FIXED MW ACCESS NETWORK DESIGN USING INTERFERENCE MATRICES

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Abstract : Density of microwave and millimeter-wave radio relay networks increased with unexpected speed in the last decade. For long time rain attenuation and thermal noise limitation were in the main focus of fixed radiolink design. Nowadays interference between the wireless links became the major limiting factor in network planning.

I. INTRODUCTION

Success of GSM systems and simultaneous liberalization of the telecom sector resulted in very dense digital microwave (μW) and millimeter-wave (mmW) access networks in several countries. In practice available frequency bands are saturated in dense urban areas. When several different service providers use a nearly congested frequency band, coordination and interference prediction become very difficult and time consuming [1-10]. This paper shows the role of interference matrix in network design. Values of the interference matrix are based on measurements [11-13]. These data are sometimes not available for network planning. For such situation we propose a method based on computer simulations using a communication network simulator tool [14].

II. THE BASIC INTERFERENCE SCENARIO

The basic interference scenario is shown in Fig.1.

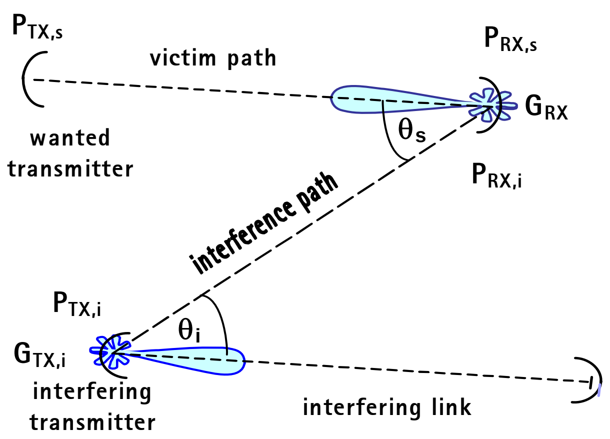

Fig.1. Basic interference scenario between two links

The wanted signal *S* at the connector point of the receiver antenna is calculated as :

$$S[dBm] = P_{RX,S} = = P_{TX,S} + G_{TX,S} + G_{RX,S} - FSL_S - L_S \quad \text{Eq.1.}$$

where :

$P_{TX,S}$ is the transmitted power of the wanted signal,
$G_{TX,S}$ is transmitter antenna gain compared to the isotropic one, given in dBi units,
$G_{RX,S}$ is the receiver antenna gain compared to the isotropic one, given in dBi units,
FSL_S in dB is the free space loss of the victim path,
L_S in dB units reflects other propagation losses such as obstacles in the victim path, e.g. buildings, power pylons or trees.

Over horizon loss due to earth surface may be also included in the value of L_S. Unfortunately undesired interferor signal of the interfering transmitter may enter into the receiver too. Due to interference the victim path may suffer from bit error rate (BER) degradation, and in long term availability targets cannot kept. The power level of the interfering signal $P_{RX,I}$ received at the antenna connector point of the victim receiver is calculated as :

$$I[dBm] = P_{RX,I} = P_{TX,I} + G_{TX,I} + G_{RX,S} - Discr(\theta_S, \theta_I, V/H) - FSL_I - L_I \quad . \quad \text{Eq.2.}$$

$P_{TX,I}$ is the power emitted by the interferor transmitter,
$G_{TX,I}$ is interferor transmitter antenna gain compared to the isotropic antenna gain, given in dBi units,
$G_{RX,S}$ is the antenna gain of the victim receiver compared to the isotropic one, given in dBi units,
FSL_I is the free space loss in the interference path,
L_I reflects other losses in the interfering path e.g. obstacles, buildings, power pylons or trees,
Discr. is the total antenna (spatial) discrimination, in dB units.

Spatial discrimination is depending on three main factors: Θ_S gives discrimination due to the angle between the main lobe of victim path and the interference path. Similarly, Θ_I grants discrimination due to the angle between the main lobe of the interfering link and the interference path (Fig.1). V/H corresponds to polarization discrimination. In general, polarization states of victim and interfering links may differ, e.g. vertical (V) victim and horizontal (H) interfering link. Calculation of this third term is given by a minimum function (Tab.1).

