International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Radio Frequency Interference: Sources, Mathematical Formulation and Resolution Methodology

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Abstract
The main mission of the telecommunications regulator is to ensure the equitable management of radio frequency resources and to intervene in the event of disputes between actors in the sector. The rational use of allocated frequencies often encounters difficulties that sometimes require the intervention of the regulator. The problem of radio frequency interference is the most recorded. In this paper, we will focus on radio frequency interference while addressing the problem under three key points: interference sources, mathematical interference formulation, and proposed resolution methodology.

Keywords: regulator, interference, radio frequency, resolution

1. Introduction
Telecommunication is the set of hardware and software means used to exchange information over long distances based on electronic devices. The market for cellular transmission technologies (mobile telephony) has experienced a growth dynamic that has been accompanied by many technological innovations from analog transmission to digital standards with GSM, GPRS, EDGE, UMTS and LTE.

With these new perspectives, mobile networks raise new security concerns. Wireless access is inherently less secure than wired access. Indeed, due to the nature of the mobile (wireless) network, it is virtually impossible to confine radio signals to a controlled region. These radiated signals can be intercepted and exploited clandestinely. Security mechanisms have been developed in response to these vulnerabilities. However, there are essential points that need to be pursued for development and improvement. In this paper, we will focus on the problem of interference, also known as radio frequency interference, which is a major obstacle, easy to implement and has serious consequences for the user's network.

Radio frequency interference is a technique for transmitting a radio signal, aimed at interrupting communications while reducing their signal-to-noise ratios, which is frequently used in mobile networks to intercept, modify and listen to the information transmitted. Our goal is to study this problem in order to

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better understand its causes and to propose a methodology for resolution.

Paper organization

The rest of this paper is organized as follows: in section 2, we will present the interference sources; the section 3 will focus on the mathematical formulation of interference and we will present our resolution methodology in section 4.

Paper contribution

In this paper we have presented a mathematical formulation of interference using two sinusoidal signals of the same impulse ($\omega 1 = \omega 2 = \omega = 2\pi f$) and different phases; Shown using the amplitude of the resulting signal, the different types of interference and then the calculation of the limit of the resulting signal, allowed us to demonstrate that when approaching one of the sources (normal source of emission and / or source of emission of noise), the resulting signal is similar to the signal emitted by this source.

2. Interference sources

Interference a radio channel means placing a high-power source close to the user and having it transmit at the frequency of the channel. In other words, it is transmitting at a high power with the same frequency of the channel or a frequency very close to that used by the latter. Generally, there are two sources of interference: internal interference and external interference.

Internal interference in most cases is due to poor frequency planning. When configuring radio sites, it is important that the radio service has a good frequency plan in place to avoid interference and many other defaults that may arise on the user network. The detection of this problem can be done following the analysis of network performance indicators, following customer complaints or following a drive test.

The external interference comes from a stand-alone external source. In the case of mobile phone companies, it most often occurs when an operator transmits waves on a frequency occupied by another, without havingchecked beforehand. It can be intentionally launched by men in the field in order to degrade the quality of service.

3. Mathematical formulation of interference

a. General expressions

Radio frequency interference is a technique for transmitting a radio signal, aimed at interrupting, often voluntarily, communications, by decreasing the signal-to-noise ratio. It can be interpreted by the sum of two signals of the same frequency, which would reflect the phenomenon of interference.

We will present in this paragraph the sum of two sinusoidal signals of the same frequency f, so of the same pulsation $\omega_1 = \omega_2 = \omega = 2\pi f$. Let be two sinusoidal signals $\mathbf{s_1(t)}$ **and** $\mathbf{s_2(t)}$**,** of respective equations:

$\mathbf{s_1(t)= A_1 \cos (\omega t + \varphi_1)}$ and $\mathbf{s_2(t)= A_2 \cos (\omega t + \varphi_2)}$.

