# Deployment scenarios and interference analysis using V-band beam-steering antennas

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## 1. V-band P2P/P2MP beam-steering motivation and use-case

V-band communication links are foreseen to be used access and backhaul applications. Access applications include street level connectivity, urban/suburban fixed broadband residential access ("FTTH") and business connectivity. Backhaul applications include connecting devices such as WiFi access-point, cellular small-cell and smart-city sensor. These applications are compatible with V-band equipment short range and small foot print characteristics, which are make street level installations using either P2P or P2MP topology possible. V-band equipment may also be used in rooftop to street connectivity, for access applications and as a feeding point for street-level chains.

The links range using beam-steering antennas is limited due to their relatively low gain to about 200m, and is additionally restricted by the availability of clear line-of-sight. Link operation is strongly protected from interference by line-of-sight blockage (typically by structures and foliage) and by Oxygen absorption which is about 16dB/Km throughout most of the band. There are also secondary protection mechanisms such as the antenna spatial filtering, the low transmit power spread across wide bandwidth, leading to low spectral power density and robust modulation schemes typically being used. To circumvent residual interference and enhance operation reliability, sharing algorithms such as dynamic frequency selection (DFS) and listen before talk (LBT) medium access protocols may be deployed.

## 2. Beam-steering antenna and P2MP operation

The motivation for using a beam-steering antenna, either in a P2P system or a P2MP system is primarily economic, as such an antenna is much easier to install, and thus reduces the installation cost. Other benefits of this type of antenna include the capability to maintain antenna alignment after installation, and even the ability to facilitate non-LOS communication by working through reflection. The beam-steering antenna further facilitates P2MP operation, but not in the traditional sense of a wide sector antenna creating interference for a wide area, but rather as an aggregation of narrow P2P links. The motivation to use P2MP system is also primarily economic as this mode of operation requires fewer boxes to provide the same coverage as compared to an aggregation of P2P links, thus reducing the average connection cost. This mode of operation also enables decoupling between the stage of installing the network infrastructure and the stage of connecting/disconnecting customers to it. A P2MP system operating in the V-band spectrum using beam-steering antenna can provides Gbit/sec connection rates at low cost, using licensed exempt spectrum with a simple installation.

The pattern of the beam-steering antenna used for simulations in this document is shown in the diagram below. This antenna is a sector antenna with 120° beamwidth and a gain of 21dBi. The diagram plots three beams directions, and shows a typical behavior in where squinted beams feature high side lobes, increasing as the squint is increased.



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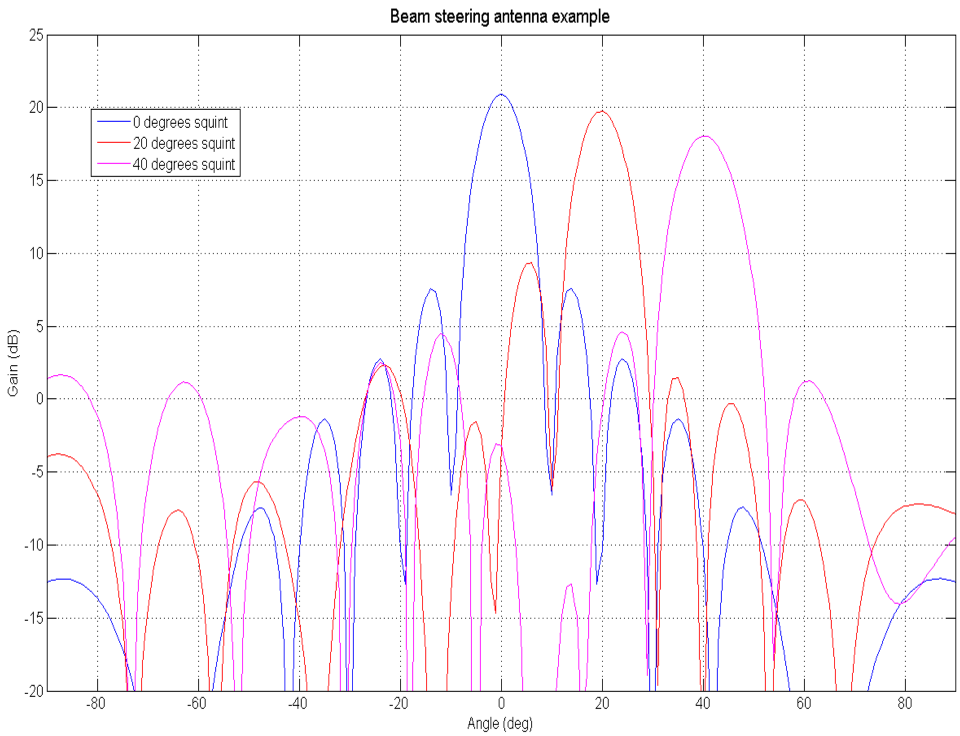