S	**V**	**V**	**H**	**H**
I	**V**	**H**	**V**	**H**
RX antenna	$VV(\Theta_S)$ no polarization discrimina-tion	$VV(\Theta_S)$ or $VH(\Theta_S)$	$HH(\Theta_S)$ or $HV(\Theta_S)$	$HH(\Theta_S)$ no polarization discrimina-tion
TX antenna	$VV(\Theta_I)$ no polarization discrimina-tion	$HH(\Theta_I)$ or $HV(\Theta_I)$	$VV(\Theta_I)$ or $VH(\Theta_I)$	$HH(\Theta_I)$ no polarization discrimina-tion
Total Discr. in [dB]	$VV(\Theta_S) + VV(\Theta_I)$	$\min[VV(\Theta_S) + HV(\Theta_I), VH(\Theta_S) + HH(\Theta_I)]$	$\min[HH(\Theta_S) + VH(\Theta_I), HV(\Theta_S) + VV(\Theta_I)]$	$HH(\Theta_S) + HH(\Theta_I)$

Tab.1. Possible spatial discrimination values between wanted and interfering signals.

Therefore the following radiation patterns are needed : VV, HH, VH, HV (vertical to vertical, horizontal to horizontal, vertical to horizontal and horizontal to vertical discrimination) for both the receiver and the interfering transmitter antennae. (In the possible VV, VH, HV and HH combinations the first character represents the polarization of the transmitting or receiving antenna, while the second character shows the polarization of the signal transmitted or received.) As usually worst case is considered the lowest value of the possible H/V or V/H combinations is selected when the victim and interfering links have different polarizations. Tab.1 summarizes the four possibilities and the resulting value of spatial filtering. For simplicity, we assume that all links of Fig.1 are in the same plane (only two-dimensional model). More accurate models are three-dimensional and especially useful when the links have significant antenna up or down-tilts. Typically this might be the case for very short links on mountainous terrain. The signal to interferer ratio is calculated then from the Eq.1-2 as :

$$\frac{S}{I}[\mathrm{dB}] = 10\log_{10}\left(\frac{P_{RX,S}}{P_{RX,I}}\right) = S[\mathrm{dBm}] - I[\mathrm{dBm}] \qquad \text{Eq.3.}$$

In Eq.3 *S* refers to signal and not to sensitivity threshold. We note that *S/I* is frequently called as carrier to interference ratio, *C/I*. Modulated carrier is often denoted by *C* in other papers despite the fact that in strict formalism carrier power equals with modulated carrier power only for purely phase modulated systems.

One way of characterizing the harmful effect of interfering source(s) is to measure the *S/I* ratio that gives a certain degradation to a digital link, e.g. in the detection or sensitivity threshold. As seen in Fig.1, in the general case the interference path differs from the victim path. (Such special cases as dual-polarized or linearly aligned links are not considered now.) So in worse case it may be possible that the victim path is deep faded e.g. by rain attenuation meanwhile the interferor transmitter is not attenuated. Therefore, similarly to Eq.3 threshold to interference ratio, *T/I* may be defined as :

$$\frac{T}{I}[\mathrm{dB}] = 10\log_{10}\frac{P_{RX,Threshold}}{P_{RX,I}} = T[\mathrm{dBm}] - I[\mathrm{dBm}] \quad \text{Eq.4.}$$

Different definitions exist for *T/I* ratio. By a generally accepted definition Eq.4 gives an interferor level that degrades the $BER = 10^{-6}$ threshold with 1 dB. Other definitions consider the threshold degradation with 3 dB or 5 dB. Sometimes not $BER = 10^{-6}$ but 10^{-3} threshold is taken into account.

III. T/I MATRICES

The specific *T/I* value is a parameter of both the victim receiver and the interferor transmitter. It is a function of modulation characteristics, digital capacity of both links and the frequency separation (Δf) between them [11-13]. *T/I* is typically measured by fading the wanted received signal level (*RSL*) in the receiver to reach 10^{-6}. Then interferor signal is injected into the receiver. The level of interfering signal is increased until BER is degraded down to 10^{-5}. (Another possibility is to set the *RSL* to reach 10^{-6}. Then *RSL* is increased by 1 dB and interferor is injected into the receiver. The level of interfering signal is increased until BER=10^{-6} threshold is reached again.)

