International Journal of Engineering Research
Volume No.5, Issue No.11, pp : 856-861

ISSN:2319-6890)(online),2347-5013(print)
1 Nov. 2016

Microwave Radio Frequency Optimization and Link Performance

Sawadogo Moumouni[1,3], Zougmoré François[1], Doumounia Ali[1] , Sanou Serge Roland[1,2], Kébré B. Marcel[1],

[1]Laboratoire de Matériaux et Environnement (LAME), UFR-SEA, Université Ouaga 1 Pr Joseph Ki-Zerbo, Ouagadougou, Burkina Faso
[2]Autorité de Régulation des Communications Electroniques et des Postes (ARCEP), Ouagadougou, Burkina
[3]Telecel Faso: Mobile phone operator company, Ouagadougou, Burkina-Faso
sawadogomouni@hotmail.fr

Abstract— this paper presents an optimization methodology for fixed service microwave link. To obtain high throughput on the microwave link, the possibility to use wideband channel and low modulation or the reverse are possible. We present a methodology to obtain high speed and best performance for microwave links based on modulation and frequency channel choice. In the first time we present a microwave design parameters, the performances of an Additive White Gaussian Noise channel (AWGN) and we propose a methodology for the ITU-RF adjacent channels arrangement optimization to obtain a high speed transmission with a best fade margin (99.9998% of annual availability) . In the second time, we present an experimental design using a microwave link design tool and measurements on physical link.

Keywords— optimization, frequency, performance, microwave, high speed

I. INTRODUCTION

Mobile radio communication technology has evolved considerably. Broadband (3G, 4G and 5G in the future) join residential access networks xDSL (x-Digital Subscriber Line) and FTTH (Fibber to the Home) for high-speed Internet access. Customers increasingly need more bandwidth with high quality of service regarding the growth of ICT services and applications quality. Given the rapid evolution of mobile broadband penetration around the world each mobile base station capabilities on number of subscriber and traffic must grow. Thus, mobile companies use microwave or optical links which have high speed capacity and best availability for interconnecting radio access network to base station controller.

Nowadays, modern microwave technology provides an efficient complement to copper and optical fiber in the access network and some of attractive are: easy to install and operate, low cost, efficiency, multi-service capability (pseudowire, Carrier Ethernet on L2/L3), operate in fixed and adaptive coding and Modulation (QPSK, m-QAM, m=16, 32, 64, 128, 256, 512, 1024, 2048), high throughput (upper than 384 Mbps by channel) on long -distance (up to 180 km by hop) and the Gigabit capacity is achievable today with XPIC mechanism [1][2][10].

The spectrum allocation is approved by ITU administrations at the World Radiocommunication Conferences held periodically each four (04) years. At Each edition of the World Radiocommunication Conference, professional organizations of frequencies users (GSMA, ITSO,..) accompany ITU member states in the preparation and make speech to keep the spectrum already allocated or acquire additional spectrum for the development of their services. At the last 2015 conference, the pressure was enormous around the frequencies used by microwaves and satellites services (7, 8, 13,… GHz). So, what strategy to enable microwave technology development of on the one hand and mobile broadband on the other hand? How to rationally use the spectrum band already allocated to terrestrial fixed links and achieve the objectives in increasing broadband services? In sum success of a microwave backhaul project depends on the availability of suitable frequencies. Our goals in this work is to propose an optimization approch to the use of radio frequencies by LOS digital microwave links based on the performances requirements: BER (Bite Error Rate), link availibility, fade margin, capacity desired. Data modulation and frequency bandwith are the key parameters for the proposed methods.

II. MATERIAL AND METHODOLOGY

A. The Microwave link design parameters

The Microwave link design is a conceptual approach and need a consideration of the following criteria: Performance, Reliability, Scalability, Security, Capex reduction and OPEX optimization. The prediction of the performance and the reliability are unavoidable and the main

doi : 10.17950/ijer/v5s11/1105

parameters must be evaluated during the microwave link design:

1. Loss attenuation
2. Fade margin
3. Bit error rate
4. Availability calculations

1) Loss attenuation

Loss attenuation is related to propagation losses caused by the Free-Space Loss, vegetation attenuation, gas absorption, attenuation due to precipitation and obstacle loss. The rain attenuation is considered for frequencies higher than 7 GHz [3] [13]. The Free-space loss is always present, and it is dependent on distance and frequency. Free space losses may be written as the equation [4] :

$$FSL(dB) = 92.45 + 20.\log_{10}\left(f_{GHz}\right) + 20.\log_{10}\left(d_{Km}\right) \qquad (1)$$

Where: f = frequency (GHz), d = line-of-sight (LOS) range between antennas (km).

