Comparison of Microwave Links Prediction Methods: Barnett-Vigants vs. ITU Models

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Abstract— Hydro-Québec operates one of the widest electricity networks in the world. The microwave network infrastructure is essential to manage the power grid in Québec and therefore, it is important to meet the reliability criteria that are generally above those accepted by traditional communication operators. In addition, over one third of the existing links has lengths between 70 km and 90 km and operates in extreme weather conditions and all year long. To address these constraints, the microwave links design needs to be as much accurate as possible. The aim of the research presented in this paper is to make a comparative study between two commonly used prediction models for microwave links: Barnett-Vigants and ITU-R P. 530. The first part of this work considers each of the following aspects (unavailability, diversity gain and conversion methods). We analyse each aspect as a function of frequency, fading margin and link length. The two models led to significantly different results for the unavailability due to multipath as a function of the link length, and also for the space diversity as a function of the gain difference between the main antenna and the diversity antenna. Remarkable differences between the two models were also observed when studying the unavailability due to rain as a function of the frequency. The second part of this work compares the overall performance of both models in terms of the total outage probability over ten links with different lengths and different locations. The differences observed for some links are significant.

1. INTRODUCTION

The microwave links deployment, like any other wireless network, requires accurate prediction methods in order to minimize the discrepancies between simulation results and real system performance. Although numerous microwave links are deployed around the world, most of them can be considered as short-range or mean-range links for which the path length is less than 20 km. Hydro-Québec operates one of the widest electricity networks in the world. The microwave network infrastructure is essential to manage the power grid in Québec and therefore, it is important to meet the reliability criteria that are generally above those accepted by traditional communication operators. In addition, over one third of the existing links has lengths between 70 km and 90 km and operates in extreme weather conditions and all year long. To address these constraints, the microwave links design needs to be as much accurate as possible. The aim of the research presented in this paper is to make a comparative study between two commonly used prediction models for microwave links: Barnett-Vigants (B-V) and ITU-R P. 530 [1].

This paper is divided in two parts. The first part analyses some main aspects (such as unavailability, diversity methods and conversion methods) as a function of various parameters, frequency, fading margin and link length. The second part compares the overall performance of both models in terms of the total outage probability over some typical links. Due to space limitation and to reduce the number of figures, we will present only some figures which illustrated significant differences between B-V model and ITU model.

2. BARNETT-VIGANTS VS. ITU: STEP BY STEP COMPARISON

The two models are compared on a step by step basis to illustrate the effect of a given parameter or the combined effect of few parameters. Four main aspects will be analysed: unavailability due to multipath, diversity method with focus on space diversity, worst month to annual conversion methods, and unavailability due to rain.

2.1. Unavailability due to Multipath

The unavailability due to multipath is a key indicator in microwave links design. Indeed, it indicates the outage probability if any engineering techniques (diversity and other engineering techniques) is used to mitigate the propagation effects. The two options for calculating the unavailability in B-V model are respectively "Baseband switching systems" and "IF combining systems". The common parameters of the two models are flat fade margin ($FFM = A$), frequency (f) and distance (d). One additional parameter is used in B-V model, C factor, while three additional parameters are used in ITU model, geoclimatic K factor, link inclination $|\varepsilon_p|$, and the lowest antenna altitude (above sea level) h_L. The outage probability is expressed in percentage (%) as follows [2, 3].

B-V model:

$$P_w = \left(\left[6 \cdot 10^{-7} C f d^{3.0}\right] 10^{-A/10}\right) \times 100 \tag{1}$$

ITU model:

$$P_w = K d^{3.0} \left(1 + |\varepsilon_p|\right)^{-1.2} \times 10^{0.033f - 0.001h_L - A/10} \tag{2}$$

For comparison purposes, real parameters of an existing link are used: $d = 70\,\mathrm{km}$, $f = 7.425\,\mathrm{GHz}$; $FFM = 37\,\mathrm{dB}$; $C = 1$; $K = 1.84E - 4$; $|\varepsilon_p| = 0.3\,\mathrm{mrad}$ and $h_L = 150\,\mathrm{m}$ [4]. Link length and frequency are the two parameters which led to significant difference on worst month unavailability due to multipath. In fact, it is obvious that the unavailability increases as the distance increases.

But using the above parameters which represent the real case configuration of a given link, B-V model overestimates worst month unavailability for link length greater than 25 km as illustrated on the Figure 1 (d varying from 5 km to 90 km).

The same observation is valid for any operating frequency used between 7 GHz and 12 GHz. The simulation of Figure 2 is done with $d = 70\,\mathrm{km}$.