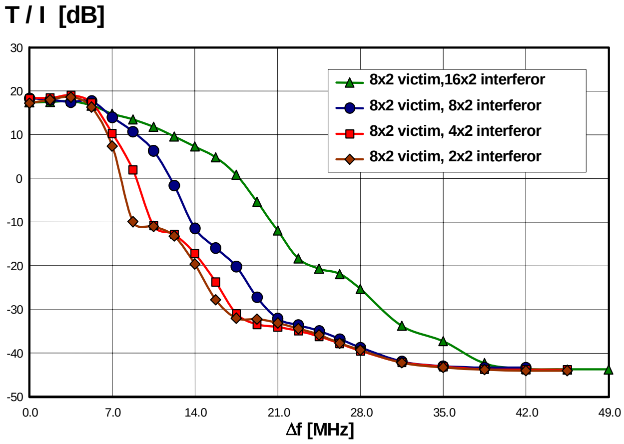

Fig.2. T/I as a function of frequency separation between victim 8x2 Mbit/s and interferor radios of 16x, 8x, 4x and 2x2 Mbit/s.

Fig.2 indicates the measured *T/I* matrix values of a 23 GHz 8x2 Mbit/s radio receiver. Both victim and interferor radios use π/4 shifted differential quadrature phase shift keying (π/4-DQPSK) modulation [1, 15] and they belong to the same radio family. 1 dB degradation of BER=10^{-6} threshold of the victim receiver is shown in the figure. As seen in Fig.2 the most harmful effect is due to the 16x2 Mbit/s interferor. 16x2 Mbit/s capacity gives the widest occupied power bandwidth. So this interfering signal tends to enter into the victim receiver even from distant frequencies.

T/I values for victim radio: 23 GHz, 8x2 Mbit/s, 1 dB degradation of BER=10^{-6} [dB]				
Δf	capacity of interferor radio [Mbit/s]			
[MHz]	16x2	8x2	4x2	2x2
0	17.4	18.3	18.3	17.2
1.75	17.5	18.0	18.4	18.0
3.5	17.7	17.5	19.0	18.6
5.25	16.7	17.7	17.3	16.3
7	14.8	14.0	10.3	7.4
8.75	13.5	10.7	2.0	-9.9
10.5	11.8	6.3	-10.8	-11.0
12.25	9.6	-1.6	-12.8	-13.2
14	7.3	-11.4	-17.2	-19.6
15.75	4.8	-15.9	-23.7	-27.8
17.5	0.8	-20.2	-31.0	-32.0
19.25	-5.3	-27.2	-33.4	-32.2
21	-11.9	-32.1	-34.0	-33.1
22.75	-18.3	-33.6	-34.9	-34.4
24.5	-20.7	-34.9	-36.2	-35.8
26.25	-21.9	-36.8	-37.8	-37.7
28	-25.3	-38.7	-39.5	-39.3
31.5	-33.8	-41.9	-42.1	-42.2
35	-37.3	-43.0	-43.1	-43.3
38.5	-42.3	-43.3	-43.7	-43.8
42	-43.6	-43.3	-43.8	-44.0
45.5	-43.7	-	-43.8	-44.0
49	-43.7	-	-	-

Tab.2. T/I matrix for a 23 GHz, π/4-DQPSK, 8x2 Mbit/s digital radio receiver

Filters of this victim receiver are optimized for 8x2 Mbit/s reception. So they efficiently suppress 2x2 or 4x2 Mbit/s interferors occupying the adjacent radio channel. The specific *T/I* values of Fig.2 are given in matrix form in Tab.2. It is important to notice that different digital radios have different *T/I* matrices depending on their modulation method, TX and RX filtering, error coding etc. used. As a further example of *T/I* matrix, Tab.3 gives *T/I* values of a radio link family using 4 level frequency shift keying modulation (4-FSK).

