Multi-beam antennas in a broadband wireless access system

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Abstract
The paper considers a high-capacity Point-to-Multi Point broadband wireless access system generally operating above 20 GHz. It is based on a cellular architecture with fixed links between a multidirectional radio hub and dispersed fixed subscriber terminals. The performed study is an up-link carrier-to-interference (C/I) performance evaluation of narrow multi-beam and wide sector-beam node antennas in such a system. It is shown that the introduction of three-beam antennas at the radio node improves up-link C/I-ratio with 5 dB compared with wide-beam sector antennas. The replacement of wide-beam node antennas can be made on a sector-by-sector basis. Simulations have shown that it is possible to get significant interference improvement in a 5 by 3 hub network by replacing as few as 20 % of the wide-beam radio node antennas with multi-beam antennas.

1. Introduction
Telecommunication operator requirements for access systems as well as users’ increased demands for bandwidth are driving forces behind the development of new broadband access systems. In this context, broadband wireless access is a competitive and complementary access technique to copper and fiber access.

This paper considers a high-capacity Point-to-Multi Point (PMP) system, operating in the 24 to 28 GHz band [1]. The PMP system follows a cellular deployment structure in which multiple square sectors cover a certain geographical area. Within each sector, there is one radio node and more than 50 fixed access points communicating over the air interface. The access points can be located anywhere within the sector coverage area.

The system typically requires line-of-sight communication in order to avoid problems with multi-path and delay spread. Frequencies and polarizations are re-used in a normally regular pattern, which causes interference from co-channel sectors. One quality measure in cellular systems is the carrier-to-interference ratio (C/I).

In the future, demands for increased capacity, better quality and/or higher spectrum efficiency could be met by exploiting higher-order modulation schemes. This requires higher C/I levels, which can be achieved by using antennas with multiple narrow beams at the nodes instead of the commonly used 90° sector beam antennas [2].
2. System description

The investigated access system exploits a square cellular deployment strategy. A hub, which contains four radio nodes covering 360° in azimuth, serves each cell. Typical sector diagonals are between 2 and 6 km. In down-link, from the node antenna to the access point, the node antenna radiates over the whole sector. In up-link, the node antenna receives information from one access point per time slot, exploiting Time Division Multiple Access (TDMA). The access point antennas are highly directive reflector antennas.

The current system is interference limited in up-link. This is due to the fact that the receiving radio node has a wide-beam 90° sector antenna with three main interfering directions. Up-link transmission occurs from one access point at a time in each sector. The power control within each sector is such that the received power from each access point is the same regardless of position within the sector. With a frequency re-use of two and two polarizations, the worst interference occurs when three main co-channel interferers are located at the sector borders four sectors away and transmit simultaneously, as illustrated with black arrows in figure 1.

In down-link, there is continuous broadcast from the radio node. The receiving access point has a highly directive narrow-beam antenna and there is only one interfering direction, as illustrated by the purple arrow in figure 1.

![Figure 1](image.png)

Figure 1 Example of main up-link (black arrows) and down-link (purple arrow) co-channel interferers in a 5 by 3 hub network cell plan at a frequency re-use of two. Same upper- and lower-case letter is the same frequency but orthogonal polarizations. Radio node hubs are marked with ⊗. At each hub there are four 90° sector-beam node antennas. Same colors indicate co-channel sectors.

3. Simulations

The C/I-ratio has been investigated by varying the number of radio node antenna beams from one to four in every sector in a 5 by 3 hub network. The number was increased and correspondingly the beam widths were reduced to get 90° sector coverage without beam overlap. A frequency plan of two was used in the simulations. In the up-link C/I-simulations, one access point per sector was randomly positioned for each time slot assuming a uniform distribution over the sector. The global cumulative distribution function (CDF) is the accumulated sums of all C/I-values calculated over all radio nodes in the cell plan and over all time slots. The C/I values were accumulated during 1000 time slots unless otherwise stated. Ideal line-of-sight propagation was assumed.

The CDF is plotted in figure 2 with the number of beams as a parameter. The C/I-ratio increases monotonically with increased number of beams. With the current cell plan, the side-lobe level in the backlobe region limits the performance at higher C/I-values. Three-beam node antennas have a potential increase in C/I with 5 dB compared to 90° sector beam antennas at a CDF of 2 %. A further increase in the number of beams at the radio nodes has negligible effect on the C/I performance.
4. Migration strategy

In mobile cellular systems, multi-beam antennas in the most disturbed sectors are considered in order to boost the capacity and/or balance the network capacity [3]. This approach is most relevant also in fixed cellular networks. In the previous C/I-simulations, all node antennas have been of the same type, either wide-beam or multi-beam antennas.

The average interference level (I/C) in up-link for each sector in a homogeneous wide-beam sector node antenna cell plan is shown in figure 3. The twelve sectors experiencing the highest interference levels are easily identified (red color).
In the next step, three-beam node antennas replaced all wide-beam node antennas in the network. The interference level in the network is reduced compared to the case in figure 3. In the twelve identified sectors, it is reduced between 4 and 5 dB. This suggests that sectors with the highest interference levels should be identified. The next step is to reduce the main interference directions by the introduction of multi-beam node antennas on a sector-by-sector basis.

As an example, the twelve worst sectors (the red ones in figure 3) with respect to C/I performance have been replaced with three-beam node antennas. This corresponds to 20% of the network’s antennas in a 5 by 3 hub network. The average interference (I/C) of the heterogeneous cell plan is shown in figure 4. It is seen that the average interference level is reduced in the substituted sectors, and that the sectors are now more equal with respect to interference levels.

![Figure 4](image4.png)

**Figure 4** Average up-link interference with respect to I/C in a 5 by 3 hub cell plan with 20% of the sector-beam antennas substituted to three-beam node antennas.

The up-link CDF per sector for the case with only wide-beam sector node antennas in the whole network is presented in figure 5a. It is clearly seen that there are clusters with sectors that experience similar interference environment. The twelve worst sectors are the ones previously identified in figure 3 (red color). The CDF presented is truncated at 0.01%, which is the reciprocal of the accumulated number of time slots (10,000) in the simulation.

![Figure 5](image5.png)

**Figure 5** Up-link CDF versus C/I-ratio per sector in a 5 by 3 hub network; a) wide-beam radio node antennas in all sectors, b) the twelve worst sectors with wide-beams antennas replaced by three-beam radio node antennas.
The CDF per sector for the twelve sectors where three-beam antennas have replaced the wide-beam antennas is shown in figure 5b. The improvement in C/I-ratio is about 3 dB at the 2% fraction level. Simulations have shown that a significant improvement in interference level can be achieved in a network by replacing a few wide-beam antennas with multi-beam antennas.

This suggests that the up-link interference situation should be analyzed in a deployed network and the interference sources and directions identified. Simulations will then tell which wide-beam radio node antennas should be replaced by multi-beam antennas to achieve an acceptable interference level in each sector.

5. Conclusions
The potential increase in C/I-ratio in up-link in a fixed broadband access system is on the order of 5 dB by utilizing three-beam radio node antennas instead of commonly used wide-beam sector antennas. The improvement in C/I can be used to implement higher modulation schemes and thereby higher bit rate or better communication quality. Increasing the number of beams of the radio node antennas further reduces the interference level marginally.

Significant improvements can be achieved in up-link by identifying sectors with highest interference level and replacing wide-beam sector antennas with multi-beam antennas in these sectors. In a 5 by 3 hub network study, only 20% of the radio node antennas had to be replaced to improve the C/I-performance considerably.

6. References