**Figure 1: Beam-steering antenna pattern**



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## 3. Rooftop deployment scenario simulation

This simulation model used is that of an unplanned deployment where multiple uncoordinated sites are deployed using a license exempt model spectrum management model. The deployment is based on use of multiple P2MP beam-steering sectors, where each sector includes a single instance of P2MP beam-steering base-station with several beam-steering terminals, all using the same antenna pattern described previously. The aim of the simulation is to check the expected performance, as well as get a feeling for the effect of various parameters on interference probability. Such parameters include the use of dynamic frequency selection (DFS), transmit power control (TPC), the overall density and the effect of terminals-per-BS density. The interference analysis is done similarly to the case of a P2P interference scenario where each base-station to terminal is considered connection is considered as a P2P link instance (ignoring the fact that transmissions on these links are not continuous). The system operates in TDD manner and the antenna pattern is selected per the pointing angle of the link in the sector. Each interference scenario between any two links is described by angles and distances as shown in the drawing below.

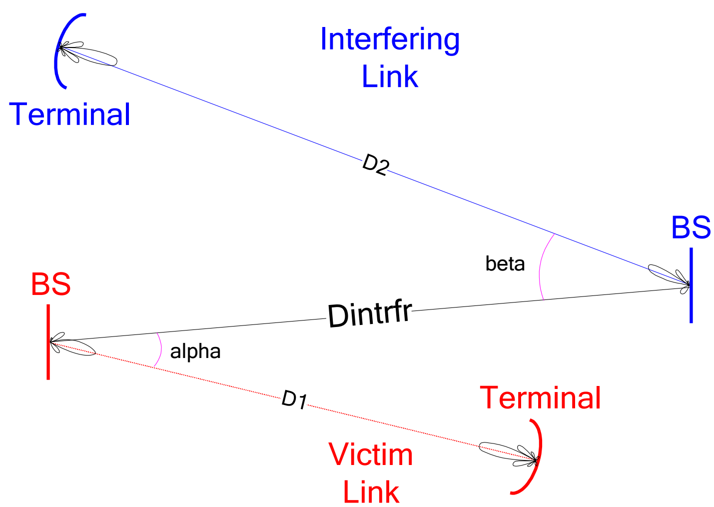


**Figure 2: Interference scenario**

The simulation assumes a certain area of operation, in which a certain base-station sector density per square Km is used. Each sector is 120° wide where coverage zone is from 20m to 200m. In each sector we assume a certain terminal per base-station density, which may be fixed or normally distributed. The simulation used a certain number of frequency channels where 20dB of adjacent channel rejection assumed. The propagation model is LOS propagation (including Oxygen absorption). The simulation results are captured by observing signal-to-interference ratio (S/I) distribution over about 10000 S/I measurements. These results are visualized as histogram with S/I bins from



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0dB to 20dB. S/I values above ~4dB are considered to possible to operate with using robust modulations such as coded QPSK. An example of a simulation scenario is shown below, where the sector density 40 base-stations per square Km and the area being analyzed is of dimension 1.5Km x 1.5Km. Each base-station has 4 terminals, where the blue slices represents the base-station sectors nominal coverage area while the red circles represent are terminals. No coordination or ordering is used and the position of base station is take from a random uniform distribution over the simulation area while the position of the terminal is taken from a random uniform distribution in their respective base-station sector coverage area.

