Frequency re-usage in radio planning systems

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***Abstract* — one of the main problems connected with radio planning is lack of free spectral resources. In the paper this issue is discussed. There are presented approaches uses in military and civilian systems. More flexible interference criterion is proposed in order to more efficient frequency usage. It base on signal to noise and interference ratio and protection ratio treated as a margin between useful signal level and interferences necessary to maintain requested bit rate. A simulation results show the tradeoff between the number of nets working on the same frequency, distances between them, its areas and MANET modes.**

Keywords—frequency planning, frequency re-usage, protection ratio.

I. INTRODUCTION

Lack of free radio spectrum resources is the stimulus for proposals of new more effective ways of its utilisation. One of such idea is the concept of cognitive radio. Cognitive radio can operate in a full autonomous manner via so called opportunistic access to the spectrum or in a coordinated one utilizing frequency broker [6]. This idea gives more flexible access to the frequency spectrum where other systems so called primary users (PU) or priority systems (PS) has license to utilize it. However it not resolves the problems with frequency shortcoming for priority systems. One of the sources of these difficulties is a policy of frequency allotment for such systems. A lot of frequency planning tools is based on classical approach. Long range communications links are taken into account as well as levels of interferences with reference to sensitivity of the receiver. This approach is valid for e.g. voice links in VHF/UHF in a 25-30 km links but achievable throughput for data services is far too low. Thus for data services shorter links are necessary what could be done via e.g. 2- or 3-hop mobile ad-hoc network (MANET). In such situation the level of useful signal at the receiver site is much higher and gives a margin for higher level of acceptable interferences. This gives an opportunity to frequency re-usage in nets located much closer one to other than it was acceptable before. To implement such mechanism in frequency planning system new criterion of systems and nets inter-compatibility has to be defined. Such criterion is presented in this paper. In the next chapter criteria of interferences in military systems as well as in civilian solutions are elaborated. Next in a chapter III proposed solution is discussed. Chapter IV deals with system model used for simulations and consecutive chapter V contain some simulations results.

II. CRITERIA OF INTERFERENCE

Most radio frequency planning systems currently used in the military environment are based on a classic approach. The main criterion is the worst case, i.e. when the link in the current radio network is the longest and the distance to the interfering transmitter is the shortest. Thus, the signal strength is minimal and the noise power (disturbances are treated as additional sources of noise) is the highest. The sensitivity level of the receiver is taken as the reference point. In such circumstances, the same frequency may be allocated only to a radio network located sufficiently far from the considered network so as not to impair the sensitivity of the receivers.

Such approach is becoming too rigid in a face of requirements and features of modern transceivers. Usually there is a need to allocate more than one frequency to the network in order to utilize frequency hopping, modern waveforms or other electronic warfare (EW) countermeasures. In a standard approach the lack of frequencies is one of the most important aspects limiting implementation of new radio systems.

A. Military Systems

To calculate parameters characterizing radio inter-system compatibility dedicated software tools are used. There are a lot of such programs like SPECTRUM XXI, Joint Automated CEOI System (JACS), Automated Communications Engineering Software (ACSE), Battlefield Spectrum Management (BSM) [1], WRAP [2] and the others.

In the SPECTRUM XXI system as a parameter to determine whether a frequency can be used in a given radio net *the Interference Conflict Margin* (ICM) is used. This parameter is a measure of protection against interference that occurs between a potentially interfering transmitter and an affected receiver. When all factors are expressed in decibels (dB) related to 1 Watt (dBW), the ICM formula takes the form:

$$\mathrm{ICM}_{[\mathrm{dB}]} = \mathrm{I}_{[\mathrm{dBW}]} - \mathrm{T}_{[\mathrm{dBW}]} \tag{1}$$

$$T = N + \Delta \tag{2}$$

where:

- I – the received interference power;
- T – the interference threshold of the receiver ;
- N – the noise level of the receiving system [dBW];
- Δ – the interference threshold relative to the noise level of the receiving system [dB].

