The Mathematical Model for Interference Simulation and Optimization in 802.11n Networks

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Abstract. One of the key problems in 802.11 standard networks are interferences. It is not possible to avoid the influence of other wireless systems. One can only minimize the power level of unwanted signals. Typically the designer should find the best localization of access points (AP), but there is no planning and coordination between different private networks. To reduce the level of interferences, the transmitting power reduction is applied. The mathematical model was built to analyze the relationship between the coverage and the level of interferences. The results of these simulations are presented in this article.

Keywords: Wi-Fi, interferences, 802.11n standard, WLAN, throughput

1 Introduction

The 802.11 standard networks are the most popular solution of wireless communication today, besides the mobile telephony networks. One of the key problems in such networks is the issue of interferences (see [6]). The main sources of interferences are various radio systems or devices, which operate on the same or similar frequency range. These networks produce both, adjacent and inter channel interferences. The reduction of internal system interferences is crucial for obtaining the proper QoS of the transmissions (see [1]). Basic methods of the interference limitation implement proper planning, which means the proper arrangement of the access point localizations. The next step is a selection of the transmission frequency dedicated for each channel. Such planning is not possible in any network. One of the important features of the 802.11 networks is the fact, that they operate at the public free frequency range (ISM Industrial, Scientific, Medical), so the high number of different devices can operate at the same time on a similar area. These devices could be elements of home or office networks. There is no coordination between such networks.

Another method of interference reduction is the diminish of the transmitted power (see [7]). In the authors opinion this method is not very efficient especially, if the coverage is an important issue. The authors built the theoretical model and carried out several calculations to show both advantages and disadvantages of such solution.

2 The Structure of 802.11n Physical Layer

The structure of the Physical Layer has a great influence on the internal system interference level. For 2.4 GHz transmission frequency range, only three channels (numbered 1, 6 and 11) are the so called not overlapping channels (see [9]). The standard deviation between the central frequencies of these three channels is 25 MHz. The level of signal within a channel is limited by the mask. The mask is a filter with specially developed characteristic. The characteristics of filters for 1, 6 and 11 channels in the 802.11n standard are presented in Fig. 1.

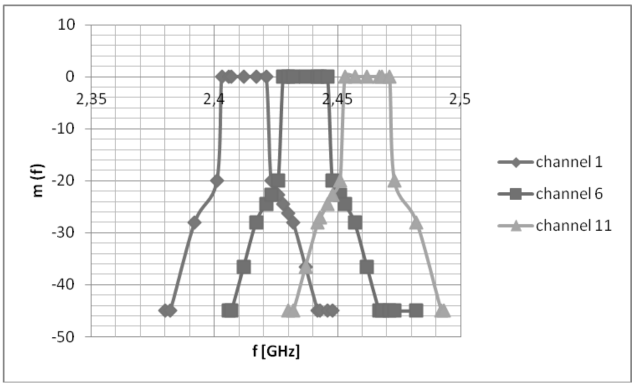


Fig. 1. Filter's (masks) characteristics for 1, 6, 11 channels in the 802.11n standard. Source: own preparation.

The channel masks overlap partly, even for non overlapping channels. Some interchannel interferences are always present in the system, when more than one network is operating on the same area. The final level of the interference signal power depends strongly on many parameters. The distance plays an important role, because the level of the received power decreases while increasing the distance between Wi-Fi stations. Two disadvantages are produced by interferences (see [2]). The first is the diminish of signal to noise ratio, because the interference power is treated as noise within the transmission channel. The thermal noise and the interference power are produced by uncorrelated sources, so we can calculate the summarized noise as the sum of power density of the thermal noise and the interference power (see [8]):

$$P_{noise} = P_{int} + P_{white\_noise} \, . \tag{1}$$

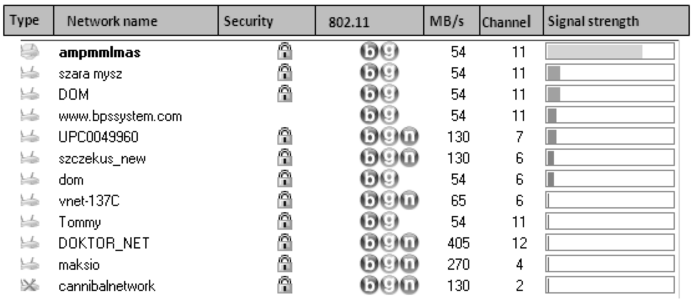
The noise power diminishes the channel throughput. The throughput is the most important parameter determining the QoS of the transmission. The channel throughput could be described by the following formula (see [3]):

$$C = B \ln \left(1 + \frac{P_{signal}}{P_{noise}} \right) \, , \tag{2}$$

where B represents the bandwidth of the transmission channel. The second disadvantage of interferences especially, when their signal power is relatively high, is the effect of the spurious carrier detection. The high level of interference power blocks the transmission channel. Some methods of interference level reduction are discussed in the next section.