The FSL increases with the high frequencies. It is therefore advisable to use the high frequencies for short distances and low frequencies for the long distances. In our work, we are going to use 7GHz band.

2) Fade Margin

The fade margin to be achieved should match the availability and performance objectives set with Barnett W. T. model, the Morita Model or ITU model [5]. The difference between the nominal receive level and the receiver threshold level is available as a safety margin against fading [4].

$$FM(dB) = RSL - Rx\_Threshold \qquad (2)$$

Where FM =Fade margin (dB), RSL =Received signal level (dBm), $Rx\_Threshold$ =Received threshold level (dBm). The receiver threshold is the minimum signal required for the demodulator to work at a specific error rate.

3) Bit error rate

The Bit Error Rate (BER) is the measuring parameter the best known of the quality of a digital transmission, and represents the ratio between the number of erroneous bits and the total number of bits transmitted. The determination of the BER is based on the following definition [7]:

$$BER = \frac{\text{Number\_of\_erroneous\_Bits}}{\text{Number\_of\_Transmitted\_Bits}} \qquad (3)$$

The standard end-to-end error performance parameters and objectives are defined by ITU-R in [6] for a 27 500 km HRP (Hypothetical Reference Path). The target BER in our work is lower than 10^{-6}.

4) Availability calculations

Three models are commonly used to predict the worst month link unavailability in the terrestrial microwave link: The ITU model, Barnett-Vigants model and Morita Model used respectively in worldwide Rec. ITU, North America, and in the Japan. We present the ITU model and the Barnett-Vigants model in this paper.

The percentage of time P_w that fade depth *A* (dB) is exceeded in the average worst month from (Rec. ITU-R P.530-16):

$$P_w(\%) = Kd^{3.4}\left(1+\left|\varepsilon_p\right|\right)^{-1.03} f^{0.8} \times 10^{-0.00076 h_L - A/10} \qquad (4)$$

Where:

f : Frequency (GHz), d (km) is the path length , A(dB) is the effective fade-out margin (or flat margin if signatures are used), K is the geo-climatic factor for the worst month , $\left|\varepsilon_p\right|(mrad) = \frac{\left|h_e - h_p\right|}{d}$ is the magnitude of the path inclination, h_e and h_r the antenna heights above sea level), *hL*: altitude of the lower antenna (i.e. the smaller of *he* and *hr*).

The probability of a fade of depth *A* using the Vigants–Barnett model is given by [18]:

$$P_w = \left(\left[6.0\times10^{-7} Cfd^3\right] 10^{\frac{-A}{10}}\right)\times100 \qquad (5)$$

Where:

P_w = probability of a fade as a fraction of time, *d* = Path length in kilometers, *f*= Frequency in gigahertz, *C* = propagation conditions factor, *A* = fade depth in decibel. This equation is only valid for fade depths of 15 dB or more.

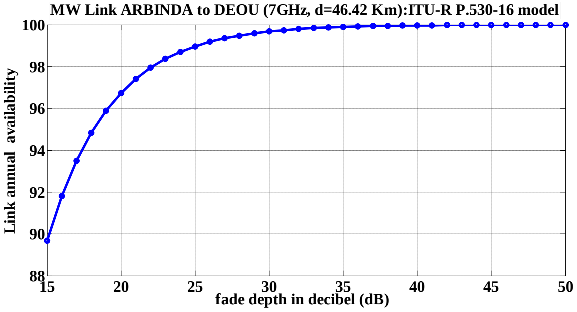

Figure 1: ITU Model for MW link 7GHz, 46.42 km

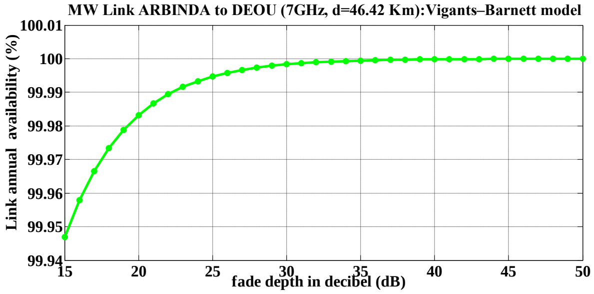

Figure 2: Vigants–Barnett model for MW link 7GHz, 46.42 km

With the figure 1 and 2, at 20 dB we have an availability less than 98 % for the ITU Model and upper 99.98% for the Vigants–Barnett model. When the availability goal of ITU-R is achieved, the Vigants–Barnett model availability is achieved. The reciprocal is false. The ITU model is very rigorous for the microwave link design and we use this model for the rest in this work.