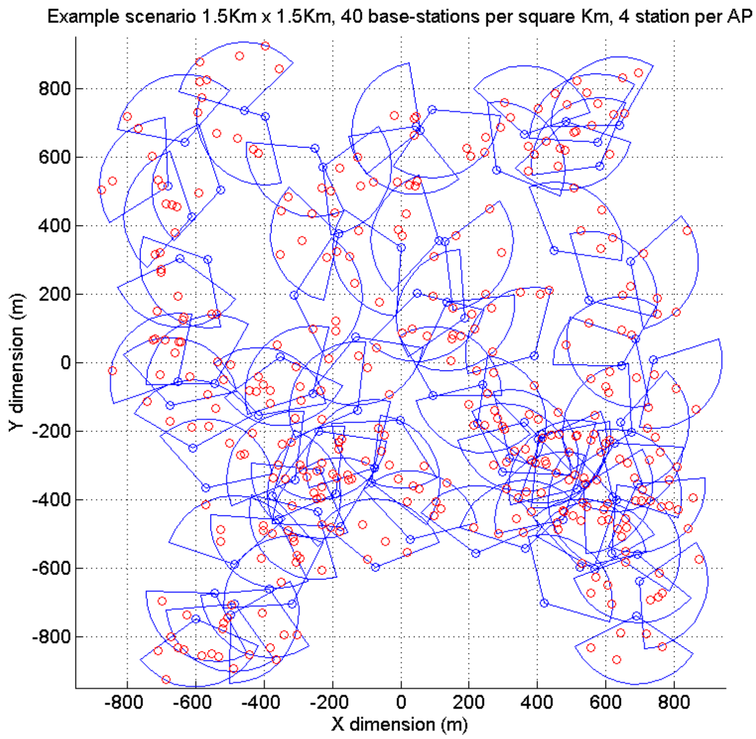


**Figure 3: Scenario example**

The next figures depict simulation results in various conditions. Typically the base-station density is being varied and TPC is being deployed. The simulation cases include

- Fixed four terminals per base-station using two frequency channels
- Fixed four terminals per base-station using four frequency channels
- Random N(4,2) distributed number of terminals per base-station using two frequency channels
- Fixed node density by adjusting terminal to base-station ratio using two frequency channels
- Fixed four terminals per base-station using two frequency channels and no TPC

The simulations include the deployment of a DFS mechanism.



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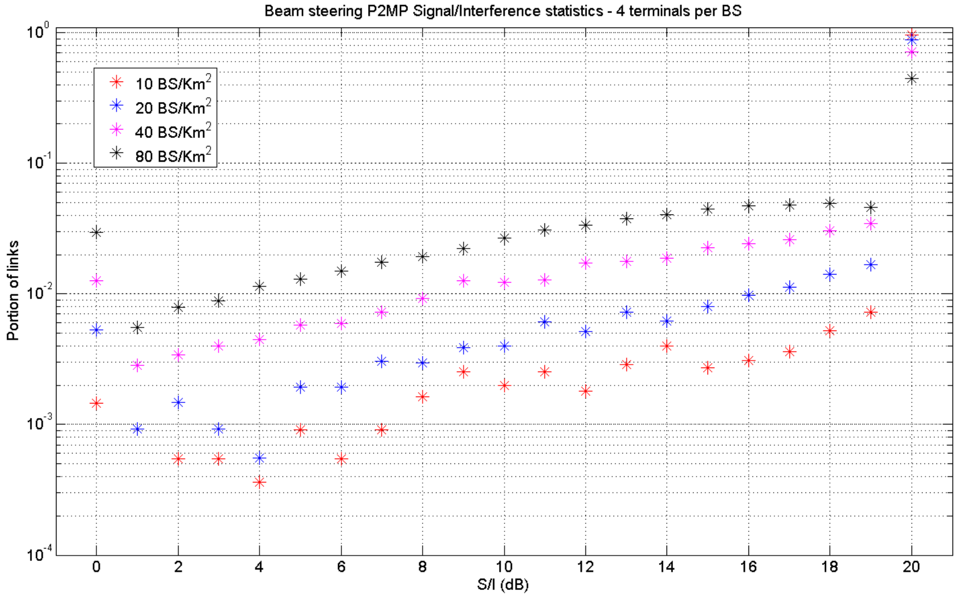