3 The Methods of Interference Level Reduction

A high level of interference power could be reduced by a proper arrangement of access points (see [4]). It is possible only in some networks eg. private networks, company networks. On the other hand, in some networks, the access points are arranged in a totally chaotic way. There is no coordination of AP localization and no coordination of utilized channels. An example of a set of private networks is shown in Fig. 2. Such a situation happens very frequently, especially in the multi-family or office buildings.



Type	Network name	Security	802.11	MB/s	Channel	Signal strength
	ampmmlmas	🔒	b g	54	11	
	szara mysz	🔒	b g	54	11	
	DOM	🔒	b g	54	11	
	www.bpssystem.com		b g	54	11	
	UPC0049960	🔒	b g n	130	7	
	szczekus_new	🔒	b g n	130	6	
	dom	🔒	b g	54	6	
	vnet-137C	🔒	b g n	65	6	
	Tommy	🔒	b g	54	11	
	DOKTOR_NET	🔒	b g n	405	12	
	maksio	🔒	b g n	270	4	
	cannibalnetwork	🔒	b g n	130	2	

Fig. 2. The sample set of private 802.11 networks. Source: own measurement (Card WLAN Monitor–Dell Wireless 1450).

Many devices use the same channel (5 devices - channel nr 11), some devices use channels other then 1, 6, 11, so the choice of a channel is random. Network planning let us achieve capacity, range and QoS (see [7], [4], [5]). There are several methods of WiFi network planning described in the literaturte, e.g. Neldeare-Mead direct planning (see [4]). This method enables the optimal determination of localization of AP stations. The coefficient of channel frequency reuse could be calculated (co channel interference reduction factor). This factor is the function of the number of available channels/frequencies especially those not overlapping and could be expressed by following formula:

$$Q = \sqrt{3}N, \tag{3}$$

where the N is the number of available channels.

The second solution suggests [7] reduction of transmitted power, but as a side effect a decrease of coverage occurs. This solution reduces the interference power level, but on the other hand leads to dead areas with no coverage, what is shown in Fig. 3.

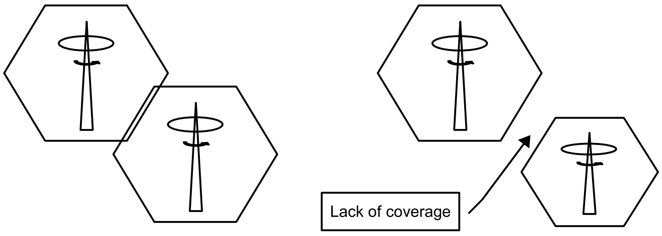


Fig. 3. Effects of transmitted power reduction. Source: own preparation.

The smaller is the coverage of one cell, the more cells we have to produce to obtain the full coverage. This means more APs and in the end, more transmissions at the same time, but it does not mean that we reduce the interference power level. The authors present some proof in Sec. 5 and Sec. 6.

4 Correlation Between Coverage, Transmitted Power and the Interference Power Level

The basic equation, which describes the radio wave distribution in a free space is the Friis formula (see[3]):

$$P_{rx}\left(r\right)=\frac{P_{tx}G_{rx}G_{tx}\lambda^2}{\left(4\pi r\right)^2}=\frac{P_{tx}G_{rx}G_{tx}c^2}{\left(4\pi r\right)^2f^2}. \tag{4}$$

This formula allows us to calculate the received power (P_{rx}) depending on the transmitted power (P_{tx}), the gains of receiving and transmitting antennas (G_{tx}, G_{rx}), the channel frequency f and the distance between the transmitter and receiver (in so called free space, the r power is equal 2):

$$P_{rx}(r)=\frac{k}{f^2r^2}. \tag{5}$$

Using the formula (4) we can calculate the attenuation of radio signal in a free space:

$$P_{odb}\left(r\right)=P_{tx}G_{rx}G_{tx}L_{fspl}, \tag{6}$$

$$L_{fspl}=\frac{c^2}{\left(4\pi r\right)^2f^2}=\frac{\left(3\cdot10^8\right)^2}{\left(4\pi r\cdot10^3\right)^2f^2\cdot\left(10^6\right)^2}=\left(\frac{40\pi fr}{3}\right)^{-2}. \tag{7}$$