By default the interference threshold (T) is set as an equal to noise figure of the receiving system. In such case the value of Δ is equal to zero and ICM reduces itself to:

$$ICM = I - N \tag{3}$$

ICM is then a measure of the level of received interference in relation to the noise power in the receiver. A positive ICM value indicates that the received interference is higher than the noise level of the received system, while its negative value indicates that the interference level is below the noise. The suggested I/N ratio is defined in the interference threshold table. For mobile terrestial radio communications services, the following I/N values are proposed:

- 0 dB – for analog systems;
- -6 dB – for digital systems.

B. Civilian Systems

This issue is much more widely considered in civilian systems, especially DVB-T. The reference document is the ITU-R BT.1368 recommendation [3]. The parameter used to determine the possibility of undisturbed operation is the protection ratio (PR). It is defined as the minimum value of the desired signal / unwanted signal ratio at the receiver input, usually expressed in decibels. This value is determined for defined conditions at which the appropriate reception quality of the signal at the receiver's output is achieved. The criterion defined in [3] is as follows.

For the digital terrestrial television system, ATSC, the protection ratios are measured for a BER = 3×10^{-6} at the input of the MPEG-2 demultiplexer. For the digital terrestrial television systems (digital video broadcasting-terrestrial (DVB-T) and integrated service digital broadcasting-terrestrial (ISDB-T)) the protection ratios are measured between the inner and outer codes, before Reed-Solomon decoding, for a BER = 2×10^{-4}, this corresponds to a BER < 1×10^{-11} at the input of the MPEG-2 demultiplexer. Co-channel protection ratios for a DVB-T signal interfered with by a DVB-T signal are presented in the table 1:

TABLE I. CO-CHANNEL PROTECTION RATIOS (DB) FOR A DVB-T SIGNAL INTERFERED WITH BY A DVB-T SIGNAL ([3], TABLE 15)

Modulation	Code rate	Gaussian channel	Rice channel	Rayleigh channel
QPSK	1/2	5	6	8
QPSK	2/3	7	8	11
16-QAM	1/2	10	11	13
16-QAM	2/3	13	14	16
16-QAM	3/4	14	15	18
64-QAM	1/2	16	17	19
64-QAM	2/3	19	20	23
64-QAM	3/4	20	21	25

III. PROPOSED INTERFERENCE CRITERION

Proposed approach is similar to presented for DVB-T system. First element of the proposed criterion is signal to noise and interference ratio (SNIR) i.e. the ratio between desired signal and undesired signals coming from other radios working on the same frequency including noise. The second one is desirable throughput.

More specifically following aspects should be taking into account in a case of modern transceivers:

- adaptive schemes of modulation and FEC and connected with it achievable bit rate;
- possibility to work in a MANET with specific number of relaying nodes (2-, 3- or more-hop nets);
- noise – in a classical approach to determine the usable sensitivity of the receiver, the own (thermal) noise of the receiver is taken into account. However, due to the high level of environmental changes associated with human activities, one of the main noise sources are human-generated interferences;
- services and necessary throughput.

Let's suppose that our aim is to allocate the same frequency nominal as many radio networks as possible. Networks are relatively close to each other so interference level is high. In a considered scenario interfering signal is transmitted on the same frequency as useful signal. On the receiver input are present two signals: useful and interfering one. Both signals are received with the levels resulting from transmitting powers and attenuations of the propagation paths. The useful signal will be treated as jammed if difference between its level and interference will be lower than necessary to maintain desirable bit rate

Above situation is depicted on the fig. 1. The receiver receive desired signal from the transmitter located 5 km away – marked red line (signal attenuation 120 dB) and undesired signal coming from another transmitter 15 km away – green line. The second signal is attenuated 140 dB. Because difference in signals levels is sufficiently high desired signal is considered as undisturbed in spite of the fact that interference is much over the sensitivity level – blue line. The distance between red and green signals can be treated as a protection ratio (PR) necessary to achieve desirable bit rate.