**Figure 4: Fixed four terminals per base-station using two frequency channels**

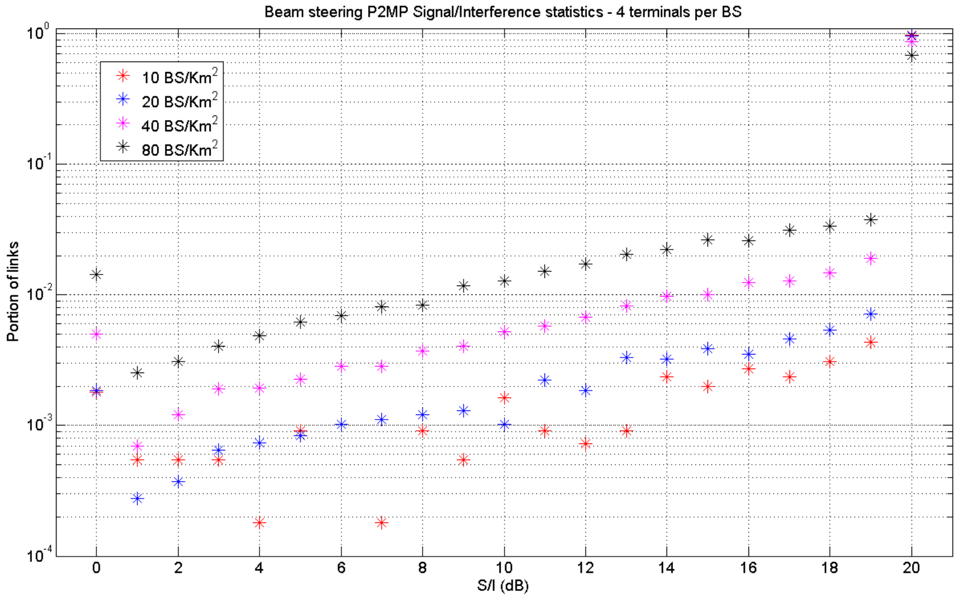


**Figure 5: Fixed four terminals per base-station using four frequency channels**



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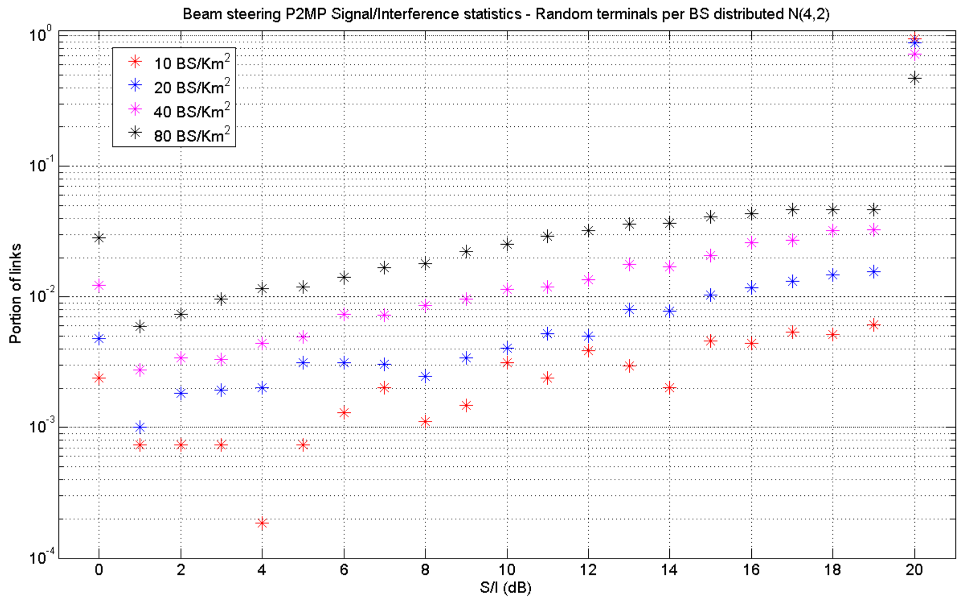


