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ABSTRACT	This document proposes a consistent framework for evaluating the levels of interference impinging on a BWA system. The framework is applicable to both FDD and TDD systems and covers both co-channel interference and adjacent-channel interference from either BWA systems, other terrestrial Point-to-Point systems, or satellite downlinks. The author proposes that this framework be adopted as the evaluation model for coordination studies. Parameters plugged into the model can then lead to quantitative statements of separation distances or power flux density limits for various cases. The document may serve as the basis to solicit specific contributions on standard values for various parameters required by the model.
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A Framework for Evaluating Interference to BWA Systems

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Introduction

This contribution is a response to the call for contributions regarding several issues of coexistence, including

- The parameters to be specified, including antenna characteristics, radiated power, and power spectral density
- The format for specifying coexistence among systems operating on adjacent frequency bands
- The format for specifying coexistence among independent systems deployed by a single license holder

The author proposes a framework for interference modelling that can handle all cases.

Forms of Interference

Interference can be classified into two broad categories: co-channel interference and out-of-channel interference. These manifest themselves as shown in Figure 1.

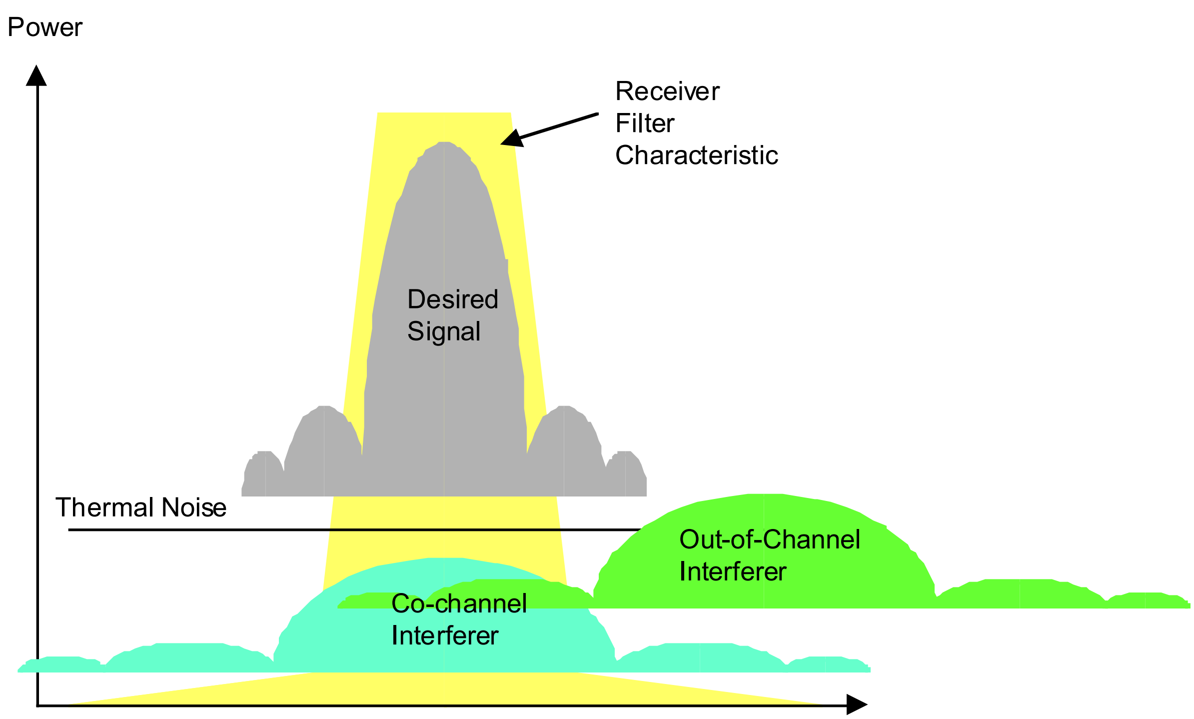

Figure 1: Forms of Interference

The power spectrum of the desired signal is shown in grey. Co-channel interference is shown in blue. Note that the channel bandwidth of the co-channel interferer may be wider or narrower than the desired signal. In the case of a wider co-channel interferer (as shown), only a portion of its power will fall within the receive filter bandwidth. In this case, the interference can be estimated by calculating the power arriving at the receive antenna and then multiplying by a factor equal to the ratio of the filter's bandwidth to the interferer's bandwidth.