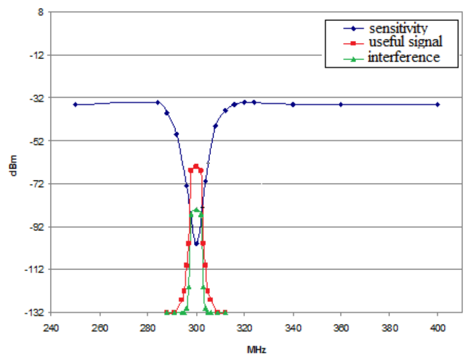

Fig. 1. Useful signal and interference on the same frequency

IV. SYSTEM MODEL

A. Broadband Radio

In order to validate proposed criterion exemplary modern radio with appropriate features were necessary. For simulation purposes, data were used as for R-450C broadband radio. It works in 225÷400 MHz band with adaptable channel width (4, 2 or 1 MHz). More detailed features were presented in [5]. Below, in the table 2, are presented exemplary modulation schemes and SNR thresholds.

TABLE II. SELECTION OF MODULATION DEPENDING ON SNR

Scheme no.	SNR [dB]	Modulation	FEC	Bit rate [Mb/s]
1	10	BPSK	3/4	0,5
2	13	QPSK	2/3	0,5
3	16	QPSK	7/8	0,5
4	19	16QAM	2/3	1
5	22	16QAM	7/8	1,5
6	27	64QAM	3/4	3
7	29	64QAM	7/8	7

B. Noise Level

Noise levels and its sources are the subjects of the ITU-R P.372-13 recommendation [4]. There are data about noise levels in frequency range from 0.1 Hz to 100 GHz coming from atmospheric discharges, man-made sources as well as cosmic and low layers of the atmosphere.

The basic formula (P.372-13 eq. 6) is as follows:

$$P_n = F_a + B - 204\ dBW \tag{4}$$

where:

- P_n – available power, 10log p_n (W);
- F_a – external noise figure;
- B – noise power bandwidth of the receiving system (Hz), 10log b;
- and -204 = $10logkT_0$, (k: Boltzmann's constant, T_0: reference temperature taken as 290 K).

External noise figure is taken from measurements [4]:

TABLE III. OUTDOOR MAN-MADE NOISE MEASUREMENTS IN EUROPE

Frequency (MHz)	Median noise figure F_a (dB rel kT_0b)			Upper decile deviation			Lower decile deviation		
	City	Residential	Rural	City	Residential	Rural	City	Residential	Rural
35	23	17	16	7	5	1	1.5	2	2
140	12	8	6	4	2	2	3	3.5	2
210	16	8	5	1	2	1	2	1	2
270	6	4	4	2	2	1	2	1	1
425	6	4	3	1	2	1	1	1	1

Since measurements were made only for few frequencies some approximations were necessary. Moreover there are various data for city, residential and rural environment. Thus three equations were defined to approximate noise in the whole considered frequency range.

City:

$$\mathrm{F_a} = \begin{cases} \mathrm{f} * \left(-\frac{1}{6}\right) + 51 & \mathrm{f} < 270 \\ 6 & \mathrm{f} \geq 270 \end{cases} \tag{5}$$

Residential:

$$F_a = \begin{cases} f * \left(-\frac{1}{15}\right) + 22 & f < 270 \\ 4 & f \geq 270 \end{cases} \tag{6}$$

Rural:

$$F_a = \mathrm{p1} * f^2 + \mathrm{p2} * \mathrm{f} + \mathrm{p3} \tag{7}$$

where f is the frequency [MHz], p1=4.7512e-05; p2=-0.039472; p3=11.194;

C. Scenarios

To confirm that at the stage of planning the frequency assignment it is reasonable to take into account the specificity of the network's work following research scenarios were considered:

- Re-allocation of a given frequency in a different radio network depending on the value of the protection ratio (the bit rate planned to obtain) and the distance between the networks;
- Possibility of re-allocation depending on the number of relaying nodes in the MANET network;
- Reallocation of the frequency depending on the physical area of the radio network.

For such scenarios Matlab simulation program was prepared. Following assumptions were made:

- number of radio nets equal to 9 on the plan of the square 3 by 3 nets;
- each net consist of 10 radios randomly placed on the plane of square;
- the distance between central points of the nets is variable and the same for all nets;
- in order to assess influence of the interfering signal the worst case is taken into account i.e. the longest link in the net (diagonal of the square) versus the shortest distance between radios belonging to different nets (the highest level of interference).

The fragment of the simulation scenario is depicted in the fig. 2.