**Figure 6: Random N(4,2) distributed number of terminals per base-station using two frequency channels**

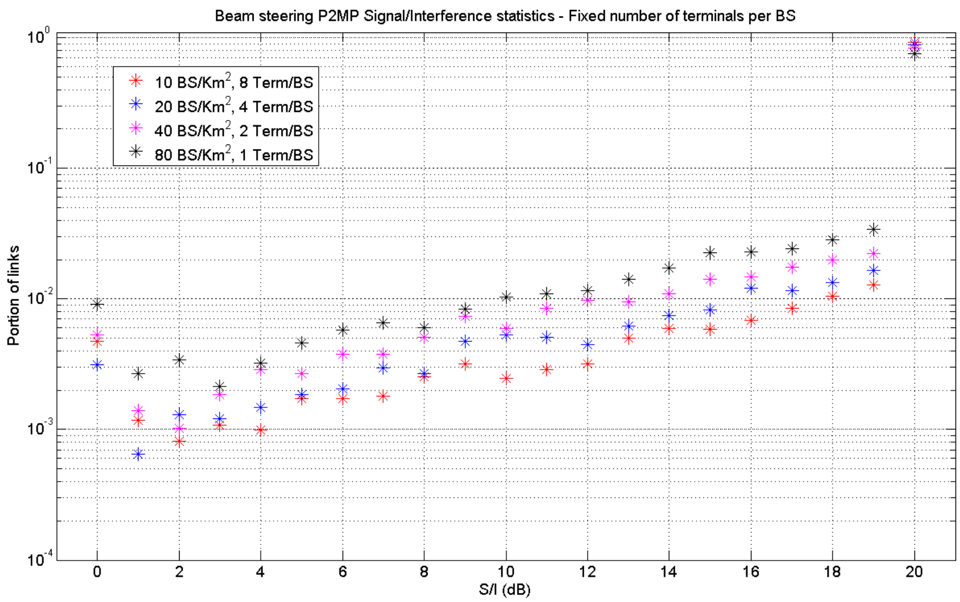


**Figure 7: Fixed node density by adjusting terminal to base-station ratio using two frequency channels**



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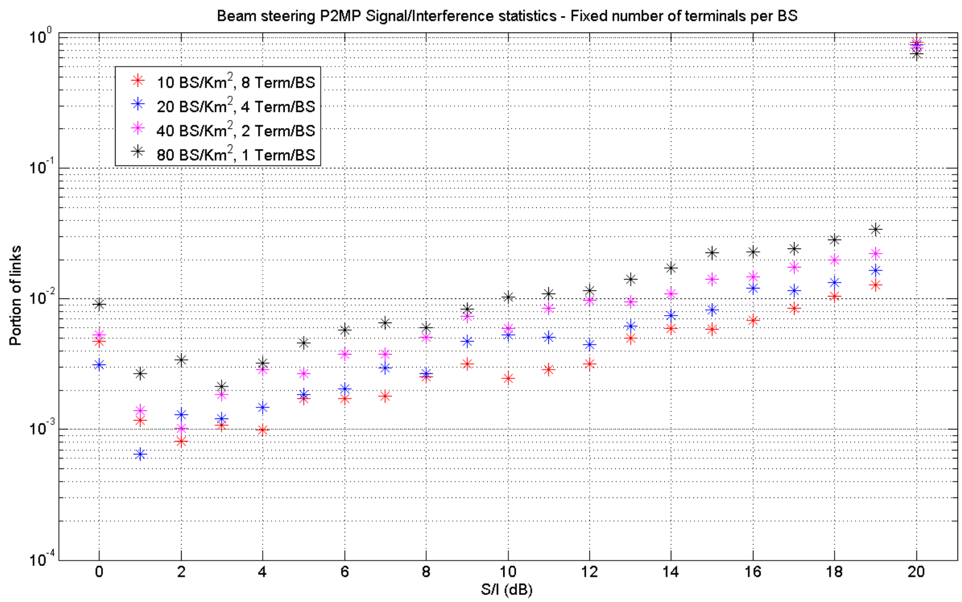


