Interference Consideration in Networks of Small and Medium Capacity Radio Relay Links

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Abstract: *This paper gives some remarks on interference, which may be useful in planning modern digital radio relay networks. Two methods to calculate link performance degradation due to interference are described: the eye-pattern degradation method and the method considering interference as noise. Methods are applied on digital radio link IMTEL RRU23/8 and compared to measured data. Results show that accuracy of both methods is higher than calculated accuracy of carrier to interference ratio in real network. So, for network planning, the second method is preferable since it requires fewer parameters, whereas the first method is good in system engineering for finding weaknesses of the radio system.*

1. Introduction

Nowadays, small and medium capacity radio relay links are very often used. Their main applications are:
- connection between base stations and switching centers in mobile communications systems like mobile telephony,
- enterprise telephone and computer networks
- connection of switching systems in public telephone or ISDN networks, etc.

Interference could be a limitation for satisfying link performance objectives in such networks, so it should be seriously considered in network planning. The basic planing strategy usually is:

1. Making of network topology.
2. Assuming parameters of individual routes (frequency range, transmitter power, antenna sizes, etc.) to satisfy error performance objectives [1] regardless of interference.
3. Calculating of interference level for each receiver.
4. Calculation of degradation due to interference and check if objectives are satisfied for all links in network.
5. Correction of link parameters of critical routes and repetition of the procedure until all objectives are satisfied.

As this algorithm shows, there are two problems concerning interference: calculation of interference level and calculation of degradation due to interference. Since the first problem is widely considered in literature, we will describe it in brief and most of our attention will be focused on the second problem. Special type of radio links are low-cost millimeter links which recently have been very much in use. Some remarks on their influence on the network as a whole are given.

2. Low-Cost Millimeter Wave Links

In recent years, large demand for wireless connections has initiated usage of higher frequency bands - 23, 38, 50 and 60GHz, which practically have been unused. There are several strong reasons to encourage using these bands:
- bands are almost free,
- small antennas give large gain and
- absorption is high, which reduces the possibility of interference.

To decrease prices of such links much larger channels and larger transmitter frequency tolerances are allowed than in lower bands. For instance, for link capacity of 2 and 8 Mbit/s a 28MHz (or even 56MHz) channel is assigned, while at lower bands the common channel spacings are 3.5 and 7MHz. Typical required frequency stability is ±200ppm (which is ± 4MHz at 23GHz), or even ±300ppm in the USA, while at lower bands stability of ±100ppm is required (which is ±750kHz at 7.5GHz).

In order to meet these requirements, a typical concept of the first-generation millimeter links is:

- For operation in wide temperature ranges (-30 to +55°C for outdoor unit) simple modulation is desired, e.g. FSK.
- Frequency stability requirements allow usage of voltage controlled oscillators with dielectric resonators (DRO). Directly modulated voltage controlled DRO is used in the transmitter part and fixed frequency DRO in the receiver part (Fig 1.).

Frequency variations due to temperature changing are usually at the very limits of requirements.

- In the receiver part, instead of using a PLL for carrier tracking, the carrier frequency changes are compensated by using larger IF frequency bandwidth. For example, to compensate frequency instability of ±4MHz of the transmitter, modulation bandwidth of 10MHz, and ±4MHz of LO, an IF bandwidth of 26MHz is required, which degrades receiving threshold by 3.8dB due to increase of noise.

Several companies adopted this concept (Alcatel, MACOM, Racon, Institute IMTEL) and their links although operating in higher frequency range, are cheaper than competing links at lower bands. Concept of Imtel RRU23/8 as a typical low-cost millimeter wave link is shown in Fig 1.

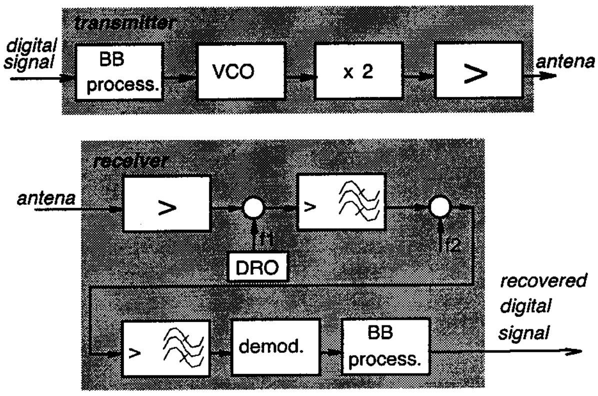

Fig 1. Concept of the IMTEL RRU23 as a typical low-cost millimeter wave link

At first sight, this concept suffers from a serious drawback - oscillators are designed for a single specific frequency, while other microwave parts could be designed to operate in subband or rarely in the whole band. This makes network maintenance more expensive due to a need for a spare oscillator for each operating frequency. As for other components, two kinds of spare parts are needed: for upper and for lower subband.