B. Throughput, Modulation, and frequency spectrum optimization

The digital microwave link can be characterized by four intrinsically linked factors

1. The first factor is the throughput
2. The second factor is the energy dedicated to this communication.
3. The third factor is the link reliability
4. The fourth factor is the bandwidth usage for the communication.

These four factors are called communication rectangle. If the energy dedicated to the communication is invariable, we have the possibility to increase the link throughput or reliability by the bandwidth augmentation or the reduction of the channel bandwidth with the high modulation choice. Our approach is to find a best compromise with the bandwidth and modulation choice to obtain a best throughput and reliability with the optimization of the use of ITU frequency channels defined in [12].

For a noiseless channel, the Nyquist bit rate (1928) formula defines the theoretical maximum bit rate $R\max$:

$$R_{\max}(Mbps) = 2\times W\times\log_2(M) \tag{6}$$

Where W =bandwidth (MHz), M is the number of bit per symbol. This theoretical bite rate is limited in the practice by the noise on the propagation channel.

For AWGN channel, the Shannon capacity is normalized with respect to the bandwidth and expressed in bps, that is, normalized with respect to the bandwidth, is [8]:

$$C(bits/s) = W(1+SNR) \tag{7}$$

Where W(Hz) is the system bandwidth and SNR is the receive signal to noise ratio, defined $\rho = E_b/N_0$, where E_b is the energy per bit [8].

The link spectrum efficiency increase with the modulation but it is limited by the M-QAM BER. The M-QAM error when using Gray coding is [9]:

$$P_b \frac{4\left(\sqrt{M}-1\right)}{\sqrt{M}} Q\left(\frac{3}{M-1}\times\frac{E_b}{N_0}\right) \tag{8}$$

Where Q is the Q-function defined by:

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^{+\infty} e^{\frac{-x}{2}} \tag{9}$$

The figure 3 below illustrates the BER for AGWN for 4-QAM, 16-QAM, 64-QAM and 256-QAM.

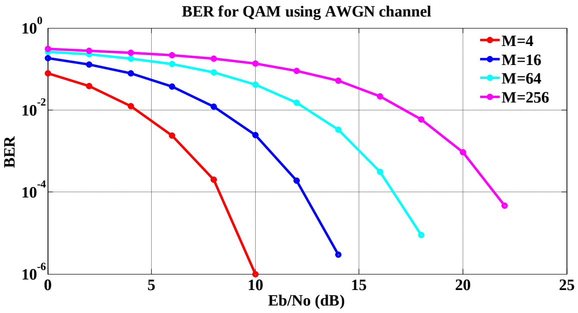

Figure 3: BER for M-QAM using AGWN Channel

For the same invariable channel width, the link capacity increases with the level of modulation. However, when the modulation level increases, the BER increases. For the same bit rate, we can increase the channel width and decrease the level of modulation to have a best performance of the link. Otherwise the spectral resources are very scarce and we propose a method of ITU-RF frequency arrangements optimization without inter-channel cosystem interference.

C. Frequency spectrum optimization

The main parameters affecting the choice of radio-frequency channel arrangements are **XS**, **YS, ZS** and **DS** developed and defined in [12]. Also, the choice of radio-frequency channel arrangement depends on the values of cross-polar discrimination (**XPD**) and on the net filter discrimination (**NFD**) where these parameters are defined in [12]. With the development of wireless technologies which can go up to 2048-QAM modulation or with the OFDM modulation, we can optimize the use of ITU-RF channels:

1. by reducing of the channel width and increasing the modulation level
2. by the aggregation of the adjacent channels to obtain a wide canal and the reduction of modultion level to increase the performance of the link.

The methodology of the frequencies optimization is described below:

- Let $F_1, F_2,..., F_n$ the ITU-RF low frequency channels, $F_1^{'}, F_2^{'},..., F_n^{'}$ the ITU-RF high frequency, $L=\frac{XS}{2}$ is the each channel width, DS the Tx/Rx duplex spacing
- Let $T_1, T_2,..., T_m$ the targets low frequency channels, $T_1^{'}, T_2^{'},..., T_m^{'}$ the targets high frequency

doi : 10.17950/ijer/v5s11/1105

channels, $L^{'}$ the channel width of each target channel with $L^{'} = \frac{XS^{'}}{2} \succ L = \frac{XS}{2}$, $DS^{'} = DS$ the $T_x^{'} / R_x^{'}$ duplex spacing

- Let $\Delta L = n \times L - m \times L^{'}$ when $\Delta L \prec L^{'}$
  n is the number of ITU adjacent channels, m the number of target channels.