An out-of-channel interferer is shown in green. Here, there are two sets of parameters which determine the total level of interference:

- A portion of the interferer's spectral sidelobes or transmitter output noise floor falls co-channel to the desired signal; i.e. within the receiver filter's passband. This can be treated as co-channel interference. It cannot be removed at the receiver; its level is determined at the interfering transmitter. By characterizing the power spectral density of sidelobes and output noise floor with respect to the main lobe of a signal, this form of interference can be approximately computed in a similar manner to the co-channel interference, with an additional attenuation factor equal to the suppression of this spectral energy with respect to the main lobe of the interfering signal.
- The main lobe of the interferer is not completely suppressed by the receiver filter of the victim receiver. No filter is ideal, and residual power, passing through the stopband of the filter, can be treated as additive to the co-channel interference present. The level of this form of interference is determined by the performance of the victim receiver in rejecting out-of-channel signals, sometimes referred to as "blocking" performance. This form of interference can be simply estimated in a similar manner to the co-channel interference, with an additional attenuation factor equal to the relative rejection of the filter's stopband at the frequency of the interfering signal.

It cannot be determined which of the two forms of interference from an out-of-channel interferer will dominate without quantitative input on equipment parameters. It would be useful to solicit further contributions on this topic.

Treatment of Interference

In any given interference scenario, the linear sum of received powers from all sources of co-channel and out-of-channel interference can be computed, and the resulting power can be approximately considered as additional additive white Gaussian noise, to be added to the thermal noise floor of the receiver. The rationale for this treatment is as follows:

- The sum of a number of independent random variables tends to be Gaussian, especially if one variable (thermal noise) is Gaussian.
- BWA signals tend to be highly-filtered QAM signals which display a great deal of overshoot over the average power; in this respect they are Gaussian-like.
- A Gaussian assumption of the envelope of the interference is conservative.
- A Gaussian assumption is computationally simple and removes the need to consider anything about the source signal except its spectral mask.

It is therefore proposed that 802.16 adopt this model of treating received interference power, post-filtering, as equivalent to additive white Gaussian noise.

Acceptable Level of Interference

A fundamental property of any millimetric-wave BWA system is its link budget, in which the range of the system is computed for a given availability, given rain fading. During the designed worst-case rain fade, the level of the desired received signal will fall until it just equals the noise floor plus the signal-to-noise ratio of the receiver. A simple way to introduce a margin for interference into the link budget is to increase the noise floor by a factor which accounts for the additive interference that will be considered as additional noise. For example, consider a receiver with 6 dB noise figure. The thermal noise floor is –168 dBm/Hz. Interference of –168 dBm/Hz would double the total noise, or degrade the link budget by 3 dB. Interference of –174 dBm/Hz, 6 dB below the thermal noise floor, would increase the total noise by 1 dB to –167 dBm/Hz, or degrade the link budget by 1 dB.

A criterion of 1 dB link budget degradation has been used for BWA interference analysis performed by the Radio Advisory Board of Canada and is proposed as the standard limit of tolerable interference from all sources for coexistence analysis in 802.16. It would be useful for 802.16 to “endorse” a standard criterion, as it would focus vendors to include this factor in all standard engineered link budgets. This would help operators in evaluating the coverage claims made by different vendors on an equal basis.

For a given assumed receiver noise figure and antenna gain in a given direction, the link budget degradation parameter can be related to a received power flux density tolerance. In turn, this tolerance can be turned into separation distances for various scenarios.

Interference Paths

Victim Hub

Figure 2 shows main sources of interference where the victim receiver is a BWA hub, having a sectoral-coverage antenna.

