Formula for Propagation Loss in Land Mobile Radio Services," IEEE TVT 1980.

[8] E. Östlin, H.M. Zepernick, and H. Suzuki, "Evaluation of the New Semi-Terrain Based Propagation Model Recommendation ITU-R P. 1546", VTC 2003.

[9] E. Östlin, H. Suzuki, and H.-J. Zepernick, "Comparison and Evaluation of ITU-R Recommendation P.1546 Versions", VTC 2006.

[10] E. Östlin, H. Suzuki, and H.-J. Zepernick, "Evaluation of the Propagation Model Recommendation ITU-R P.1546 for Mobile Services in Rural Australia", VTC 2008.

[11] D.R. Siddle, E.M. Warrington, and S.D. Gunashekar, "Transhorizon Propagation over the Sea: Observations and Predictions", EuCAP 2006.

[12] S.D. Gunashekar, D.R. Siddle, E.M. Warrington, "Important Aspects of Transhorizon Propagation at 2 GHz over the English Channel", EuCAP 2006.

[13] M. Liniger, M. Marghitola, M. Rohner, M.A.N. da Silva, E. Costa, "Wave propagation models - Comparison of prediction results with measurements", ICIT 2006.

[14] "Expression of Uncertainty in Measurement Calibration", EA-4/02, European Cooperation for Accreditation, 1999.

[15] "VHF and UHF propagation curves for the frequency range from 30 MHz to 1 000 MHz - Broadcasting services", ITU-R Rec. P.370-7, ITU, 1951-1995.