If $\Delta L \prec 0$ the targets frequency channels can be create inter-channel cosystem interference and the method is not applicable. If $\Delta L \geq 0$, the method is applicable and we have the following results:

$$T_1 = F_1 - \frac{L}{2} + \frac{L^{'}}{2} \tag{10}$$

$$T_m = T_{m-1} + L^{'} = T_1 + (m-1) \times L^{'} \text{ for } m \geq 2, \tag{11}$$

For k=1… m:

$$T_k^{'} = T_k + DS \tag{12}$$

If $\Delta L \succ 0$, $\exists$ one supplementary usable channel T_{m+1} with

$$T_{m+1} = T_m + \frac{L^{'}}{2} + \frac{\Delta L}{2} \tag{13}$$

$$T_{m+1}^{'} = T_{m+1} + DS \tag{14}$$

D. Experimental method

This experimental method is realized with a microwave link newly installed without traffic. The hop length is 21.56 km between 2 sites Zabré and Youga in Eastern Region of Burkina-Faso and the operating frequency is 7 GHz. The experimental link is illustrated by figure 4. The objectives are: $BBER \prec 10^{-6}$, the annual availability 99.9998%. The link annual availability evaluated using the equation (4) with the following parameters: h_e=309.31 m, h_r=311.86 m, d=25.1 km, $|\varepsilon_P|$= 0.118274583 mrad, K=0.000173, A= 30 dB. The tools used are:

1. Pathloss 5 for the link design, the ITU rain region is K.
2. Two IDUs (microwave indoor unit) and two RACs (radio access card supporting the QPSK to 256 QAM modulation)
3. Two ODU with Tx power equal 22.5 dBm
4. IF cable
5. Two antennas VHLP3 single pole with gain equal 33.5 dBi
6. Link polarization: vertical without protection
7. Power : -48 V-DC
8. Tower type at Zabré: self-supporting (60 m)
9. Tower type at Youga: guyed (100 m)

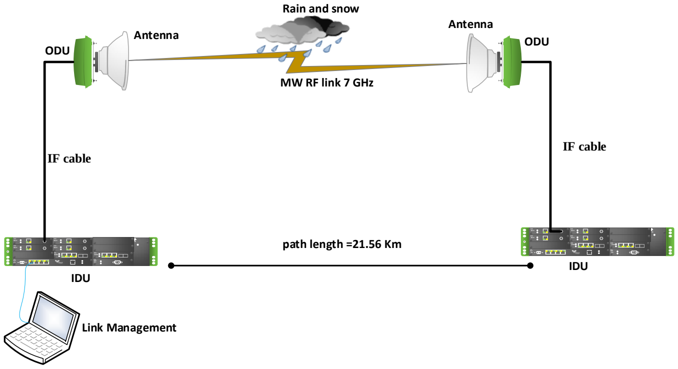

Figure 4: Experimental Microwave link

III. RESULTS AND TABLES

A. Theoretical results

The implementation of Theoretical method to the UIT-R F.384-11 Frequency channels of Figure 5 shows the results of figure 6. The Figure 5 shows ITU-R frequency channels with 28 MHz channel width for each channel. There are no frequency channels of 40 MHz in this frequency band, the application of the method allows to obtain the frequencies of 40 MHz in this band for a project. The reverse procedure may be performed to obtain the narrow frequency channels with a high modulation level.

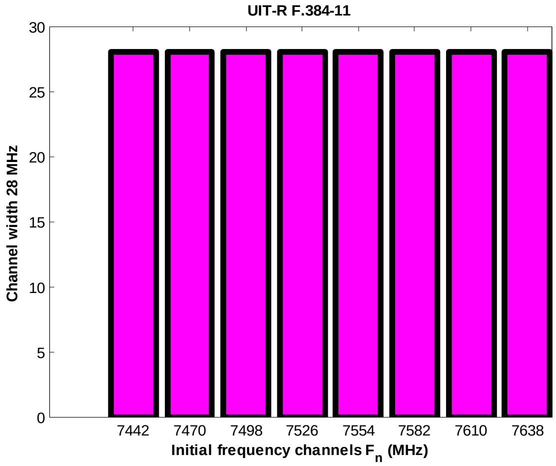

Figure 5: Initial frequency channels low F_n.

Application of the methodology: The application of the frequency optimization methodology using equation (10), (11), (12), (13) and (14) obtain the results illustrated by the figure 6 of the next page.

