White Paper

SmartBeam® Antennas: How the three degrees of freedom impact load balancing, network optimization, and CAPEX/OPEX

By: Kevin Linehan, Chief Technical Officer for Base Station Antenna Systems

Introduction 2

How SmartBeam Antennas Work 3

Introduction of the 3rd Dimension 3

Use Cases of SmartBeam Antennas in 3G Networks 4

Comparison of RET, 2D, and 3D SmartBeam Antennas 5

Gaining Improvements in Coverage, Interference, and Load Balancing with SmartBeam Antennas 6

Balance Between the Different SmartBeam Benefits 7

Network Optimization Versus Load Balancing 8

The Value of Load Balancing 11

Antenna Beamwidth Distribution 12

How SmartBeam Antennas Manage Cyclical Traffic Patterns 14

Saving CAPEX and OPEX with SmartBeam Antennas 14

CAPEX reduction 14

OPEX reduction 14

Conclusion 15

Visit our Web site at www.commscope.com/andrew or contact your local Andrew Solutions representative for more information.

Introduction

Traffic distribution in wireless networks varies over location and time. Even in 2G systems with a low capacity demand per user, traffic distribution change is significant over a day or a week. As an example, the hourly traffic distribution for two different sectors, from the same network cluster, over a one-week period, is presented in Figure 1A. The inhomogeneous nature of the traffic distribution requires that networks are heavily overbuilt in order to handle peak traffic.

With high data rate traffic demands on the horizon for 3G and beyond, the inhomogeneous nature of wireless traffic distribution will increase exponentially. Applications such as mobile music and video downloads will drive the need for greater capacity. Figure 1B shows the expected increase in mobile video services through 2010.

In order to handle this flexible traffic demand in a cost-effective manner, that is, without overbuilding the 3G networks to satisfy peak capacity demand, intelligent RF technologies can help to adapt the network and balance the load.

Figure 1A

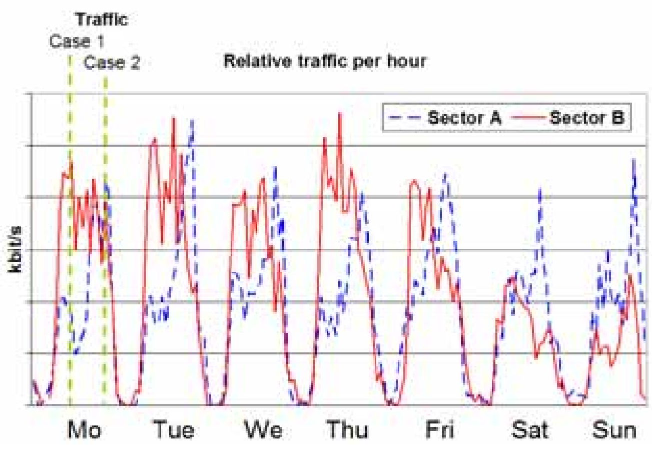
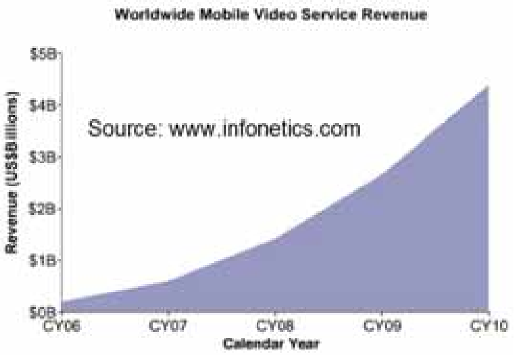


Figure 1B



Source: www.infonetics.com

The inhomogeneous temporal traffic distribution in a 2G GSM network is shown in Figure 1A for 7 days of a week at two different sectors in the same network cluster. The indicated traffic cases (1 and 2) will be used later in this paper. In Figure 1B, the expected increase in high data rate mobile video services until 2010 is indicated. The increase in high data rate traffic demand will cause a strong increase in peaks of the already inhomogeneous traffic distribution. In order to combat the varying traffic demand, flexible and intelligent RF infrastructures are required.