In recent systems, oscillators designed for single frequency are replaced by frequency synthesizers which usually cover one subband, so the spare parts problem is less drastic, but it still exists. Unfortunately, the price of the link is significantly increased.

Let us summarize: ***network maintenance is cheaper if devices operating at the same frequency are used. However, this is limited by interference in the network. Therefore, too pessimistic consideration of interference makes the network unnecessarily expensive.***

3. Interference Sources and Calculation of Interference Level

According to ITU-R recommendation [2] interference sources could be divided into two groups: the faded and those not faded with wanted signal (Fig 2.).

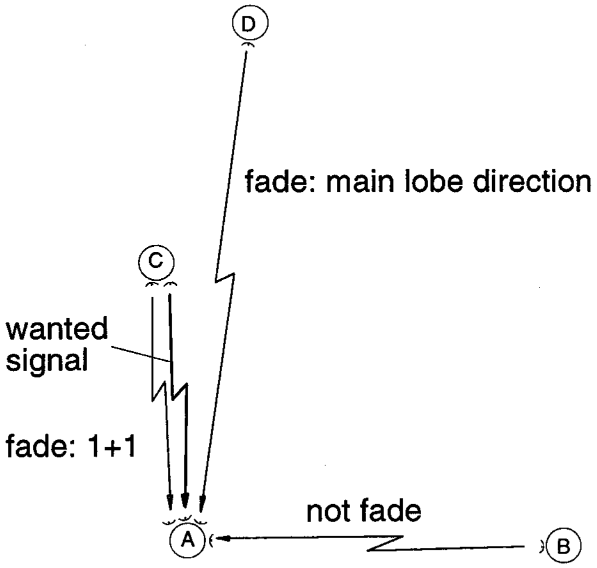

Fig 2. Types of interference in a radio relay network

Upon taking into account interference which fades with wanted signal, a planner should be aware of degradation of residual bit error ratio (*BER)* and errored seconds objectives. As the main source of interference from the first group ITU-R mentiones cross-polarized channel(s). In practice this could be a protection link in configuration 1+1 or N+1. In a millimeter wave link networks, this type of interference could be any source of interference that radiates from direction of main antenna lobe, since hops are short (up to 20km) and the main source of fading is attenuation due to rain absorption. As further study will show, the level of such interference should be maintained at 20 - 25dB bellow the level of unfaded wanted signal.

The interference which does not fade with main signal degrades receiver thresholds and therefore the fading margin. This type of interference could be radiated from any source whose path neither completely nor partially passes through the path of wanted signal. ITU-R assigned opposite hop front to back reception as the main source. Modern radio relay networks usually consist of nodes where links from several directions are crossed, so a network planner should take much care about interference. Right choice of frequencies and polarization could minimize the number of necessary frequencies and thus significantly reduce maintenance cost.

4. Interference Effects

A radio link receiver is usually designed as super-heterodyne receiver (Fig 1.). The receiving signal is amplified by a low-noise amplifier, down-converted and filtered at first IF (usually about 1GHz), down-converted to second IF and strongly filtered. After demodulation at the input of decision circuitry, we observe an eye-pattern. For given eye-pattern and decision thresholds, we can calculate noise margin. Specified signal to noise ratio at receiver input ρ causes related BER. Values for ρ for different modulation types could be found in [3] and [4]. The main receiver characteristic is the receiver threshold for given BER ($n_{RT}(BER)$) which gives level of wanted signal at the input, necessary to obtain it. The relation between $n_{RT}(BER)$ and $\rho(BER)$ is:

$$n_{RT}(BER) = 10\log_{10}(kTB_{RF}F) + \rho(BER) \quad (1)$$

where:

k	Boltzman constant
T	Absolute temperature
B_{RF}	Equivalent receiver bandwidth
F	Noise figure

Interference signal is added to wanted signal in random phase and after demodulation the result is eye-pattern degradation and noise margin decrease (Fig 3).