T/I values for victim radio: 4-FSK, 2x8 Mbit/s, 3 dB degradation of BER=10^{-6} [dB]				
Δf	**capacity of interferor radio [Mbit/s]**			
[MHz]	**2x8, lo d.**	**8, lo d.**	**2x2, lo d.**	**2, hi dev.**
0	21	21	21	21
10.5	15	3	2	2
14	-1	-10	-11	-11
17.5	-14	-17	-18	-18
21	-23	-29	-30	-30
24.5	-30	-35	-36	-36
28	-37	-40	-41	-41
31.5	-43	-45	-46	-46
35	-50	-50	-50	-50
42	-50	-50	-50	-50

Tab.3. T/I matrix for a 4-FSK (low deviation) 8x2 Mbit/s digital radio receiver

All T/I matrices of different manufacturer's various radio equipment must be available in the computer simulation tool [16-18] that is used for frequency planning purposes. However, in most of the cases it is very difficult to obtain these *T/I* values. Their measurement [4] is very time consuming and requires a well equipped test laboratory. User manuals of μW or mmW digital radio links seldom contain this information in such details. Usually not more than co-channel and adjacent channel interference tolerance is given but only for like-modulated interferors.

IV. CUMULATIVE INTERFERENCE

If more than one interference paths were present in the radio network due to several interfering sources, then cumulative interference takes place. Let us assume now that the wanted and interferor signals have the same frequency. In this case the resulting interference level is calculated by power addition of all the *k* individual interfering levels :

$$I_\Sigma\,[\mathrm{dBm}] = 10\log_{10}\left(\sum_{k=1}^{n} 10^{I_k[\mathrm{dBm}]/10}\right) \qquad \text{Eq.5.}$$

In Eq.5 frequencies of the signal *S* and all interferors I_k are assumed to be the same. *n* is the total number of interfering transmitters within a reasonable radius depending on the frequency band (e.g. 36 km for 38 GHz but 120 km for 13 GHz links). Power addition may be used since these *n* different interference signals are not correlated. Each individual I_k is calculated as given in Eq.2. Interfering signals with fading events correlated to that of the wanted signal may be disregarded (e.g. interfering path longer but linearly aligned to the victim link may suffer the same rain fading.) Also interferers having levels significantly below the strongest interferor (e.g. 30 dB) may be neglected [7]. There are two possibilities to use result of Eq.5 during the frequency planning of the network :

- either to calculate BER threshold degradation due to interference,
- or to calculate the threshold to interference ratio, *T/I* and compare it to a predefined value called interference margin. Using Eq.5 the threshold to interference ratio becomes :

$$\frac{T}{I_\Sigma}[\mathrm{dB}] = 10\log_{10}\frac{P_{RX,Threshold}}{\sum_{k=1}^{n} 10^{I_k/10}}\,. \qquad \text{Eq.6.}$$

When the signal and the interferor(s) operate on different frequencies (as they occupy different radio channels) effect of frequency separation must be taken into account in Eq.5 and 6. There are different methods to calculate discrimination due to frequency separation. One possibility is to convolve transmitter spectrum of the interferor source with the receiver filter [5, 18]. Another possibility is to use the T/I matrix. For given Δ*f* frequency separation the difference of *T/I* values measured at co-channel and at the given frequency Δ*f* apart from co-channel must be calculated :

$$\left(\frac{T}{I}\right)'[\mathrm{dB}] = \frac{T}{I}(\Delta f = 0) - \frac{T}{I}(\Delta f)\,. \qquad \text{Eq.7.}$$

Using this spectral discrimination value given by Eq.7 any interferor may be converted to co-channel interference. Performing the calculation of Eq.7 for all the interference cases, the resulting threshold to interference may be calculated as :

$$\frac{T}{I_\Sigma}[\mathrm{dB}] = 10\log_{10}\frac{P_{RX,Threshold}}{\sum_{k=1}^{n} 10^{\left(I_k - (T/I)'_k\right)/10}}\,. \qquad \text{Eq.8.}$$

It is important to conclude that total discrimination between wanted and interferor signals is a combination of spatial filtering (due to antenna) and spectral filtering (due to frequency separation). Rough estimations e.g. using 30 dB as a default objective of interference margin cannot result in a spectrally efficient network and will significantly limit the possibility of frequency re-use.