**Figure 8: Fixed four terminals per base-station using two frequency channels and no TPC**

The above results all demonstrate very robust performance in view of the high densities and lack of any planning simulated. The percent of nodes that remain blocked by interference even at their most robust modulation (which is assumed to 4dB S/I) is typically ~1%. As expected, use of more frequency channels improves the chances for lack of interference. We expect that real life scenarios will provide even better results due factors not considered in this analysis such as obstacles to pure LOS propagation, such as rooftop height being nom uniform across the deployment area and foliage height often exceeding the rooftop height. The results are expected to be potentially improved even further by used of a listen-before-talk (LBT) protocol. An LBT protocol is based on verifying there is no ongoing transmission before starting a new transmission. It is used in many shared media networks (most notably in Ethernet and WiFi). In wireless networks the detection is based on signal strength measurements. Adherence to the LBT protocol enables coexistence between uncoordinated systems in the sense that it is able to eliminate cases of unavailability. The cost for this includes some overheads due to the media sensing deployed and also potential latency for individual links, as the collision avoidance is implemented by backing off transmissions. There is also a throughput reduction for individual links as compared to the non-interfered case. However, the less overloaded the shared channel the smaller are the LBT adverse effects, so in case where only a small percentage of the links are interfered, LBT enables those low C/I links to retain high availability at the cost of reduced throughput and higher latency.



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# 4. Street-level deployment scenario simulation

The street level deployment scenario assumes a Manhattan grid of buildings in which wireless links are deployed across the streets. In the specific scenario analyzed, block size is taken as 90m and street width is taken as 15m. The simulation examines the chances for interference between a collocated pair of links using the same frequency channel. The link distance for both links ranges from 20 to 300m. The distance between the interfering link to the interfered link also ranges from 20 to 300m. The simulation consists of generating 10,000 random configurations per interfering-to-interfered distance. The frequency simulated is 61.5GHz, and co-channel interference thresholds are taken from ETSI EN 302 217-2 standard. A graphical depiction of the simulation scenario is shown below, where the blue lines represent the victim link whereas the red lines represent the interfering link.

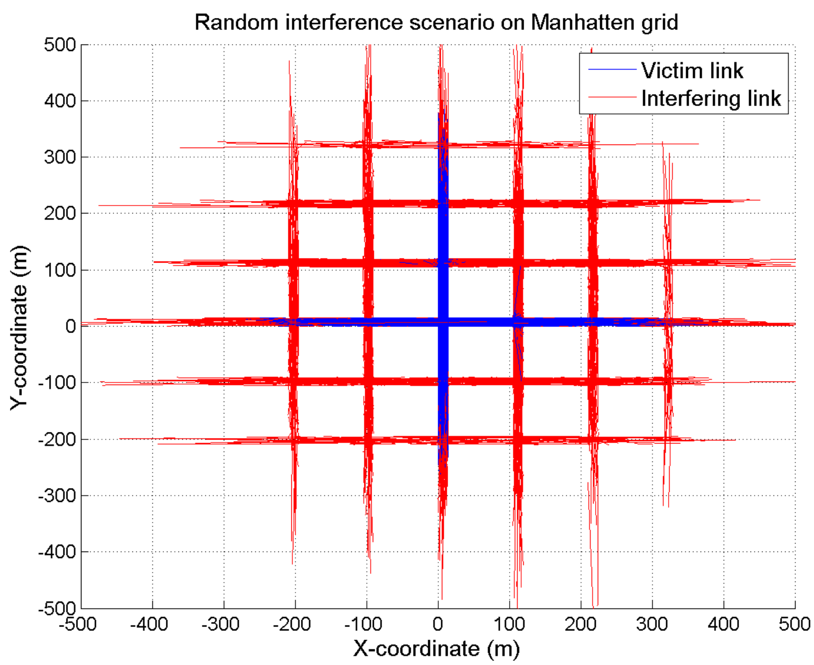


**Figure 9: Street level interference scenario depiction**

The figure below shows the simulated probability of interference shown when using a 30dBi regular antenna conforming to F.699 radiation pattern envelope (RPE). No polarization discrimination is assumed. It shows that the interference probability is moderate within the same block but drops rapidly at more than one block distance.