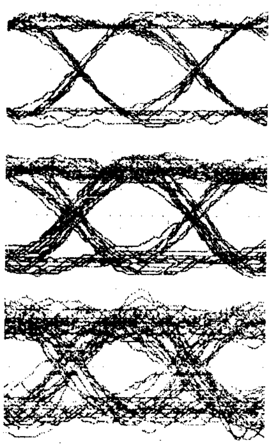

Fig 3. Eye pattern degradation and decrease of noise margin

The main difference between noise and interference is that the noise amplitude could be infinitely large but probability of such case is very small (e.g. Gaussian distribution), since interference has limited amplitude because its sources radiate limited amplitudes at output. In other words, when observing eye-pattern in a long period of time, noise peaks close it, but interference peaks do not.

Theoretically, in FM systems interfering signal could produce very large amplitudes as a consequence of derivation in demodulation process, but such event is prevented by IF and base-band filtering.

There are several methods to calculate receiver threshold degradation, but three of them are mostly in use:

1. Eye-pattern degradation [3][4],
2. Consideration interference as noise [4][5] and
3. Analytical and numerical simulation of receiver in presence of interference and noise.

Since the third method is very sensitive to a specific case (modulation and interference type) and requires a lot of mathematics even for very simple cases, it is not considered in this work. Nevertheless, it is always a hot topic in current world's communications literature.

6. Eye Pattern Degradation

The basis of this method is to find eye-pattern in the decision circuitry when wanted signal is in presence of interference and to compare it to eye-pattern without interference. In the first approximation, degradation of the receiver threshold could be calculated by formula:

$$\Delta n_{RT} = 20\log_{10}\left(\frac{NM_{ref}}{NM_i}\right) \quad (2)$$

where

NM_{ref}	reference noise margin (without interference)
NM_i	noise margin with interference

This formula is not completely accurate since it does not take into account signal with interference and noise distribution for specific modulation, so it does not give differences in degradation of receiver threshold for different BERs. Actually, the degradation is lower for higher BER (e.g. the degradation for BER=1E-3 is 2.5dB, while for BER=1E-6 it is 3dB). In practice, for relatively high C/I these differences are bellow 1dB.

In systems with multilevel modulation like HDB3-FSK, 4-FSK, 8-PSK, 16-QAM, circuitry for adaptive adjustment of receiver thresholds is necessary and interference (especially adjacent channel interference) could affect its functions. In such cases formula (2) could give the upper bound of degradation when applied to the most closed eye. This is usually a case in high capacity radio links (above 34Mbit/s) and they are not subject of this paper.

The simplest method for constructing eye-pattern is discrete time equivalent of the system (Fig 4). Digital signal is represented by its samples (N=16 to 32 samples per symbol interval is typical). Base band processing is simulated by equivalent filter and RF processing by complex anvelope. Modulation and demodulation process are given analytically. If system includes some nonlinear processing (like nonlinear power amplifier or hard-limiting at receiving site) it is performed by its quasi-static characteristic. At the receiver input attenuated and random phase-shifted interference is added to wanted signal. Actually, random-phase shifting means to construct an eye-pattern for any phase shift and to take the worst case.

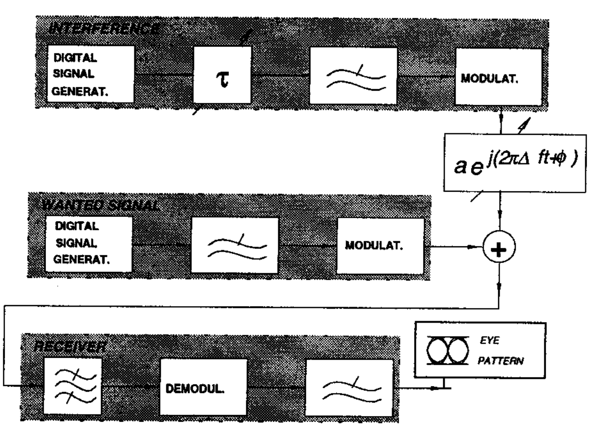

Fig 4. Basic simulation model

The basic simulation model could be extended to cover some system specialties like adaptive equalization, adaptive receiving threshold positioning or cross polarization cancellation circuitry [4]. Therefore, this method is good for system engineering since designers could find weaknesses of the system.