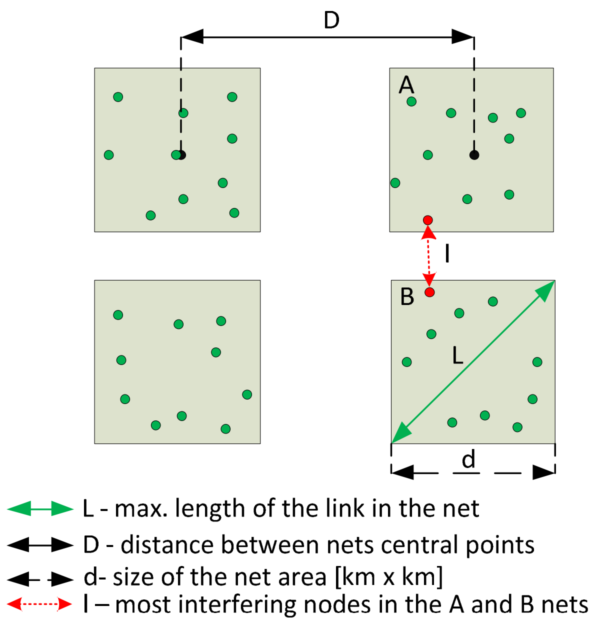

Fig. 2. Fragment of Matlab simulation scenario

The plot of terrain on which all nine nets are located has dimensions:

$$2D + d \quad (8)$$

in both directions.

V. Simulation Results

Simulation model required some additional data like propagation model as well as data connected with radio equipment. More specifically in the simulation Hata model for rural environment was used and radio with features as presented in the table.

TABLE IV. PARAMETERS OF MODELED RADIO

Transmitted power	20 W
Channel bandwidth	2.5 MHz
Frequency range	225-400MHz
Antenna height	5 m
MANET mode	3 hops max.

A. The Influence of the Network Area

In this scenario the distance between centers of radio nets was fixed and equal to 10 km. The extent of the radio network and possibility of using MANET mode were parameters which were changed over consecutive simulation loops. Results are shown in the table V. The first column contains areas of the networks which were considered (from 2x2 km to 7x7 km) and three cases for each of them:

- there are only direct links available (no hop);
- one retransmitting node between source and destination (1-hop net) and;
- two retransmitting nodes (2-hop net).

Consecutive columns show numbers of nets with possibility of reuse the same frequency. The whole area where the nets are placed is in general 2D+d (see Fig. 2) and in considered scenario varies from 22x22 km to 27x27 km.

TABLE V. THE INFLUENCE OF THE NETWORK AREA AND MANET MODE

Network area [km x km]	**No of nets with the same frequency allocation**		
	PR 29 dB	**PR 27 dB**	**PR 22 dB**
2x2 (no hop)	3	3	5
2x2 (1- hop)	7	8	9
2x2 (2- hop)	9	9	2
4x4 (no hop)	**0***	1	4
4x4 (1- hop)	3	4	5
4x4 (2- hop)	4	5	**0***
6x6 (no hop)	**0***	**0***	2
6x6 (1- hop)	1	2	4
6x6 (2- hop)	3	3	**0***
7x7 (no hop)	**0***	**0***	2
7x7 (1-hop)	**0***	1	3
7x7 (2-hop)	2	2	5

*SNR for the longest link in the net too low for desirable bit rate

The first conclusion of the research is rather obvious if the network area is small the signal level even for the longest link in the net is sufficient to achieve desirable bit rate. Moreover there is enough power margin to re-allocate the same frequency in another nets. Of course in MANET length of the links is shorter thus the margin for interferences is broader. Together with the growing extent of the links (the net is placed on the bigger area) this margin becomes smaller and smaller.

B. The Influence of the Distance Between Nets

Above scenario was rather static. In real it is difficult to assume that in a case of movement spatial relations between networks will be preserved. To find out if there is a margin when the nets are closer and closer to one another in the second scenario the network area was fixed but the distance between nets was shortened. The network area was set 2 x 2 km and the distance between nets was changing from 10 km to the moment where there was no possibility to maintain desirable bit rate. Thus the area were the nets were located had been changing from 22 by 22 km to 4 by 4 km. The last one size is the case where distances between center points of nets are equal to 1 km. Results are shown in fig.3-4.