V. EXAMPLE FOR SIMULATION BASED T/I MATRICES

Values of the interference matrix are required to calculate Eq.7 or Eq.8. These values may be obtained from measurements. However, these data are hardly ever available in such detail that is required for the purpose of correct network planning. For such situations a method based on computer simulations is proposed in this part.

COMSIS software was used as a communication network simulation tool. The basic interference scenario is shown in Fig.3 as displayed in COMSIS [14]. In the simulations always raised cosine filters were assumed with roll off factors α=0.5. For faster calculation of the T/I matrix elements only 100.000 points were calculated. 10.000 bits were transmitted over the wanted link (10 points per bit). Simultaneously noise and interference disturbed the transmission. The level of interference was increased until a BER degradation from *BER*=10^{-4} to 10^{-3} not occurred.

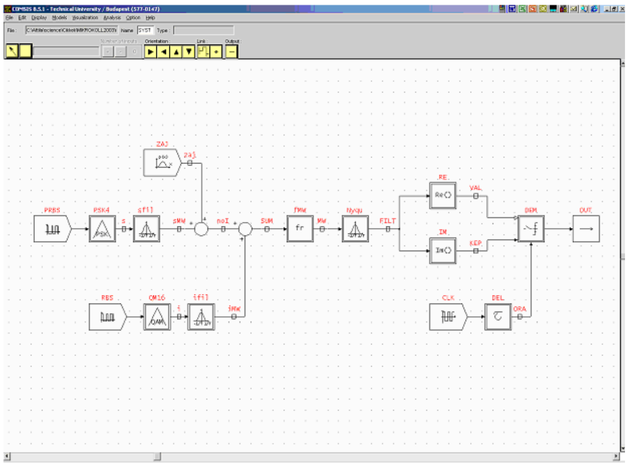

Fig.3. COMSIS simulation of 8 Mbit/s QPSK victim link interfered by a 16-QAM interferor.

Simulation results are shown in Fig.4 for three different cases. The QPSK link operating at 23 GHz with 8 Mbit/s capacity was interfered by 8, 16 and 32 Mbit/s 16-QAM links, respectively. Channel bandwidths (raster) were selected according to ETSI standards [19].

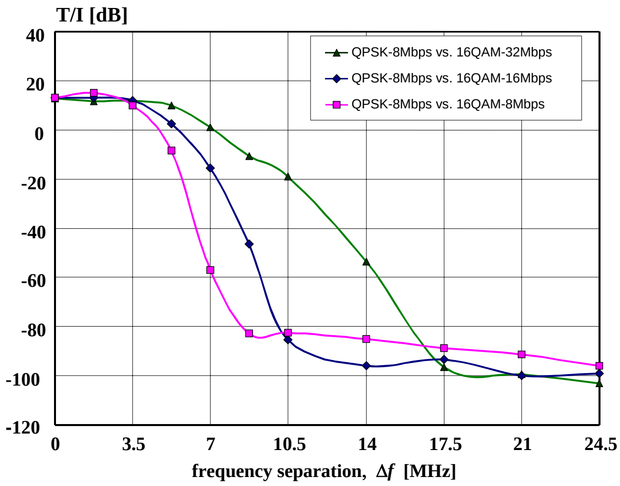

Fig.4. Simulated interference sensitivity curves between QPSK victim link and 16-QAM interferors having different capacities.

As seen in Fig.3 the simulation tool is modular. It is possible to define transmitter and receiver blocks by frequency, output power, modulation type, bit rate and demodulation method. Other type of digital links e.g. FSK, 64-QAM or 128-QAM [1- 4, 14] may be simulated to obtain their T/I matrix elements similarly.

VI. CONCLUSION

Availability of sites in GSM networks is strongly depending on transmission quality. Access networks are rather interference than noise limited in dense urban areas. It was shown that radio frequency interference among existing links is a main source of degradation nowadays. Correct interference prediction may results in better frequency re-use thus more dense access network increasing capacity. The paper showed the importance of interference matrix in network design [20]. A method was proposed to estimate *T/I* values of interference matrices using a communication network simulator tool.

VII. ACKNOWLEDGMENTS

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