L_{fspl} could be presented in the logarithmic scale:

$$L_{fspl}[dB]=-10\log L_{fspl}, \tag{8}$$

and finally we obtain the following formula [6]:

$$L_{fspl}[dB] = 32,44 + 20\log r[km] + 20\log f[MHz], \tag{9}$$

where r is in [km] and f in [MHz]. The more general formula takes the following form (see [6]):

$$L_{fspl} = \frac{c^2}{16\pi^2 r^\alpha f^2} \tag{10}$$

This formula for frequencies f in [Hz] or [MHz] can be rewritten respectively as:

$$L_{fspl}[dB] = -147.6 + 10\alpha\log r[m] + 20\log f[Hz], \tag{11}$$

$$L_{fspl}[dB] = -27.56 + 10\alpha\log r[m] + 20\log f[MHz]. \tag{12}$$

The α coefficient is rather unstable in time and very sensitive to the environment e.g. it changes strongly in rooms.

The coverage in the 802.11n standard is determined by the minimal received power (received signal sensitivity), which is necessary for obtaining required level of throughput. The set of minimal received power in the case of a single spatial transmission in 802.11n standard is presented in Table 1.

Table 1. Minimal received signal sensitivity for the station operating in SISO mode

MCS Index	**Modulation/coding**	**Data Rate [Mbit/s] 20MHz channel**	**Received signal sensitivity [dBm]**
0	BPSK/1:2	6.5	-82
1	QPSK/1:2	13.0	-79
2	QPSK/3:4	19.5	-77
3	16QAM/1:2	26.0	-74
4	16QAM/3:4	39.0	-70
5	64QAM/2:3	52.0	-66
6	64QAM/3:4	58.5	-65
7	64QAM/5:6	65.0	-64

The minimal sensitivity is respectively -82 dBm for throughput of 6.5 Mbit/s and -64 dBm for 65 Mbit/s. It is difficult to correlate these values with a specific distance, because in practice this distance could vary in a broad range due to a lot of factors.

5 The Analysis Assumptions

The authors tried to verify the assumption that the decreasing of transmission power and reduction of coverage help to diminish the internal interferences in

802.11n networks (see [7]). The analysis was reduced to a model with one spatial stream in 802.11n standard. One spatial stream means the use of the SISO (Single Input Single Output) antenna solution. The isotropic characteristic of transmission power is also the assumption. The analysis was carried out for three non overlapping channels 1, 6 and 11. The Tx and Rx configurations are presented in Fig. 4.

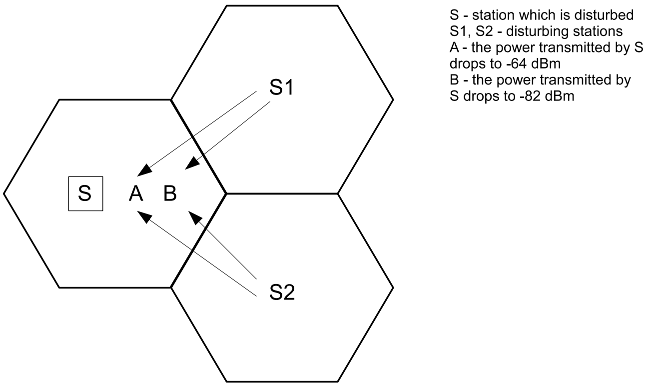


Fig. 4. Station configurationw, where the S station is disturbed by S_1 or S_2 or both the stations at the same time. Source: own preparation.

The Table 2 includes the channel allocation, which is used in simulation.

Table 2. Channel number allocation for stations S, S_1 and S_2

Channel Number		
S1	**S**	**S2**
11	6	-
11	6	11
6	6	11
6	6	6
-	6	6
1	6	1

We assume that all stations are the transmitters. The localization of a station within the cell (coverage area) could vary from the center of the area to its edge. We analyze the 802.11n standard with 20 MHz channel bandwidth. The center frequencies for channels 1, 6, 11 are shown in Table 3.