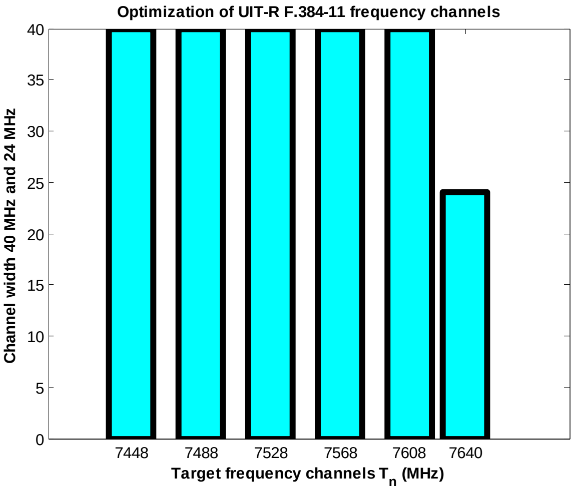

Figure 6: Target frequency channels T_n

B. *Experimental results*

The results of the design are consigned in the table 1 below, the measurement results in the table 2.

Table 1: Results of design

Frequency	Bandwidth	Modulation	Fade margin
7 GHz	14 MHz	256 QAM	27,7 dB
7 GHz	28 MHz	16 QAM	35,02 dB
7 GHz	28 MHz	256 QAM	25,52 dB
7 GHz	56 MHz	16 QAM	32,5 dB

Table 2: Results of measurement on the site

Frequency	Bandwidth	Modulation	Fade margin
7 GHz	14 MHz	256 QAM	28,8 dB
7 GHz	28 MHz	16 QAM	36,3 dB
7 GHz	28 MHz	256 QAM	25,20 dB
7 GHz	56 MHz	16 QAM	34,00 dB

The design parameters are obtained using Pathloss 5, the microwave design toll with the following parameters: Clearance of Fresnel zone: 100%, tree height: 15 m, frequency band: 7 GHz, ITU-R rain region: Region K, Link polarisation: Vertical.

The table 1 above shows the summary of the mains parameters of the link for each channel width and modulation level. For the 14 MHz of channel width with 256-QAM modulation, the fade margin is 27.5 dB, the Rx threshold -71.5 dBm and the link throughput 87 Mbps. With the 28 MHz of channel width and 16- QAM modulation, we have the best performance (35.02 dB of fade margin) and throughput (189 Mbps). The table 2 shows the measurements results on the site after the link installations and confirms the design parameters.

The mean incertitude of the design results and the measurement for the fade margin, the Rx threshold and the link capacity are lower than 4%.

IV. CONCLUSION

In this work, we presented the parameters of microwave link design, the link performance and the comparison of the Rec. ITU-R P.530-16 model and Vigants–Barnett model for the link availability calculation. The ITU model is the best because it is rigorous. Based the link performances goals and the evolution of wireless technology, we have proposed a theoretical method to optimize the frequency utilization. The design and the experimental measurement results confirm the necessity to find a best compromise for the modulation level and the frequency bandwidth to obtain a best performances (99.9998% of annual availability) and high throughput of the link.

V. BIBLIOGRAPHIE

i *MEF, «Microwave Technologies for Carrier Ethernet Services,» MEF, 2011.*

ii *IEE, «Is Microwave Backhaul Up to the 4G Task,» IEEE Microwave Magazine, 2009.*

iii *a. Mukesh Chandra Kestwal, «Prediction of Rain Attenuation and Impact of Rain in Wave Propagation at Microwave Frequency for Tropical Region (Uttarakhand, India),» Hindawi, 2014.*

iv *a. R.K Manjunath, «Design of High Capacity Microwave Link between Two Cities,» IJIRC, 2014.*

v *a. Basile L. Agba, «Comparison of Microwave Links Prediction Methods: Barnett-Vigants vs. ITU Models,» PIERS Proceedings,, 2010.*

vi *I.-T. G.826, «End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections,» 2002.*

vii *S. S. Roland, «Performances of Neural Networks and LDPC Decoders for OFDM High Speed Transmission in Optical Fiber,» IJER, 2013.*

viii *a. JingjingWang, «Capacity of 60GHz Wireless Communications Based on QAM,» Hindawi, 2014.*

ix *O. B. E. Aboagye Isaac Adjaye, «M-QAM Based Single-Carrier Baseband Communication System Research,» IOSR-JECE, 2014.*

x *B. I. Zambrano, «Record 180 km Hybrid Diversity IP Microwave Link,» Aviat, 2012.*

xi *F. Xiong, Digital Modulation Techniques, 2006.*

xii *I.-R. F.746-5, «Radio-frequency channel arrangements for fixed service systems».*

xiii *A. D. &. all, «Rainfall monitoring based on microwave links from cellular telecommunication networks: First results from a West African test bed,» AGF, 2014.*

doi : 10.17950/ijer/v5s11/1105