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|  |  Doc. RXIM(18)006 |
| SE FG RXIM |
| Forum |
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| Source:  | FAU, 450connect, 450 Alliance (contact: georg.fischer@fau.de) |
| Subject:  | Algorithm Requirements |
| Group membership required to read? (Y/N)N |
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| Summary:  |
| This contribution comments on the requirements for development of a versatile algorithm to compute RX intermodulation inside SEAMCAT for various signal scenarios.A long term strategy for handling non-linear effects in wireless systens inside SEAMCAT is sketched. |
| Proposal: |
| It is proposed to incorporate algorithm requirements proposed here in the consolidated catalogue of algorithm requirements by FG\_RXIM. |
| Background: |
| High level requirements as defined at WG SE end of 2018 are mapped into more detailed requirements. |

# High Level Algorithm requirements as agreed by WG SE

WG SE has agreed on four essential requirements for the algorithm to facilitate RX intermodulation studies in SEAMCAT. According Work Project SE\_15 the algorithm should:

a) be able to work in the frequency domain

b) be applicable for various modulation formats between an interfering Link TX and victim Link RX

c) run fast enough to allow for a sufficient statistical number of events within a reasonable time

d) contain a sufficient number of parameters to reflect various RX models

# Detailed Comments on Requirements

## Requirement a) – frequency domain

SEAMCAT is an event based simulator and works in frequency domain. It is able to handle spectral masks of signals and filter shapes. Therefore it is natural that any algorithm reflecting non-linear behaviour inside a VLR (Victim Link Receiver) should also run in frequency domain.

A treatment in frequency domain also abstracts from detailed information content i.e. sequences of bits or symbols in time domain.

A spectral mask is given as a PSD power spectral density distribution i.e. a power within a frequency bin. SEAMCAT allows for conversion between different widths of frequency bins.

The algorithm presented by FAU in [1] is versatile to handle arbitrary spectral shapes. It thus can serve as a flexible basis for handling various combinations of Interfering Link Transmitters (ILT) having different spectral properties and victim link receivers (VLR) having different receiver bandwidths.

An analysis in time domain would require too many details about signal content. It is also not possible to transform from frequency domain into time domain as only the averaged PSDs in frequency domain of the involved signals are known.

## Requirement b) various modulation formats

Essentially only the PSD of the signal and modulation formats involved needs to be known, as SEAMCAT only works in frequency domain and mainly considers average power levels. Outage Criterions are defined as ratios between average power levels of C (carrier), I (interference) and N (noise). One can thus abstract from the details of modulation formats.

In a single carrier system, like the digital narrowband systems, the PSD distribution equals the abs of the Fourier transform of the impulse response of the pulse shaping filter used in modulation. The PSD thus is not dependent on what exact constellation is used, e.g. whether BPSK or QPSK or 16QAM or other constellations. As the PSD is not dependent on the symbols, it is also not dependent on the bits. Due to treatment of averaged power in every frequency bin, the peak powers are not processed and thereby also the crest factor, sometimes also named PAPR (Peak to average power ratio) is not relevant. Crest may be data dependent, but is irrelevant for outage derivation.

A typical wideband system like OFDM, e.g. used with 4G LTE and L-DACS in Avionic band can be described by a near rectangular PSD distribution with side emissions depicted in detail with a spectral mask. OFDM systems are multicarrier systems, and radio resources are allocated by the scheduler in terms of time-frequency-tiles named RBs (resource blocks). The lower the activity factor, the more sparse the PSD distribution thus will get. However it is not feasible to model the details of radio resource allocation. An abstracted equivalent model needs to be found.

In [2] a simple methodology for mapping activity factor into IM reduction was presented. It reveals that an OFDM signal with 50% activity will lead to more or less equivalent behaviour w.r.t. average IM products than a signal with 100% activity but attenuated by 3 dB. The errors are within +/-3 dB in prediction of IM power. With a large number of events this error -as it can happen positive as well as negative- should average out. Therefore it is questionable whether modelling the vary details of resource allocation with modulation should be modelled. An abstracted modelling by activity factor could be sufficient. Such an approach is simple, but may not be accurate enough.

The fundamental problem is that behaviour of resource schedulers for resource allocation is not known, as it is not standardized and proprietary. The optimization of resource scheduler is up to the equipment vendor. These details of modulation characteristic can thus not be incorporated in the algorithm.