However, in interference consideration in radio relay networks, results of such modeling could be easily and accurately applied when one source is dominant (more than 10dB stronger than the sum of the others) which often occurs in practice. Actually, it could be also applied in other circumstances, but this requires much more calculation and in practice the result has no more significance than the simple method where interference is considered as noise.

This method has one very important advantage: nature of interference source need not be the same as wanted signal. In practice this usually means that we can simulate influence of narrow-band interference sources on relatively wide-band wanted signal. Generally, it is the case with radio-links located near strong transmitters (like radar or broadcast transmitters) which could enter the system through IF circuitry. In such cases the main problem is to determine the level of interference, but we need to say that in a well-designed radio such problem rarely appears.

7. Considering Interference as Noise

The simplest method to calculate degradation due to interference is considering interference as noise. It is assumed that sum of interference and noise makes equivalent noise source whose power is equal to sum of the total interference power and noise power. Although this assumption hides true nature of interference, it could be correct in cases of many interference components with almost equal power and when its interference components have the same nature (in sense of modulation type, bandwidth etc.) as wanted signal. This is the main drawback of the method. If we put this assumption in equation (1), we can derive that degradation due to interference is:

$$\Delta n_{RT} = 10\log(1+10\sum_{i=1}^{N}10^{0.1(I_i - A_i + \rho + n_{RT})}) \qquad (3)$$

where

I_i power of i-th interference component, and

A correction factor for adjacent channel interference

From equation (3) we can see that influence of co-channel and adjacent channel interference could be easily summed by using correction factor A. It describes attenuation in RF and BB filter circuitry of adjacent channel signals. Measured correction curve for digital radio relay link IMTEL RRU23/8 is given in Fig 5.

For low-cost microwave links where IF bandwidth is larger than necessary and transmitter frequency has large tolerances, the worst case analysis is preferable. Usually, the worst case is when wanted signal frequency and the frequency of the strongest interference signal are changing in such a way that frequency difference is decreased.

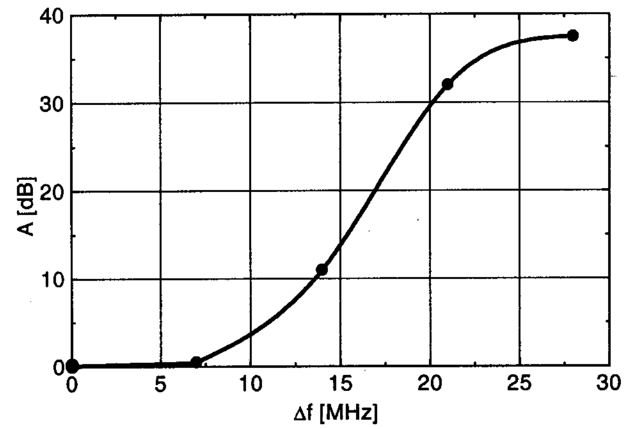

Fig. 5. Measured adjacent channel C/I correction curve for IMTEL RRU23/8

Since this method requires very small number of parameters, it is strongly recomanded by many manufacturers. As we shall show later, the method is pessimistic because the interference peaks can not have infinite amplitudes as it is case with noise.

8. Simulation and Experimental Results

These two methods are tested on digital radio relay link Imtel RRU23/8 whose basic characteristics are given in Fig. 6. The results for co-chanel interference are given in Fig.7 [6].

Frequency range	21.2 - 23.6GHz
Modulation	2-FSK
Modulator realization and stability	VC-DRO ±200ppm
Receiver	Super-heterodyne
Local oscillator and stability	DRO ±200ppm
First IF	1010 MHz
IF bandwidth	27 MHz
Noise figure	5 dB
ρ(BER=1E-3)	9.7 dB
n_{RT} *(BER=1E-3)*	-85 dBm
ρ(BER=1E-6)	13.6 dB
n_{RT} *(BER=1E-6)*	-81 dBm

Fig. 6. Characteristics of the RRU23/8

For this type of modulation and this modulation index, results obtained using method 1 slightly disagree with measured data (±2dB). Our opinion is that the main reason for this disagreement is inaccuracy of formula 2, because simulated and measured eye-patterns agree well. Another drawback of the formula is that occurrence of significant residual BER (greater than 1E-7) can not be predicted. Experiments show that it occurs when degradation is higher than 6-8dB (50 to 60% eye-closure).