The resulting signal, which is the sum of these two signals, is in the form:

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$S(t) = s_1(t) + s_2(t)$

$S(t) = A_1 \cos(\omega t + \varphi_1) + A_2 \cos(\omega t + \varphi_2)$

$S(t) = A_1 (\cos \omega t \cos \varphi_1 - \sin \omega t \sin \varphi_1) + A_2 (\cos \omega t \cos \varphi_2 - \sin \omega t \sin \varphi_2)$ $S(t) = (A_1 \cos \varphi_1 + A_2 \cos \varphi_2) \cos \omega t - (A_1 \sin \varphi_1 + A_2 \sin \varphi_2) \sin \omega t$

It is clear from this sum that the result is a sinusoidal signal of the same pulsation as the $s_1(t)$ and $s_2(t)$ signals. The amplitude of the resulting signal is therefore:

$A^2 = (A_1 \cos \varphi_1 + A_2 \cos \varphi_2)^2 + (A_1 \sin \varphi_1 + A_2 \sin \varphi_2)^2$

$A^2 = A^2_1 (\cos^2 \varphi_1 + \sin^2 \varphi_1) + A^2_2 (\cos^2 \varphi_2 + \sin^2 \varphi_2) + 2 A_1 A_2 (\cos \varphi_1 \cos \varphi_2 + \sin \varphi_1 \sin \varphi_2)$ $A^2 = A^2_1 + A^2_2 + 2 A_1 A_2 [½ (\cos(\varphi_1 - \varphi_2) + \cos(\varphi_1 + \varphi_2)) + ½ (\cos(\varphi_1 - \varphi_2) + \cos(\varphi_1 + \varphi_2))]$ $A^2 = A^2_1 + A^2_2 + 2 A_1 A_2 \cos(\varphi_1 - \varphi_2)$

Hence: $A = \sqrt{A^2}$

The result reflects the fact that the amplitude of the sum is not equal to the sum of the amplitudes. The following cases are distinguished:

When both waves are in phase, i.e. $\varphi_1 = \varphi_2$, the resulting signal reaches its maximum possible amplitude (**$A = A_1 + A_2$**). We talk about constructive interference:

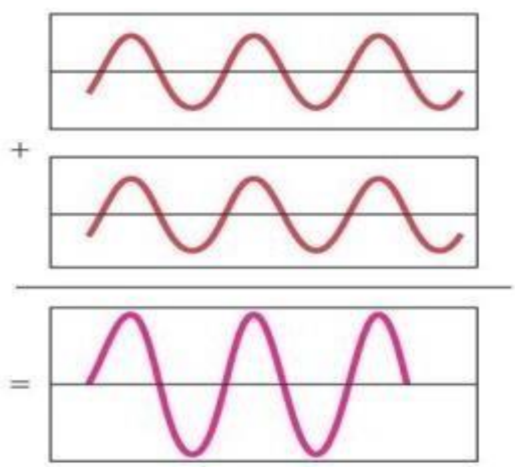

Figure 1: Constructive interference

When the two waves are in opposition of phases, i.e. $\varphi_1 = \varphi_2 + \pi$, the resulting signal reaches its minimum possible amplitude (**$A = A_1 - A_2$**). In particular, if $A_1 = A_2$ then $A = 0$. This is called destructive interference:

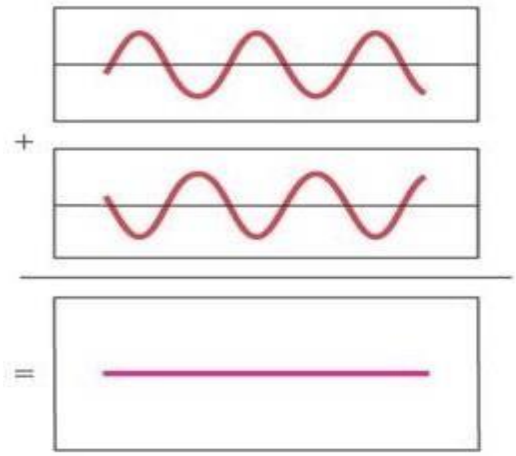

Figure 2 : Destructive interference

When the two waves are in quadrature, i.e., $\varphi_1 - \varphi_2 = \frac{\pi}{2}$, we speak of partial interference:

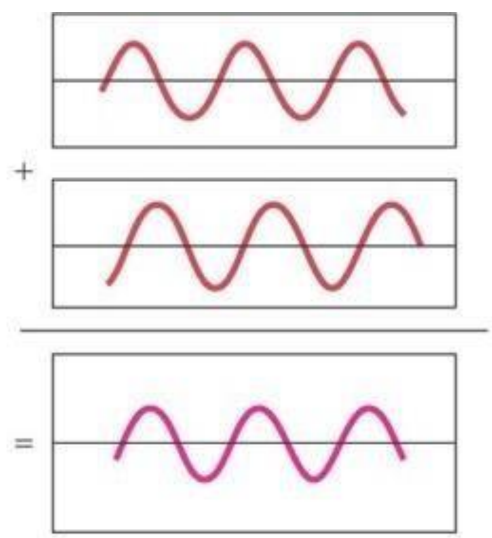

Figure 3 : Partial interference

Taking into account the position of the user and the distance between the two (2) sources, we obtainmore complex expressions that can be illustrated as follows:

$$s_1(x, t) = A_1 e^{-\alpha_1 x} (\omega t - kx + \varphi_1)$$

$$s_2(y, t) = A_2 e^{-\alpha_2 y} (\omega t - ky + \varphi_2) \text{ avec } y = d - x$$

The resulting signal $(x, t) = s_1(x, t) + s_2(d - x, t)$

$$S(x, t) = A_1 e^{-\alpha_1 x} \cos(\omega t - kx + \varphi_1) + A_2 e^{-\alpha_2 (d - x)} \cos(\omega t - k(d - x) + \varphi_2)$$

With α_1, α_2: linear attenuation coefficient

k: wave number $\mathbf{k} = \omega/c = 2\pi f/c$

$\lim_{x\to 0} (x, t) = A_1 \cos(\omega t + \varphi_1) + A_2 e^{-\alpha 2d} \cos(\omega t - kd + \varphi_2)$If

d is large, $A_2 e^{-\alpha 2d} \to 0$ hence $\lim_{x\to 0} (x, t) \approx s_1(0, t)$

$(d, t) = A_1 e^{-\alpha 1d} \cos(\omega t - kd + \varphi_1) + A_2 \cos(\omega t + \varphi_2)$With

large d, $A_1 e^{-\alpha} \to 0$ hence $\lim_{x\to d} S(x, t) = s_2(d, t)$

These results lead to the conclusion that when one approaches one of the sources, the resulting signal is similar to the signal emitted by this source.

b. Signal-to-noise ratio

The signal-to-noise ratio is an indicator for assessing the quality of a signal and determining the sensitivity of a device for a given noise spectral density. The signal-to-noise ratio is an important data for analog signals, since it makes it possible to estimate the degradation suffered by the latter. It is expressed by the following relation:

SNR= Ps/N

Where **Ps is the power of the transmitted signal and N is the power of the noise signal**

Indeed, the lower the signal-to-noise ratio, the more the signal is degraded by noise. It is necessary to ensure a high signal-to-noise ratio to ensure that the received signal remains a faithful copy of the transmitted signal.