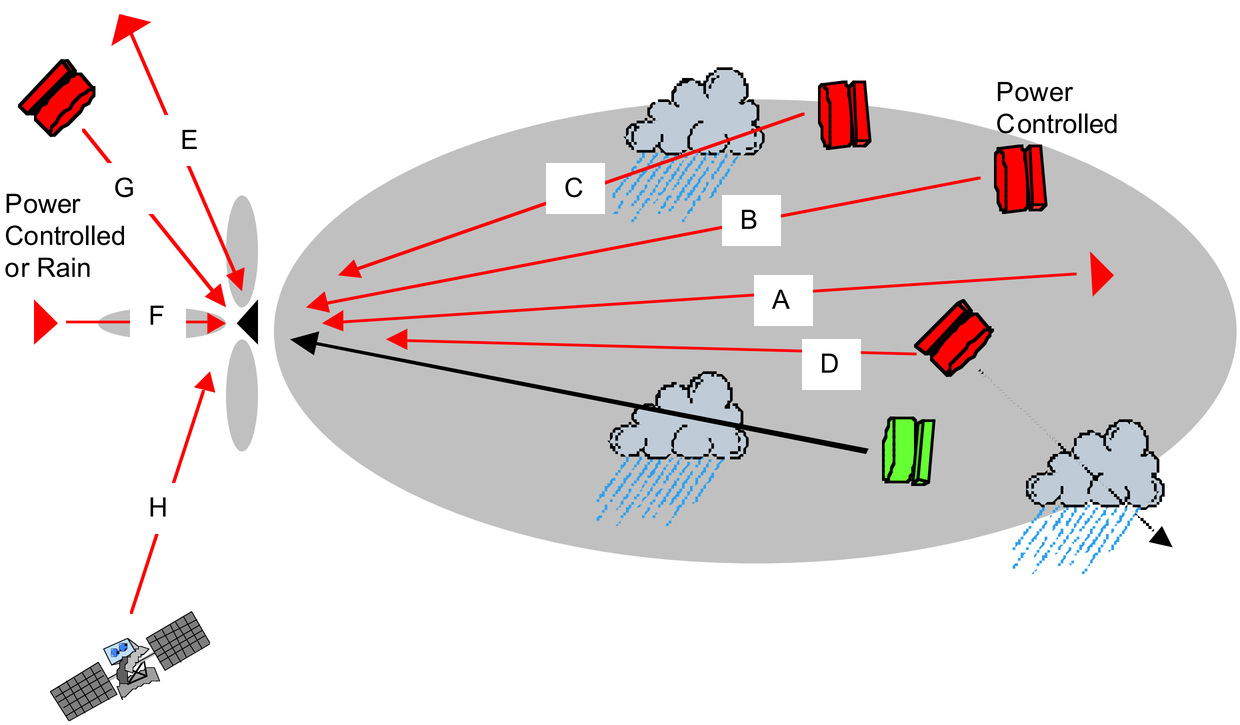

Figure 2: Interference Sources to a BWA Hub

The victim hub is shown as a black triangle, with its radiation pattern represented in grey. The desired subscriber transmitter is shown in green. In the worst case, the desired signal travels through a localized rain cell, hence the desired signal could be received at minimum signal strength. Thus, interference levels close to the thermal noise floor are significant.

Case A shows hub-to-hub interference where each hub antenna is in the main beam of the other. This case could occur commonly, as sector coverage angles tend to be wide—up to 90 degrees; in fact, a victim hub would tend to see the aggregate power of several hubs. In addition, hub antennas tend to be elevated, with a high probability of line-of-sight path to each other. As rain cells can be very localized, as small as a few hundred metres across, it is quite conceivable that the interferer travels on a path relatively unattenuated by rain, while the desired signal is heavily attenuated. Hub-to-hub interference can be reduced by ensuring that there is no co-channel hub transmission on frequencies being used for reception at other hubs. This is possible with FDD through band planning, whereby vendors agree to use a common sub-band for hub transmissions and another common sub-band for hub reception.

