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Request for Information on the National Spectrum Research and Development Plan

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Response to "Request for Information on the National Spectrum Research and Development Plan"

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Abstract: The one-line summary of this comment is: *efficient spectrum usage needs more research on wireless propagation channels*. This will serve to provide flexible and generalizable insights into spectrum planning, and allow to incorporate both currently existing, as well as future (and maybe not even yet conceived) systems into the spectral planning.

1. Two ways of modeling interference

There are fundamentally two ways of measuring and modeling interference. The first one is what one could call the "direct" method: the engineers measure or simulate the amount of interference power arriving at a victim receiver, and how this interference impacts the reception quality (e.g., bit error probability) at the receiver. Models for the number and location of both transmitters and receivers, the transmit power spectral density and direction, and the interference rejection capability of the receivers, are usually an inherent part of this approach. A number of simulations establish a cumulative distribution function of the interference level and/or reception quality, from which further conclusions can be drawn. Importantly, a change in the considered system requires a completely new simulation.

An alternative is what I will call the "composite" approach. In this method, we first establish a *double-directional* channel model, i.e., it describes (for a given transmitter and receiver location), the power, angle of departure, and angle of arrival of each multipath component (MPC). Such double-directional models can be deterministic (as obtained from ray tracing), stochastic, or mixed geometric-stochastic. In any case, these models and the channel descriptions that they entail, are independent of the particular system operating over the channel. This allows to use them in a flexible manner, because they can be combined with arbitrary systems – it does not matter whether the transmitter has directional or omnidirectional antennas, whether the receiver filter and transmitter filter are identical or have only a narrow overlap, etc. , as well as independent of the transmitter and receiver spatial density and distribution. They furthermore allow to easily determine which system parameters need to change to avoid excessive interference – for example, in the recent discussion about interference from cellular links to airplane altimeters, they could have easily shown (without further experimentation) how the altimeter receive filters need to be changed (or how the transmit beams at the cellular base stations need to be shaped). They also allow to test various methods for reducing interference under fair and reproducible circumstances – while the transmitted spectrum and directions might change, the channels remain the same; this is also what happens in nature.

While the composite simulation method is clearly superior in its flexibility and accuracy, the direct method is still more widely used. This is partly due to historic reasons, but also partly because for a number of situations, suitable channel models are still missing. This latter statement sounds surprising, and will therefore be elaborated in the next section.

2. Gaps in existing channel models.

Propagation channels have been measured and modeled for some 100 years, and the statement seems surprising that there are significant gaps that need to be filled. This is caused by the fact that channel models differ with the configurations (frequency range, the environment, as well with the spectral (bandwidth) and spatial (antennas/directions) degrees of freedom) for which the measurements are done. The past 15 years have seen the emergence of a number of systems with configurations that were previously overlooked, such as

* millimeter-wave and sub-THz communications systems. An important example is the potential interference of 24 GHz cellular systems to water-sensing satellites - a problem that essentially reduces to the question of the double-directional channel between base stations and satellites (or handsets and satellites). In particular, how much of the potential interference can be suppressed by suitable beamforming? The double-directional channel would give the answer.
* non-terrestrial networks: interference from ground stations to drones, from drones to ground stations, from both to satellites, and so on. With a few exceptions, double-directional characteristics are hardly known. Thus, while the properties of the desired signal for these links have been explored, those for the interfering channels are hardly known.
* upper midband: while several frequency ranges between 6 and 18 GHz are being assigned to cellular communications, double-directional models for these bands currently do not exist.

… and many more.

It must be stressed that in many situations where a model exists for the *desired* channel, the modeling of *interfering* channels is much less developed. One might ask: "the channel is the channel – it does not know whether it carries desired signal or interference". This is true, but there are numerous *aspects* of channels that are relevant only for interference, but which are not measured because no measurement unlimited range and accuracy. For example, the channels of a cellular signal at distances considerably larger than the cell radius are typically not carefully measured/modeled, because they are irrelevant for the coverage prediction, and are furthermore more difficult to measure because they are weak – yet they do play a major role for interference prediction.

3. The 3GPP models

It is often claimed that the 3GPP channel models are valid over 0.5-100 GHz, and cover a wide range of situations. However, these models are not suitable for interference assessment for a variety of reasons:

1. They are designed to allow a fair comparison of different *systems*, not to give an exact description/prediction of wireless propagation channels. They are based on a small number of measurements, in a set of narrow bands, in a limited number of environments.
2. They are mostly based on measurements in the 2-6 GHz frequency range (with a few sample measurements above and below), and the validity over a larger frequency range is simply postulated instead of being based on actual measurements.
3. They contain a number of simplifications that were done in the context of 3G systems in the early 2000s, and carried forward through the need of backward compatibility, not because they are actually valid.

I state these points as somebody who has contributed to the 3GPP model since its inception in 2002.....

4. **What is needed**

In light of all of this, there should be a concerted national effort to create better channel models, for a wide variety of situations, and in particular for those aspects that affect the propagation of potential interference signals. These efforts should encompass both deterministic prediction methods (ray tracing/launching) and measurements. Ray tracing/launching is well suited to creating large sets of data from which more reliable statistics could be extracted, while measurements are the "gold standard" of any scientific investigation, and are needed to calibrate and validate ray tracing.

Based on the input from the stakeholders about which scenarios are currently, and likely in the future, the ones where coexistence problems could most likely occur, an extensive program of channel measurements and modeling should be funded.