Using the previous expressions, the signal-to-noise ratio is written:

$$SNR\ (x) = 10 \log(A_1 e^{-\alpha 1x} / A_2 e^{-\alpha 2(d-x)})$$

$$SNR\ (x) = 10 \log(\frac{A1}{A2} * e^{-\alpha 1x + \alpha 2d - \alpha 2x})$$

$$SNR\ (x) = 10 \log(\frac{A1}{A2} * e^{\alpha 2d - (\alpha 1 + \alpha 2)x})$$

$$SNR(x) = 10 * \left(\ln\frac{A1}{A2} + \ln e^{a2d-(a1+a2)x}\right) / \ln 10$$

$$SNR(x) = \frac{10}{\ln 10} * \left[\ln\frac{A1}{A2} + a_2 d - (a_1 + a_2)x\right]$$

$$\lim_{x\to 0} SNR(x) = \lim_{x\to 0}\left\{\frac{10}{\ln 10} * \left[\ln\frac{A1}{A2} + a_2 d - (a_1 + a_2)x\right]\right\}$$

$$\lim_{x\to 0} SNR(x) = \frac{10}{\ln 10} * \left(\ln\frac{A1}{A2} + a_2 d\right) \quad (1)$$

$$\lim_{x\to d} SNR(x) = \lim_{x\to d}\left\{\frac{10}{\ln 10} * \left[\ln\frac{A1}{A2} + a_2 d - (a_1 + a_2)x\right]\right\}$$

$$\lim_{x \to d} SNR(x) = \frac{10}{\ln 10} * \left(\ln \frac{A_1}{A_2} + a_2 d - a_1 d - a_2 d\right)$$

$$\lim_{x \to d} SNR(x) = \frac{10}{\ln 10} * \left(\ln \frac{A_1}{A_2} - a_1 d\right) \quad (2)$$

Hence $\lim_{x \to 0} S_{(x)} > \lim_{x \to d} SNR_{(x)}$

Expressions (1) and (2) clearly show that the signal-to-noise ratio degrades as one approach the source of the noise.

4. Resolution methodology

As mentioned above, the radio frequency interference attack is one of the easy attacks to perform in mobile networks and results in the degradation of the quality of service offered to subscribers. Given its impact on the network and in order to guarantee a good quality service to users, this section proposes a methodology for solving this problem. Our proposed methodology consists of four (4) steps presented below. The first three steps are the tasks falling within the competence of operators well before referring the matter to the regulator of last resort.

Step 1: Evaluation of radio indicators

The first step is to evaluate the radio indicators (KPIs) to realize the problem. These indicators are:

The call drop rate: normal call drop rate must be less than or equal to **1.5%** on all calls initiated in a given area where the test was performed. However, a rate of 2% can be tolerated, but once beyond this limit, there is a deterioration.

The CSSR: call setup success rate, is also one of the key indicators that must be checked in order to detect the presence of interference on the network. For **CSSR > 95%,** we are in an almost perfect situation where there is a low rate of failed calls. The level of the CSSR is acceptable for **90%< CSSR ≤ 95%,** but it must be noted the presence of some problems that may cause damage in the long run on the network. When the CSSR rate is strictly below 90**% (CSSR< 90%),** we are in a situation of degradation.

Signal-to-Noise Ratio (SNR) is the power ratio between signal and noise. This is a very important indicator of transmission quality. For a fault sound link, the SNR must be less than or equal to **-9 dB**. For a link with some anomalies that do not have a great effect on transmission, the SNR is between **-13 dB** and **-9 dB**. For a degraded link, the signal-to-noise ratio is strictly less than **-13 dB**. In practice, the **HQI** (High Quality Index) is used, which provides information on the percentage of signals with an SNR greater than -13 dB and whose acceptable values are those greater than 94%.

The handover success rate: is also an indicator to evaluate in the case of interference. It makes it possible to verify the success rate of maintaining communication between cells in the case of mobility. For a handover rate above 95%, there are more successes when maintaining communications. Every effort must be made to maintain this rate as high as possible, to guarantee continuity of communications.

The BER (Bit Error Rate): is the level of attenuation and / or disturbance of a transmitted signal, it determines the number of errors that appeared when receiving the packets sent. This rate must remain as low as possible for reliable transmission. The table below gives us an idea of the different values of the BER.