Case B shows subscriber-to-hub interference where each antenna is in the main beam of the other. As subscriber antenna gain is much higher than hub gain, this might appear to be the worst possible case. However, BWA systems can safely be assumed to employ upstream adaptive power control at subscriber stations. (Power control is required to equalize the received signal strength arriving at a hub from near and far subscribers on adjacent channels. Note that downstream power control from hub transmitters is usually not employed, as the hub signal is received by a variety of subscribers, both near and far, and power control would tend to create an imbalance in the level of signals seen from adjacent sectors.) Assuming that the subscriber station in Case B sees clear air, it can be assumed to have turned its power down, roughly in proportion to the degree of fade margin of its link. Note, however, that power control is imperfect, hence the degree of turn-down may be less than the fade margin. The turn-down compensates for the fact that the subscriber antenna has such high gain, so the net effect is that Case B may not be more severe than Case A. In addition, the narrow beamwidth of a subscriber antenna ensures that Case B is much less common an occurrence than Case A. However, Case B interference cannot be eliminated by band planning. Case B also covers interference generated by terrestrial point-to-point transmitters.

Case C is similar to Case B, except the interferer is assumed to see a rain cell, hence it does not turn down its power. However, as the interferer's beamwidth is narrow, the interference also must travel through this rain cell on the way to the victim receiver; hence, the net result is roughly the same as Case B. Because power control tracks out the effect of rain, interference analysis can be simplified: we need consider either Case B or Case C but not both. The author contends that Case B should be used, as it is more conservative with imperfect power control; i.e. the turn down will tend to be less than the fade margin, so the net received power at the victim receiver is several dB higher than Case C.

Case D is similar to Case C, except the interference is stray radiation from a sidelobe or backlobe of the subscriber antenna. In the worst case, the subscriber antenna sees rain towards its intended receiver, hence it does not turn down its power. Modelling of this case requires assumptions of the sidelobe and backlobe suppression of typical subscriber antennas. These assumptions must take into account scattering from obstacles in the mainlobe path appearing as sidelobe emissions in real-world installations of subscriber antennas;. an antenna pattern measured in a chamber is one thing; the effective pattern installed on a rooftop is another. It would be useful to solicit contributions on this topic. If effective sidelobe and backlobe suppression exceeds the power turn down assumption for clear skies, then Case B dominates and Case D need not be considered. The only exception is where Case D models a source of interference which is not a BWA system, but a point-to-point transmitter or a satellite uplink. In these cases, the transmit parameters may be so different from a BWA subscriber station that the interference could be significant.

Case E is another case of hub-to-hub interference. In this case, the interfering hub's main beam is in the victim's sidelobe or backlobe. There is a reflexive case (not shown) of the interfering hub's sidelobe in the victim's main lobe. As BWA systems tend to use intensive frequency reuse such that every frequency is used once at every hub, it is likely that Case A concerns will dominate rather than Case E.

Case F covers hub-to-hub backlobe-to-backlobe or sidelobe-to-sidelobe. The low gains involved here ensure that this is only a problem for co-deployment of systems on the same rooftop. Like all sources of hub-to-hub interference, this can be virtually eliminated in FDD via a bandplan.

Case G covers interference from a subscriber antenna to the victim hub's sidelobe or backlobe. Referring to tbe commentary concerning Cases B and C, we need only consider the clear air case, but assume the interferer has turned down its power. As hub antennas see wide fields of view, Case B is expected to dominate and Case G need not be considered.

Finally, Case H covers interference from a satellite downlink. As long as hub antennas are never up-tilted, this interference should always fall into a (vertical) sidelobe of the victim.

With the above simplifying assumptions, the dominant sources of interference which require detailed modelling are shown below.