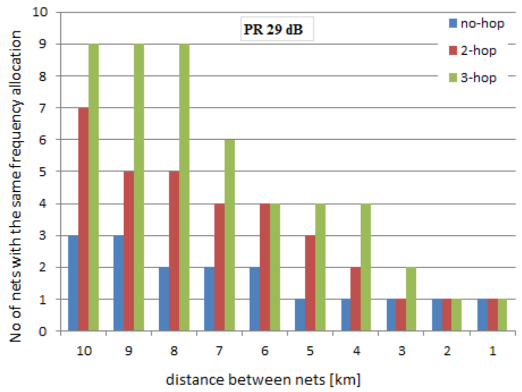

Fig. 3. Number of nets with the same frequency allocation against the distance, PR 29 dB

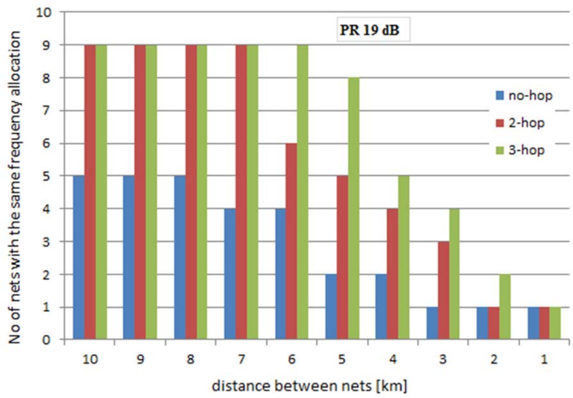

Fig. 4. Number of nets with the same frequency allocation against the distance, PR 19 dB

As one can see on the above figures there is enough space in the interference margin to allocate the same frequency more than one radio net even if there are spaced closer than 10 km each other. However it is clear that it is a tradeoff between achievable bit rate, distance between nets and the network area. According to results presented in the figure 3 for a networks where requested bit rate is very high (in considered case 7 Mb/s) direct link between each nodes (no-hop) is possible if interfering net is spaced no closer than 6 km each other. In other case to maintain requested bit rate MANET mode is necessary. On the other hand if required bit rate could be not as high e.g. 1Mb/s there is a much bigger field for frequency planning system to allocate frequencies to more than one net. In the fig 4 one can see that there are even four nets working on the same frequency at the distance of 6 km with no-hop manner.

VI. Conclusions

In the paper the problem of frequency re-allocation was discussed. As a starting point criterion similar to civilian commercial systems like DVB-T was proposed. The idea is to use in a planning stage parameters connected with requested bit rate like protection ratio i.e. the distance (in dB) between all interfering signals and the level of useful signal instead of receivers sensitivity and noise figures of the receiving systems. As simulation results show there is a possibility of re-usage the same frequency and maintain quite high bit rate in the link especially if the net is on the not very extended area like 2x2km or 3x3km even relatively close to each other. Another aspect is MANET modes which make possibilities of re-allocation much broader. However it need be necessary to define the policy of using it e.g. how many hops is acceptable (if any) because of delays or other operational aspects.

References

[1] M. Suchański, P. Gajewski, J. Łopatka, P. Kaniewski, R. Matyszkiel, and M. Kustra, "Coordinated Dynamic Spectrum Management in Legacy Military Communication Systems," WinnComm-Europe, 2016.

[2] W. Meisel, "Automated Spectrum Plan Advisor for On-The-Move Networks," MILCOM 2006.

[3] Recommendation ITU-R BT.1368-13 (06/2017). Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands.

[4] Recommendation ITU-R P.372-13 (09/2016). Radio noise.

[5] R. Matyszkiel, P. Kaniewski, R. Polak and, D. Laskowski "The result of transmission tests of polish broadband SDR radios," Conference: Communication and Information Technologies (KIT), Vysoke Tatry, SLOVAKIA, pp. 150-155, 2017

[6] M. Suchański, P. Gajewski, J. Łopatka, P. Kaniewski, R. Matyszkiel and, M. Kustra "Coordinated Dynamic Spectrum Management in Legacy Military Communication Systems" WinnComm-Europe Paryż 2016 r.