The interference power level was calculated as the sum of interferences from stations S_1 and S_2 and white noise and the noise figure representing the noise

Table 3. Center frequencies for channels 1, 6, 11

Channel number	**Center frequency [GHz]**
1	2.412
6	2.437
11	2.462

of electronic circuits (mainly electronic amplifiers).

$$P_{int} = \sum_{x=1}^{2} P_{intx} + (P_{white\_noise} + P_{NF}) \ . \tag{13}$$

White noise or thermal noise [3] within the channel bandwidth could be described as:

$$P_{white\_noise}(f) = kT \, [W/Hz] \ , \tag{14}$$

T denotes the environment temperature in K degree, while k is a Boltzman constant. Threshold of white noise in 1 Hz bandwidth at 0 Kelvin degree is -228.6 dBW. White noise in B bandwidth can be calculated as:

$$P_{white\_noise}[dBm] = 10 \log(kTB) \, . \tag{15}$$

The white noise in 20 MHz channel at 17 C degree could reach the following level:
$P_{white\_noise}(T = 17°C, B = 20MHz) = -174 + 10\text{log}B = -131dBm$.
The following formula was developed by the authors to calculate the received power:

$$\begin{aligned} P_{received}(r) = M(f - 2412 - 5(K-1)) + P_{transmitted} \\ -(-27,56 + 10\alpha \log r[m] + 20 \log f[MHz]) + G_{sum} . \end{aligned} \tag{16}$$

We will denote $P_{received}$ and $P_{transmitted}$ by P_{rx} and P_{tx} respectively. The $M(f)$ function represents the mask (filter) of the relevant channel. The signal outside the mask is eliminated while the one below the mask characteristics passes. The authors assume that the mask characteristic determines the maximal internal level of interferences. G_{sum} is equivalent to the additional gain of the system including the influence of the antennas of the receiver and the transmitter and respectively the gain connected with modulation, coding and different types of signal dispersions. P_{tx}, α and G_{sum} are the parameters of the simulation and their values are presented in Table 4.

The parameters of $m(f)$ function correspond to the mask of 802.11n standard. We assume that the function (for f in MHz) is continuous, piecewise linear and

Table 4. Simulation parameters values range

Transmitted power [dBm]	**Alpha parameter**	**Additional gain [dB]**
-10 to 20	2 to 8	0 to 15

is described by the following formula:

$$m(f) = \begin{cases} 0 & \text{for } f \in (-\infty, -30] \\ 2f + 60 & \text{for } f \in [-30, -20] \\ \frac{5}{9}f + \frac{280}{9} & \text{for } f \in [-20, -11] \\ 10f + 135 & \text{for } f \in [-11, -9] \\ 45 & \text{for } f \in [-9, 9] \\ -10f + 135 & \text{for } f \in [9, 11] \\ -\frac{5}{9}f + \frac{280}{9} & \text{for } f \in [11, 20] \\ -2f + 60 & \text{for } f \in [20, 30] \\ 0 & \text{for } f \in [30, \infty) \end{cases} \tag{17}$$

The stations are placed on Cartesian plane. The S transmitter has the (x, y) coordinates and S_1 respectively (x_1, y_1). The distance d_1 between the above stations is equal:

$$d_1 = \sqrt{(x - x_1)^2 + (y - y_1)^2}\,. \tag{18}$$

The practical formula for interference power level, which influences the S station (operating on channel 6) in d_1 distance from the station S_1, producing interferences while operating on channel 11, will be as follows:

$$P_{rx}(d_1) = M(f - 2462) + P_{tx} - (-27.56 + 10\alpha \log d_1[m] + 20 \log 2462) + G_{sum}. \tag{19}$$

The average interference power within the whole channel is the integral from P_{rx} over f within the proper channel (6th in our case):

$$P_{rx}(d_1)average = \int_{2.427}^{2.447} P_{rx} df\,. \tag{20}$$

The authors correlate the distance d_1 with the minimal received signal sensitivity (see Table 3).