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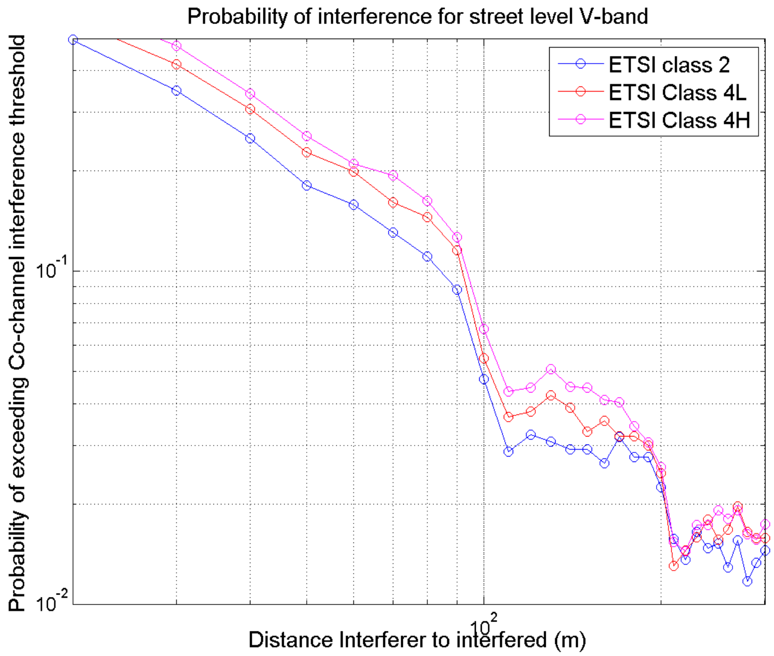


**Figure 10: Regular antenna probability of interference as a function of interferer distance**



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The same simulation is repeated with the use of a beam-steering antenna (the same one used for the rooftop simulation. The result is shown below.

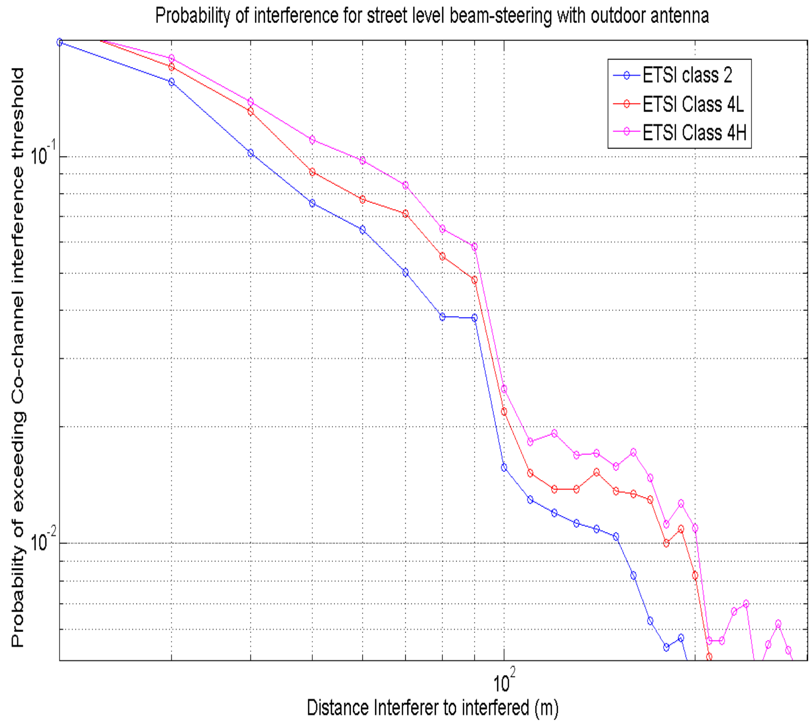


**Figure 11: Fixed four terminals per base-station using two frequency channels and no TPC**

The street level analysis is performed on a simplified grid, but results should be valid to a general urban grid. In any such grid, the street structure (i.e. buildings) isolation is the main isolator and the antenna pattern contribution is secondary. This happens because the antennas are forced to be aligned to the streets directions, which implies that antennas are either on the same street, non-isolated, and pointing more or less to the same direction, or on parallel or orthogonal streets, isolated by building. The Oxygen absorption plays an insignificant role at such short distances. The most important observation form this analysis is that the beam-steering antenna results are the same as a regular antenna. Other than that we expect that use of more than one frequency channel with a DFS mechanism as well as deployment of an LBT protocol should enable uncoordinated use also in this case, even with low gain beam-steering antennas.



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