A pragmatic approach between the two extremes of a very simple and a very detailed modelling mentioned above could be to slice the spectrum according RB widths and then turn the spectrum slices on and off in a random fashion. This would be pretty close to reality without having to know the details of the resource allocation scheme. Indeed this was done in [2]. The algorithm presented in [1] and [2] can account for this. This would lower the uncertainty of +/- 3 dB.

Aside of the signal scenario given by a wideband ILT next to a narrowband VLR, there are further scenarios, that are also worth to be reflected by the capabilities of a new RX IM algorithm to be incorporated into SEAMCAT. Recently the case of operating a PMSE link in airband got a lot of attention. Here the Interferer like a DME (Distance Measurement Equipment) could interfere a streaming PMSE link. The issue here is that DME link is highly pulsatile, whereas the PMSE link would be stationary. This looks pretty close to the case of any other modulation subject to activity factor. The only difference here is that with a wideband OFDM signal every RB is subject to a random process that turns the RB either on or off described by activity factor whereas in DME it is just a single carrier that turns on and off according to an activity factor, which is indirectly expressed as PPPS (pulse pairs per second) in the case of DME. But the metric PPPS can be converted to activity factor.

A new algorithm should therefore have the general capability of handling interferers going on and off in random fashion. This would empower SEAMCAT not only to study the case of Wideband ILT aside of narrowband VLR, but also the case of pulsatile ILT aside of a VLR.

In general any new algorithm for studying RX Intermodulation should allow for an arbitrary combination of wideband and narrowband devices and also reflect pulsatile character of interferers.

## Requirement c) – Speed

As it is proposed to handle non-stationary interferers being switched on and off due to resource scheduling, pulsatile nature or activity factor, a large number of events needs be generated in SEAMCAT, implying that the computation time for one event must be kept low. It is therefore necessary to minimize the computation time for nonlinear effects in the VLR. There are different ways of addressing this need:

The complexity of the algorithm itself must be kept low. Here it is proposed to do some benchmarking of different algorithms. Two basic algorithmic approaches were already presented in SE7: The 3-frequency algorithm, which is based on several nested loops which usually leads to long computation time. The other algorithm based on a closed form analytic solution and presented in [1] however is based on convolving 3 spectra, whereby this can be efficiently implemented as vector multiplication of IFFTs. As it is based on an analytic solution it is in no way an approximation. Also it inherently reflects the spectral widening of third order products which has to be done in approximate way with the 3-frequency algorithm.

IFFT and FFT used with convolution are fast processes anyhow which are not time consuming. Heavily optimized code for iFFT/FFT is readily available. Thus a high accuracy thanks to a rigorous analytic solution is obtained at low computational costs.

As normally only the spectral components of intermodulation that fall into VLR bandwidth are relevant for derivation of outage criterion, action should be taken to not compute results for frequency bins lower and upper of VLR bandwidth, that are anyhow dropped. Both the approximate 3 frequency algorithm and the analytic solution would allow for avoidance of computation of these unnecessary results.

In [3] it was also proposed to focus on dominant interferers, like e.g. disregarding second tier interferers and focusing on first tier interferers. Due to the 3x increase of IM products it might even be pragmatic to just identify the strongest interferer and only compute its third order IM products falling in VLR bandwidth. FAU and 450connect fully support this proposal as it will allow for speeding up computation without large errors in IM power derivation.

## Requirement d) – RX models

In the reverse engineering study of terminals available from multiple vendors on the market presented in SE7 it was found that different architectures were used and the design philosophies were pretty different. Due to necessity for simultaneous fulfilment of a multitude of receiver requirements: i) RX intermodulation, ii) spurious response, iii) blocking, iV) NER large signal test, it is not straightforward to derive one typical non-linear receiver model.

It is therefore proposed to define 3 different RX models: i) a low performance one, just meeting solely the RX intermodulation test alone but ignoring the other 3 receiver requirements, ii) a typical model and iii) a high performance one as found on the market.

The question now is, how to define a non-linear receiver model in a generic way?