6 The Simulation Results

In the first simulation the station S, operating on channel 6, was disturbed by S_1 station, operating on channel 11. The transmitting power distribution was firstly simulated. The figure 5 shows the distribution of points correlated with

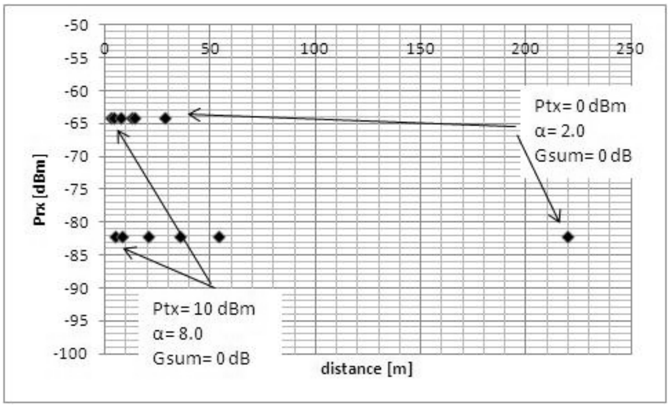


Fig. 5. Change of coverage in channel 6 versus P_{rx}, α and G_{sum}. Source: own preparation.

respectively -64 dBm and -82 dBm of received power (upper and lower lines). This analysis concerns the transmission in channel 6. We assume that the power transmitted by the S station is equal to receiver sensitivity.

The points corresponding to the -64dBm received signal are within the range from single meters to about 25 meters, while these corresponding with -82 dBm are within the range from a few meters to more than 200 meters. The coverage diminishes especially for the higher value of α. Figure 6 presents the characteristics of the diminish of transmitted power with distance for different values of P_{rx}, α and G_{sum}. The critical parameter is the α. The highest slope is for $\alpha = 8$.

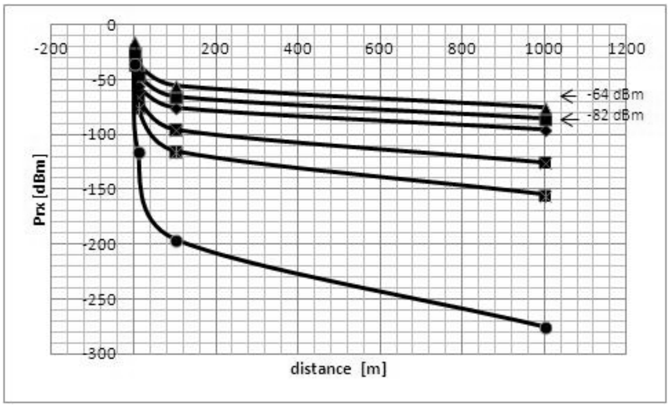


Fig. 6. The characteristics of received power in channel 6 versus P_{rx}, α and G_{sum}. Source: own preparation.

The characteristics of the interference power for the fixed distance beetwen S and S_1 are presented in Fig. 7. The P_{int} characteristics are versus the level of the disturbances source power. The following assumptions are made: the S is transmiiting in the channel nr 6, P_{tx} is 10 dBm, G_{sum} is 0 [dBm] and $\alpha = 3$; while the S_1 station (disturbing) is transmitting in the channel nr 11, G_{sum} is 0 [dBm], α is 3 and the P_{tx} change in the range from -10 to 20 dBm. The point of the interference level calculation coresponds with the maximum coverage of the S station, where the P_{rx} is -82dBm. This distance is 53,38 m while the distance between stations is 106.76m. The results are shown in Fig. 7.

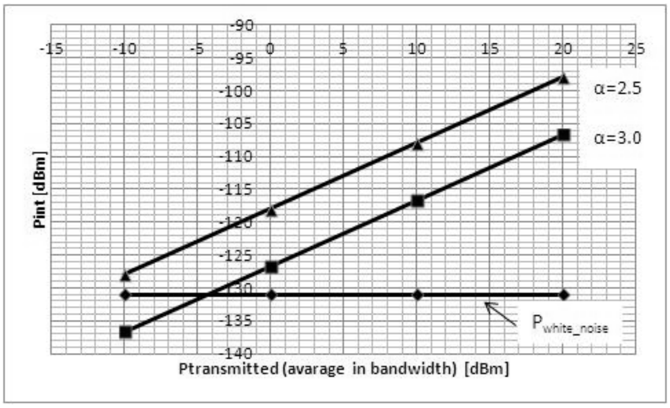


Fig. 7. The characteristics of the interferences power level for d1=53.38 m versus P_{rx}. Source: own preparation.

The interference power level diminishes, when the P_{tx} of S_1 diminish, but at the same time the coverage area is reduced, so the dead zone arises with no possibility of transmission. The white noise could have higher level than interference power for low P_{tx} of disturbing station and for non convenient transmission conditions (high value of the α coefficient- eg. rooms, halls etc.).