Method 2 shows better agreement with experimental data than method 1 even for higher C/I and BER=1E-3. Inaccuracy increases for lower BER since interference is considered as noise and according to this the system cannot operate below ρ-bound. Unlike this, method 1 shows that system can operate bellow this bound and therefore it is more accurate.

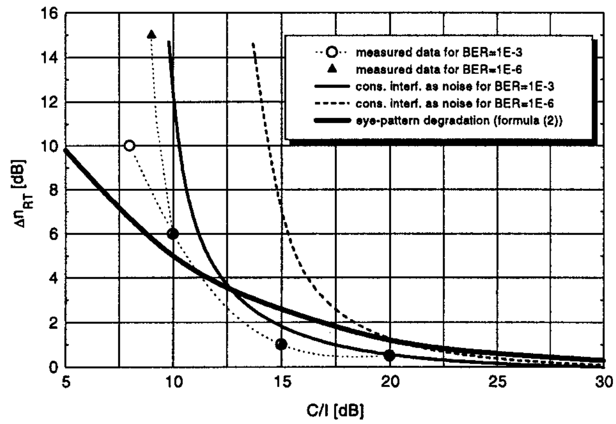

Fig. 7. Results comparison for the RRU23/8

Such analysis is performed on different types of modulation and results are shown in Fig.8. For all modulation types, except for 4-PSK, applied method is eye-pattern degradation. For 4-PSK, data are taken from [2]. We can see that for FSK modulation increase of modulation index *m* decreases influences of interference. It should be pointed out that results for HDB3-FSK and 4-FSK modulation represent the upper bound of degradation.

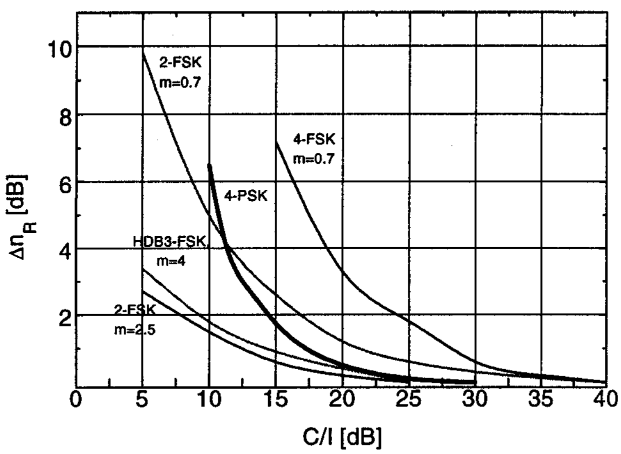

Fig. 8. Degradation due to co-channel interference for different modulation types

For adjacent channel interference, the total interference power is attenuated by RF and BB filters. Eye-pattern simulation shows that BB filtering is very important and can cover the lack of RF filtering to some extent. This is significant in FSK modulation schemes which are highly nonlinear and signals that are away from carrier make higher amplitude at decision circuitry. This is not the case with PSK modulation schemes. The results depend very much on assumed system characteristics, especially on IF and BB filters characteristics in stop band region [7]. Usually, it is very hard to obtain them from manufacturers. Instead, they most often give curves of suppression of adjacent channel interference (Fig 5.) [6]. This curve presents differences between co-channel and adjacent channel interference levels that causes residual BER of 1E-6.

9. Conclusion

Measured and simulated data show that the flow of interference degradation curves is: for high C/I ratio (e.g. 10dB higher than ρ) degradation is below 2dB and asymptotically approaches zero, but for C/I close to ρ degradation abruptly increases to infinity which means occurrence of serious residual BER in practice. Consequently, when the level of interference that does not fade with wanted signal is close to the level of receiver threshold, corrected receiver threshold should be calculated as a sum of interference level and ρ, rather than as a difference of nominal receiver threshold and degradation due to interference.

Differences between the results of these two methods and measured data exist, but they are lesser than accuracy of calculated C/I for a particular network. For example, allowed tolerances of transmitter power are 2dB, while tolerances of antenna radiation patterns are much higher. This fact favorises usage of the method considering interference as noise, since it requires minimum parameters which could be easily obtained from manufacturers, but only in cases when interfering signal is similar to Gaussian noise or when its nature is the same as the nature of wanted signal. When this is not the case, the eye-pattern degradation method should be performed.

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