Table 1 : BER Values

Bit Error Rate (BER)	Interpretation
BER ≤ 0.2%	Excellent reception
0.2% < BER ≤ 0.8%	Good reception
0.8% < BER≤ 3.2%	Degradation at reception
3.2%< BER≤ 12.8%	Poor reception
BER>12.8%	Very poor reception

Step 2: Determining the type of interference

Determining the type of interference is as important as the first step because, despite the evaluation of the indicators, it is necessary to know the type of interference being encountered.

The identification of the type of interference is derived from the analysis of the above-mentioned indicators, mapping the graphs obtained to those of the types of interference presented above.

Step 3: Identification of interference sources

In case of internal interference, this step is the last phase of the resolution because the solution will befound internally by performing the following steps:

- **Verification of the frequencies used in the area concerned;**
- **Check if there has been no reversal of sectors;**
- **Revision of the tilt or azimuth of one or more cells in the area;**
- **Neighborhood check.**

In the case of external interference, radio field measurements should be made based on previous findings.

Step n°4: Verification with the Regulator and implementation of recommendations

Verification with the regulator can only take place in case of external interference confirmed after the analyses and verifications of the previous steps. The regulator, for its part, faced with such a situation, must first make a recheck to reassure itself of the problem. It will then proceed to the revision of the frequency ranges allocated to operators.

The Regulator to solve the problem will allocate to the operator a new frequency range. In the event of fraudulent use of a frequency range by an operator, the Regulator is called upon under the laws in force to impose sanctions on the offending operator.

After changes and implementations are made on the network, to ensure that the problem is resolved, key performance indicators must be monitored and re-evaluated. At this level, the new evaluation of the indicators must present a better result.

The diagram below summarizes the different steps of this resolution process.

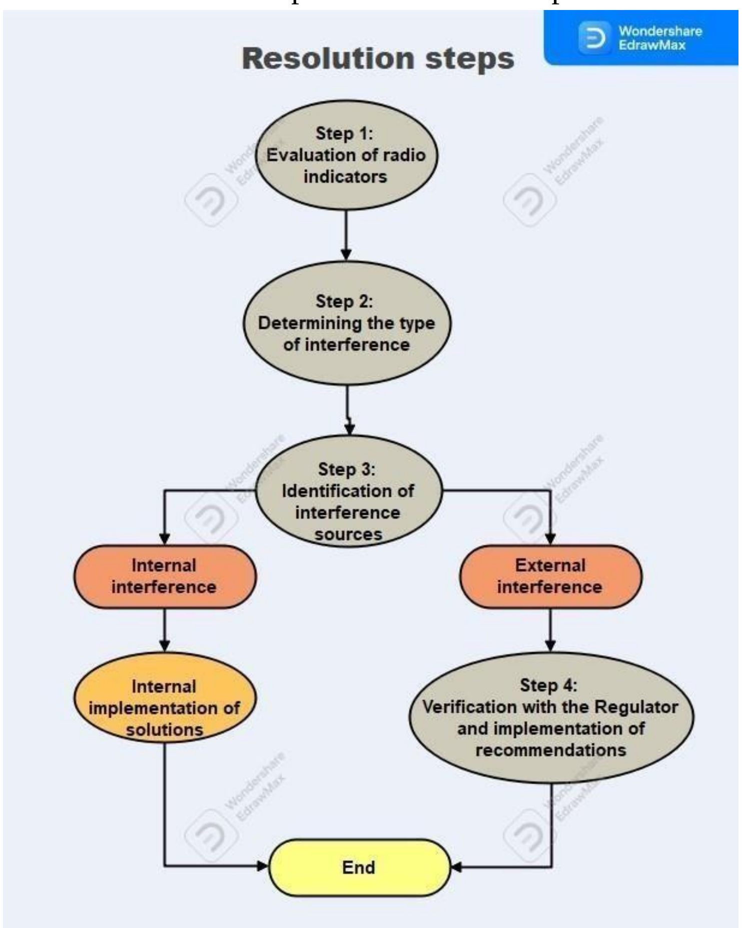

Figure 4 : Resolution steps graph

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