A major drawback of B-V model is the choice of C factor which is somewhat subjective. ITU-R P. 530 model is more appropriate to design detailed links. Indeed, there is flexibility to adjust optimally K factor value in contrast to C factor value which is solely based on generic tables or maps.

2.2. Diversity Methods

The frequency diversity calculation for the two models is significantly identical. Only the space diversity gain, I_{sd} is studied first as a function of the gain difference between main and diversity antennas in the receiver side, and second as a function of these two antennas separation. Figures 3 and 4 show that B-V model is also overestimated regardless the system used, "baseband switching" and "IF combining" [5].

B-V baseband switching systems

$$I_{sd} = 1.2 \cdot 10^{-3} \cdot \frac{f}{d} S^2 v^2 10^{A/10} \tag{3}$$

B-V IF combining systems

$$I_{sd} = 1.2 \cdot 10^{-3} \cdot \frac{f}{d} S^2 \frac{16 \cdot v^2}{(1+v)^4} 10^{A/10} \tag{4}$$

where, S is the main and diversity antennas separation; $v \leq 1$ and $v_{\mathrm{dB}} \leq 0$.

Typically the gain difference is $v_{\mathrm{dB}} = -|G_1 - G_2|$.

ITU-R P. 530-12

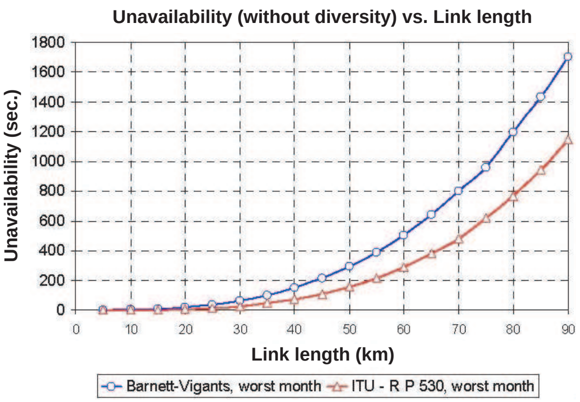

Figure 1: Worst month unavailability due to multipath as function of link length.

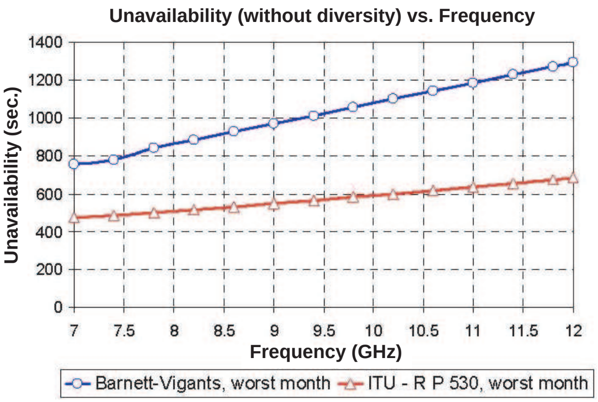

Figure 2: Worst month unavailability due to multipath as function of the operating frequency.

The diversity improvement is calculated differently for non selective and selective fading using radio signature method [2, 6]. The non selective outage probability with space diversity employs a basic formula given by $I_{sd} = I$:

$$I = \left[1 - \exp\left(-0.04 \times S^{0.87} f^{-0.12} d^{0.48} p_0^{-0.104}\right)\right] 10^{\left(\frac{A-|G_1-G_2|}{10}\right)} \tag{5}$$

where, p_0 is the occurrence factor of multipath propagation.

If there is no propagation problem along the diversity path, it is recommendable to ensure that the gain difference is as small as possible, ideally $|G_1 - G_2| = 0\,\mathrm{dB}$. Although the unavailability based on B-V model is higher compared to the ITU model, all the curves of Figures 3 and 4 follow the same trend. It is also noticeable that the space diversity gain increases very quickly in the B-V model while its variation is slow in the ITU model.

2.3. Conversion Methods for the Multipath Unavailability

For the unavailability due to multipath, the worst month value P_w is calculated first and then is converted to annual value P_{an} using one of the two following methods: mean annual temperature method (generally used in B-V model) and the conversion procedure described in ITU-R P. 530-12 [2, 7]. To show how the conversion method influences the annual value, we consider a typical link with the parameters defined previously. The following simulations are performed:

- Worst month unavailability is calculated by B-V model then converted to annual value using each of the two conversion methods.
- Worst month unavailability is calculated by the ITU model and converted into annual value also using each of the two conversion methods.

The simulation results are summarized in Table 1.

Depending on the conversion method, the annual unavailability values are completely different. But it seems to be more suitable to use ITU method because the formulation is only based on objective parameters such as length, inclination and latitude.