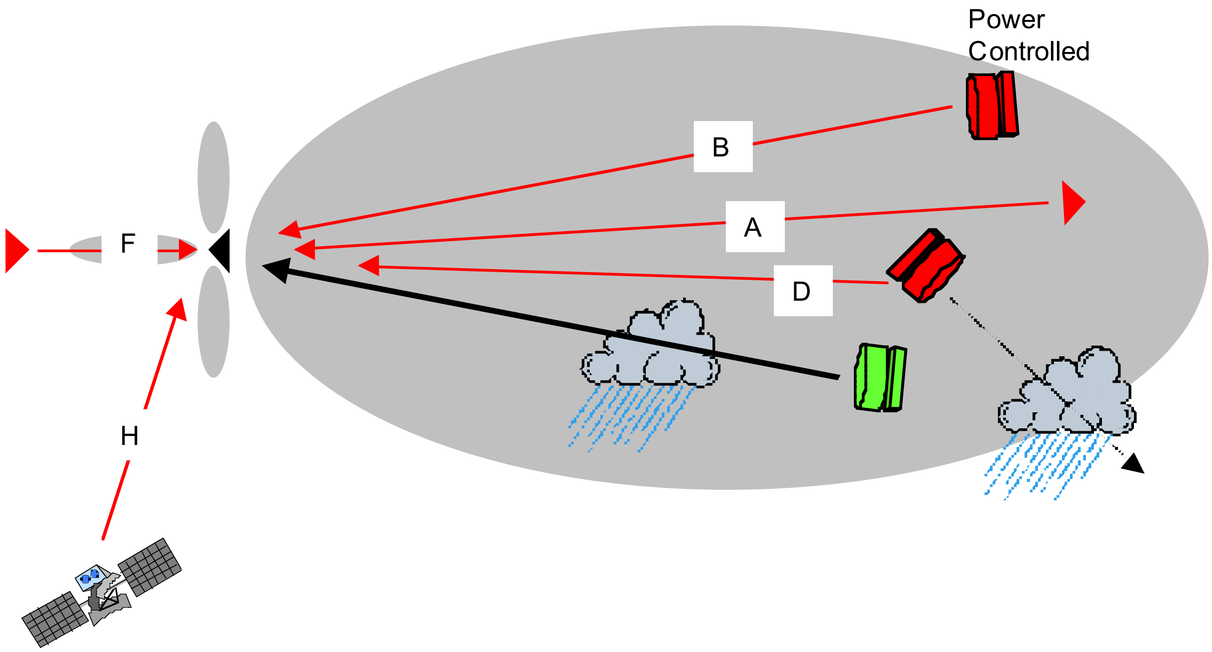

Figure 3: Simplified Model for Interference to a BWA Hub

Case A will tend to dominate unless there is a harmonized band plan for the use of FDD. It will be of concern for unsynchronized TDD. Case B is always a concern. Case D is probably of less concern than Case B where the interferer is a BWA system, but could be significant if the interferer is a higher-power point-to-point transmitter or satellite uplink. Case F is only a concern for co-sited hubs, and can be largely mitigated by the use of a harmonized band plan with FDD. Case H requires further input to evaluate its impact.

Victim Subscriber Station

Figure 4 shows the main sources of interference to a subscriber station having a narrow beamwidth antenna.