It is proposed to define an input referenced IIP3. By this, receiver gain becomes obsolete. As in the reverse engineering studies several terminals with tracking filters (Preselector) were found, it is also proposed to define an input filter mask in front of non-linearity. In real receivers there is a cascade of filtering, amplification by LNA, yet another filtering and mixing. As architectures, selectivity and frequency plans are all way different on various devices it doesn’t look sensible to set-up a very detailed RX model. From the perspective of plugin parameterization it looks advisable to keep numbers of receiver parameters simple, which means a definition of IIP3 together with input selectivity should be enough. This somehow abstracts from cascaded non-linearity by LNA and Mixer. However it was found in reverse engineering studies that anyhow the mixer dominates non-linearity due to LNA gain in front and the widespread availability of high linearity LNAs. This also implies if a high linearity LNA is in place, it makes no big difference whether tracking filters are placed before or after LNA.

FAU and 450connect propose to keep the receiver model simple but at the same time in line with the multitude of receiver specifications and implementations on the market.

# Outlook on handling further non-linear effects in wireless systems

With the work project SE\_15 defined by WG SE, the Forum Group RXIM is requested to address receiver intermodulation and to develop algorithms to empower SEAMCAT detecting outage due to receiver intermodulation.

However RX intermodulation is not the only non-linear effect in wireless systems. There is also non-linearity by the PA (Power amplifier) at ILT, leading to spectral regrowth. This effect is typically covered inside SEAMCAT by the TX spectral emission mask. However, this is a very pessimistic approach. In reality no TX is completely making use of transmitter emission mask. An algorithm for computation of non-linearity can also be used to compute spectral regrowth that arises inside the PA of ILT. Thereby the side emissions from an ILT would be modelled more realistically increasing the reliability of outage prediction.

The analytic solution presented by FAU in [1] can easily be expanded for further non-linear order effects like 5th and 7th order nonlinearities as they arise in power amplifiers.

Another non-linear effect in wireless systems is TX intermodulation, also called reverse intermodulation, which can show up if transmitters are spaced closely. In analysis of PMSE usage this effect is treated with care. The analytic solution by FAU could also be applied in such cases to study outage due to TX intermodulation. In PMSE scenarios treatment of IM7 products is very common.

Also in car radar scenarios empowering SEAMCAT with a capability of handling TX intermodulation to derive outage events due to TX intermodulation would be an attractive feature to stimulate further use of SEAMCAT. A typical scenario here is two cars approaching each other. The radar signal from one car would reversely enter the transmitter of an approaching car. This problem gets more attention due to widespread deployment of car radars.

The analytical solution developed by FAU for prediction of non-linear spectral components is future proof in the sense that it can also be applied to other non-linear effects aside RX intermodulation, which is spectral regrowth with non-linear PA in VLT and also TX intermodulation. The analytic solution by FAU also is future proof in the sense that it can easily be expanded to cover higher order non-linear terms like 5th and 7th order effects that are relevant with PA spectral regrowth and TX intermodulation. The issue of spectral spreading which is handled approximate in the 3-frequency algorithm needs much more care with 5th and 7th order effects. Thanks to the analytic approach by FAU, no approximations are necessary. The analytic solution is inherently accurate and needs no approximation for spectral spreading. Otherwise the approximations would become more inaccurate the higher the order of non-linearity.

# Summary

This contribution has discussed the requirements on an algorithm for empowering SEAMCAT to calculate outage due to RX intermodulation. The high level requirements as formulated by WG SE were mapped into more detailed requirements for algorithm development and non-linear receiver modelling.

Initial comments were given on the algorithms presented so far in CEPT which are the analytic solution by FAU and the 3 frequency algorithm which is approximate with respect to spectral widening.

An outlook was already provided which further non-linear effects in wireless systems could be addressed inside SEAMCAT.

It is the general aim to develop a flexible and future proof approach for dealing with non-linear effects that is versatile to handle a large variety of scenarios and combinations of wideband and narrowband systems.

In contrast to past scenarios nowadays interferers might be pulsatile or active only part of the time as arising from radio resource schedulers and inherently to the air interface, which poses a new requirement on SEAMCAT.

# References

[1] SE7(18)105 Efficient frequency domain algorithms for calculation of RX Intermodulation

[2] SE7(18)106 Impact of LTE BS Activity Factor on TETRA RX Intermodulation

[3] FGRXIM(18)005 Algorithm Requirements