Table 1: Annual mean temperature method vs. ITU-R P. 530-12 method.

		Annual mean temperature	ITU-R P. 530 method
	Worst month unavailability	*Annual unavailability*	*Annual unavailability*
Barnett-Vigants	14.2 min.	30.7 min.	42.8 min.
ITU-R P. 530	13.9 min.	29.6 min.	42.07 min.

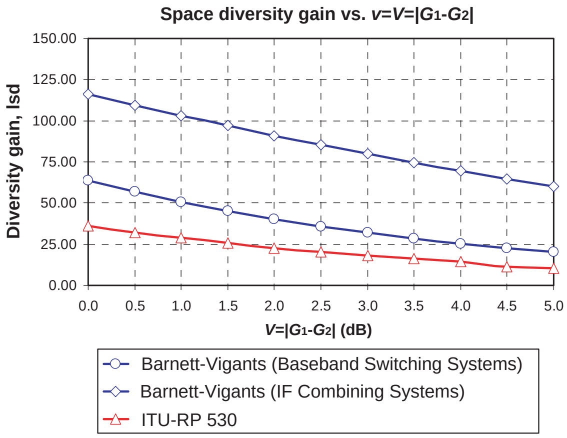

Figure 3: Space diversity gain as function of the gain difference between main and diversity antennas.

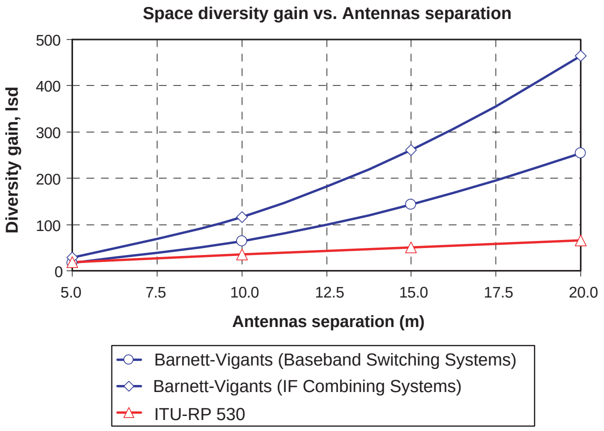

Figure 4: Space diversity gain as function of the main and diversity antennas separation.

2.4. Unavailability due to Rain

The commonly used method in B-V model to calculate the unavailability due to rain is the Crane method [8, 9]. The same calculation is made in ITU-R P. 530 model using the method described in ITU-R P. 838 recommendation [2, 10]. The rain regression coefficients (k and α defined as function of the frequency and the polarization) are essential. Although the two methods are different, the same coefficients are used.

For a given frequency (7.425 GHz), the annual unavailability due to rain increases with the link length. Figure 5 shows that:

- The vertical polarization is better than horizontal polarization for each method.
- For the link length more than 60 km, ITU method, especially in horizontal polarization will reduce the unavailability due to rain about ten seconds.

The unavailability due to rain is largely dependent on the operating frequency. Figure 6 shows that:

- The vertical polarization is better than the horizontal polarization for each method.
- Below 8 GHz and for horizontal polarization, the unavailability due to rain based on the ITU method is lower than the Crane method. Inversely, above 8 GHz, ITU method leads to much higher unavailability. Recall that this observation is valid for 50 km link length.

3. BARNETT-VIGANTS VS. ITU: OVERALL PERFORMANCE COMPARISON

We now present some main results using comparison table. Some main parameters used for simulation are summarized in Table 2. It is important to note that the ITU model includes radio signature method. In this case, we calculate separately the non-selective outage probability P_{ns}

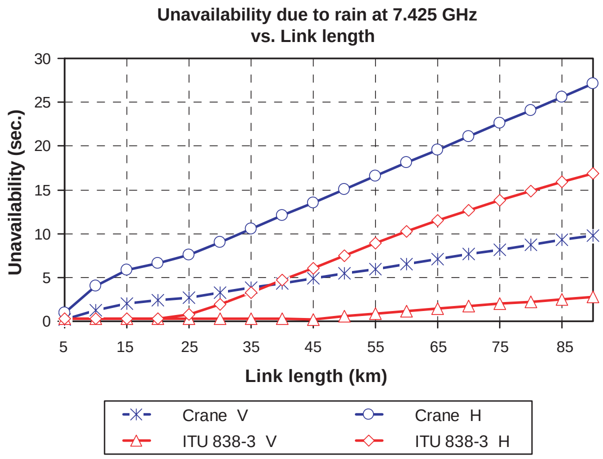

Figure 5: Annual unavailability due to rain as function of the link length.