The characteristics of interference level with another assumption is presented in fig. 8. In this case together with the change of the P_{tx} we change the point of S_1 localization (x_1,y_1) to reduce the dead zone. The point of the interference level calculation (distance from S) is constant and its value is 53.38 m, but the distance between S and S_1 stations (d_1) diminishes relatively to P_{tx} (S_1) reduction. The dead zone is minimized. The level of interference power is constant versus P_{tx} and α values (Fig. 8). The next simulation concern the situation when the P_{tx} power is increased for both S and S_1 and the interference power level is calculated for maximum coverage points corresponds with received power equal -82 dBm (Fig. 9). The results of the simulation are the same as previously. The inteference power level is higher than the thermal noise, but if we take into account the the electronic circuits noise figure, then the total noise could be above interference power level.

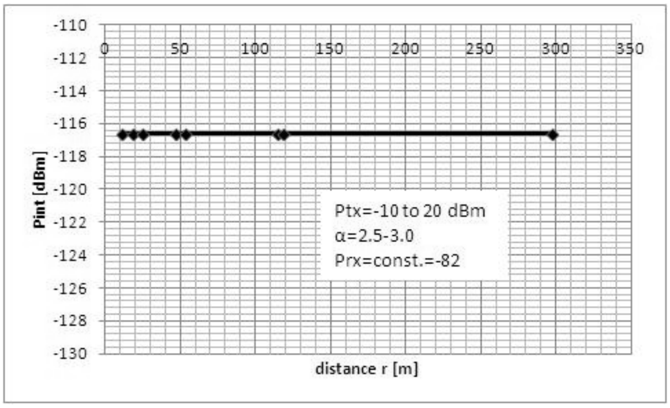


Fig. 8. The interferences level characteristics, where the distance from S is constant (53.38 m) while S_1 changes its position (r). The r distance each time corresponds to -82 dBm power level. Source: own preparation.

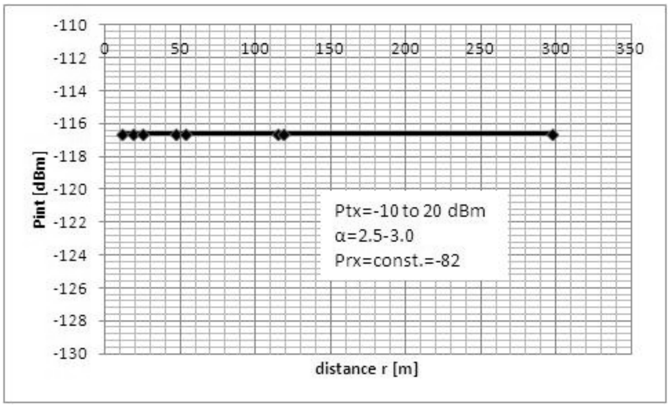


Fig. 9. The interferences power level versus changes of P_{tx}, $P_{int} = f(P_{transmitted})$ for r [m] relative to $P_{received}$ =-82 [dBm], with the assumption that both the P_{tx} and the distance between stations is reduced. Source: own preparation.

7 Conclusions

The model for interference power level simulations from one or two disturbing sources (S_1 /S_2) was developed. The model includes the efects of the mask and several other parameters such as antennas gain, modulation coding and dispersion gain (G_{sum} coefficient). The following simulations based on this model were carried out :

1. the characteristic of interference power level, when the P_{tx} of source of disturbances is reduced, but the localisation remains the same (see Fig. 7) ,

2. the characteristic of interference power level, when the P_{tx} of source of disturbances is reduced, but the localisation is changed to avoid the dead zone (see Fig. 8),
3. the characteristic of interference power level, when the P_{tx} of source of disturbances is changed as well as the power of disturbed station S and the localisation of both stations is also changed to avoid the dead zone (see Fig. 9).

Taking into account the mentioned above simulations, we can conclude:

1. for the 1st simulation: the power level of interferences decrease, but the coverage diminishes at the same time,
2. for the 2nd simulation: the interference level is constatnt,
3. for the 3rd simulation: the interference level is constatnt.

The achieved results let us make a conclusion, that reduction of P_{tx} could reduce the interference power level, but at the same time cause the dead zone to arise. This solution may be applied, if the station is close to AP, so we can temporary (for one or more sessions) reduce transmission power, keeping reasonable throughput. This solution requires communication between different APs to establish the most efficient transmission power level. Such solutions are not available nowadays.

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