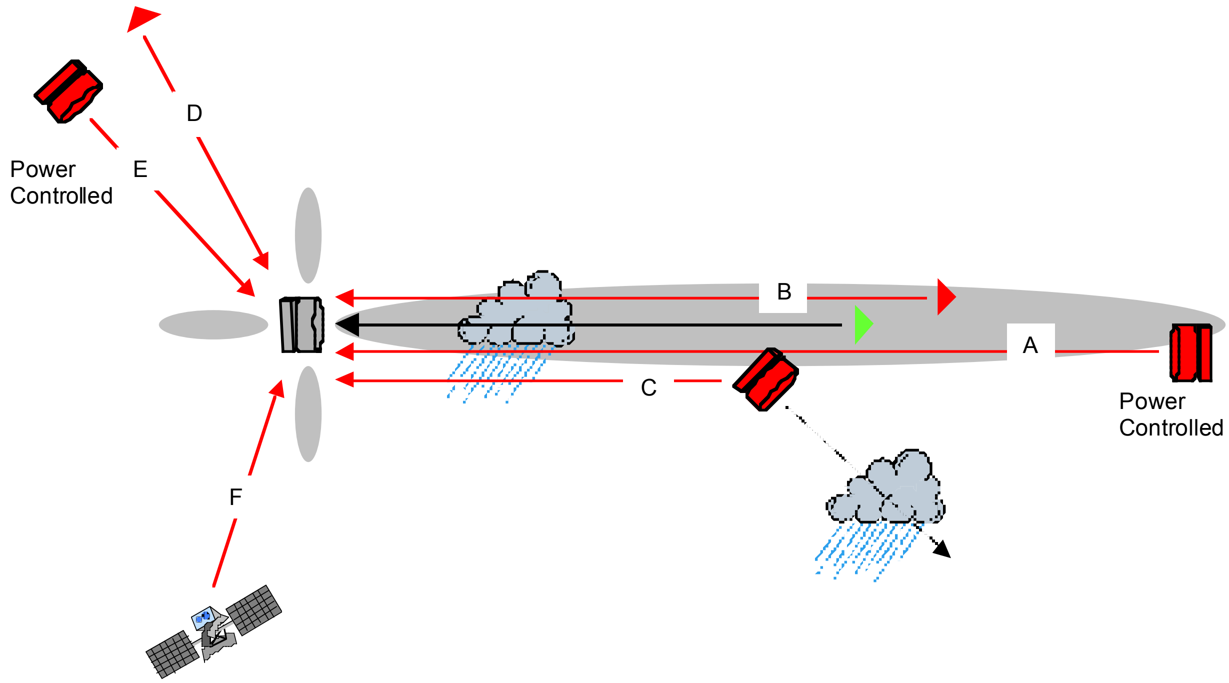

Figure 4: Interference Sources to a BWA Subscriber Station

The victim subscriber station is shown in grey along with its radiation pattern. The hub supplying the desired signal is shown in green and interferers in red. The victim subscriber cases are fundamentally different from the victim hub cases because the antenna pattern is very narrow. If the desired signal is assumed to be attenuated due to a rain cell, then interference arriving in the main lobe must also be assumed to be attenuated.

Case A covers subscriber-to-subscriber interference where the beams are colinear (which is relatively rare). In these cases, the interferer is generally far away from the victim; therefore, it must be assumed that the rain cell attenuating the interference as it arrives at the victim is not in the path from the interferer to its own hub. In this case, the interferer sees clear air and turns down its power.

Case B covers hub-to-subscriber interference.

Case C covers the case of a narrow-beam transmitter (BWA or point-to-point) or satellite uplink which is at full power, due to rain in its path, but radiates from its sidelobe towards the victim. This case is more likely to occur than Case A because it could occur with any orientation of the interferer.

Case D covers hub-to-subscriber interference picked up by a sidelobe or backlobe of the victim. This case could be common because hubs radiate over wide areas, and this case could occur for any orientation of the victim.

Case E covers subscriber-to-subscriber interference picked up by a sidelobe or backlobe of the victim. Similar to reasoning in the victim hub cases B and C, the worst case can be assumed to be clear-air in the backlobe with the interferer having turned its power down.

Case F covers interference from satellite downlinks.

Conclusion

This document has presented 10 potentially significant paths for interference, five for victim hubs and five for victim subscribers. For each path, there are three possible mechanisms of interference: co-channel, out-of-channel transmitter out-of-band spill, and out-of-channel receiver blocking. With further input on quantitative parameters, as suggested in the document, it will be possible to narrow the focus down to the most significant interference paths and mechanisms. For example, the use of FDD with a harmonized band plan can virtually eliminate hub-to-hub and subscriber-to-subscriber cases from consideration.

Once the focus is narrowed, numerical outputs can then be generated giving power flux density limits and/or safe separation distances for the dominant cases.

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