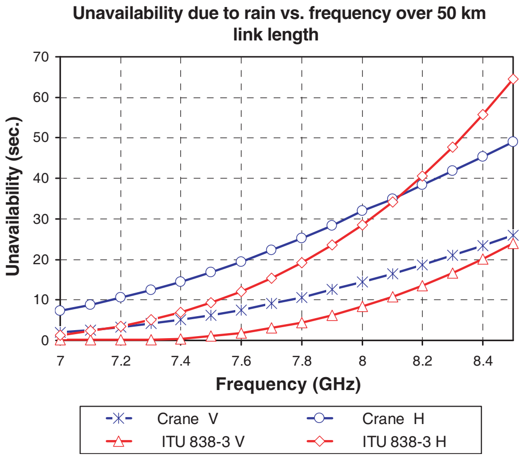

Figure 6: Annual unavailability due to rain as function of the operating frequency.

Table 2: Main parameters used for simulation.

Link	Link length (km)	Flat Fade Margin (dB)	Barnett-Vigants, C factor	ITU-R P. 530, K factor
1	70.00	41.52	0.25	1.24E-04
2	40.10	41.75	1.00	9.70E-05
3	22.30	40.66	3.29	1.55E-04
4	38.70	40.04	3.16	1.48E-04
5	60.30	43.63	0.25	1.11E-04
6	12.70	39.63	0.25	9.60E-05
7	82.30	45.93	0.52	1.41E-04
8	61.30	32.57	0.52	8.30E-05
9	70.10	41.19	0.25	1.06E-04

Table 3: Total bidirectional annual unavailability.

Link	Bidirectional annual unavailability with space and frequency diversity (sec.)		
	Barnett-Vigants, (Pathloss 4.0)	ITU-R P. 530-12 (MWLinkSim 1.0)	ITU improvement %
1	8.77	2.54	71.0%
2	5.15	0.81	84.3%
3*	6.42	6.64	−3.4%
4*	17.47	2.26	87.1%
5	2.20	0.57	74.1%
6	7.00	0.28	96.0%
7	1.28	3.12	−143.8%
8	352.39	43.58	87.6%
9	1.70	0.29	82.9%
The mean improvement % of ITU model over Barnett-Vigants model			48.4%

*ITU method is used without signature parameters

and the selective outage probability P_s. Then the two values are added together to obtain the total outage. The obtained results are also summarized in Table 3.

The analysis of overall performance in terms of worst month unavailability over the nine links shows clearly that the B-V model is oversized compared to the ITU model. This analysis confirms the results of step by step study made previously. The gain when the ITU model is used is rated at 50%.

4. CONCLUSION

The unavailability due to multipath and the unavailability due to rain are the two main phenomena we have studied in this paper. The results can be summarized as follows. The unavailability due to multipath is lower in the ITU model. In addition, the calculation procedure proposed by Recommendation ITU-R P. 530 provides extensive information on the criticality of the link and shows how some parameters affect microwave link design. For rain, the ITU model seems less severe for operating frequencies below 8 GHz while it is much more severe for frequencies above 8 GHz. In addition, the ITU model offers the possibility to take into account the combined effect of rain and wet snow (a phenomenon which may be interesting to consider in Quebec). The ongoing work is focused on in-situ measurements which will be compared to simulation results.

REFERENCES

1. Anderson, H. R., *Fixed Broadband Wireless System Design*, John Wiley & Sons, 2003.
2. International Telecommunication Union, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems," ITU-R P. 530-12, 2005.
3. Barnett, W. T., "Multipath propagation at 4, 6 and 11 GHz," *Bell System Technical Journal*, Vol. 51, No. 2, 311–361, Feb. 1972.
4. Agba, B. L., "Comparaison des modèles de propagation pour les liaisons hertziennes," IREQ-2008-0180 report, 2008.
5. Vigants, A., "Space-diversity engineering," *Bell System Technical Journal*, Vol. 54, No. 1, 103–142, Jan. 1975.
6. International Telecommunication Union, "Effects of multipath propagation on the design and operation of line-of-sight digital fixed wireless systems," ITU-R F-1093-2, 2006.
7. International Telecommunication Union, "Conversion of annual statistics to worst-month statistics," ITU-R P. 841-4, 2005.
8. Crane, R. K., "Prediction of attenuation by rain," *IEEE Transactions on Communications*, Vol. 28, No. 9, 1717–1732, Sep. 1980.
9. Crane, R. K., *Electromagnetic Wave Propagation through Rain*, John Wiley & Sons, New York, 1996.
10. International Telecommunication Union, "Specific attenuation model for rain for use in prediction methods," ITU-R P. 838-3, 2005.