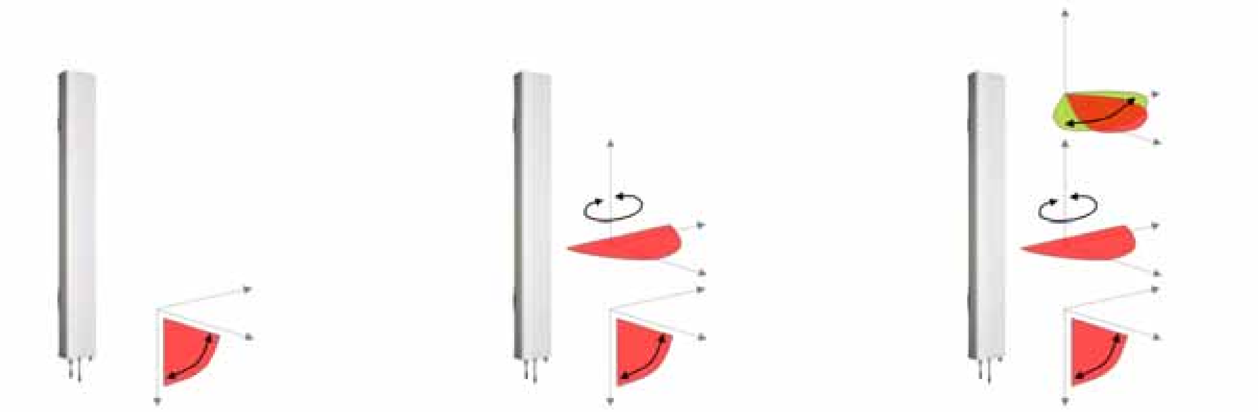
Multi-dimensional remote antenna systems, such as the SmartBeam® antenna system provided by Andrew Solutions, already allow flexible adaptation to meet varying capacity demand. This enables operators to significantly improve network capacity, while also saving more CAPEX and OPEX.* This white paper will explore how SmartBeam antennas, particularly the third dimension, improve load balancing and network optimization and reduce CAPEX and OPEX spending.

*See references for additional examples of earlier studies on advanced antenna techniques to improve system capacity.

How SmartBeam Antennas Work

SmartBeam antennas extend the range of remote beam changes from a single dimension for elevation beam steering (remote electrical tilt, RET) to multiple dimensions. These antennas include the possibility to change the boresight or azimuth direction (panning), as well as the beamwidth of the antenna (fanning) remotely (schematically shown in Figure 2).

Figure 2
Comparison of the different degrees of freedom for the SmartBeam antenna family



1D SmartBeam (RET)
[tilting]

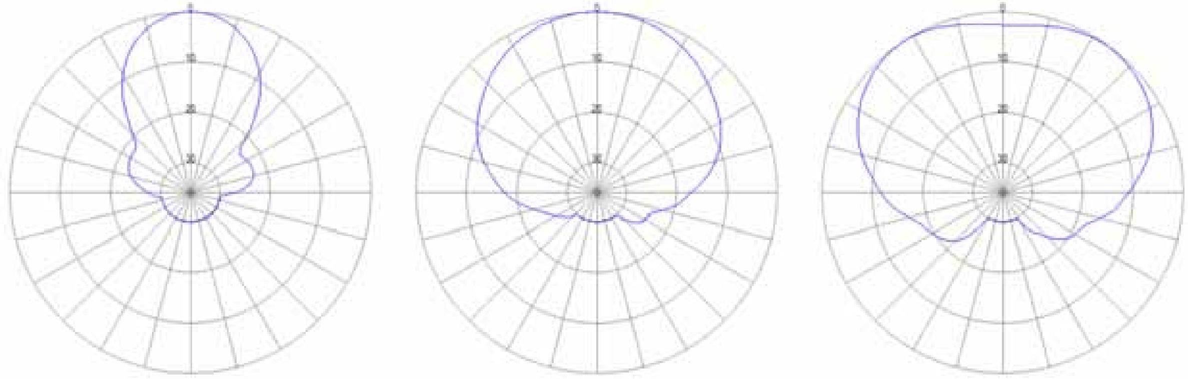
2D SmartBeam (RET and RAS)
[tilting + panning]

3D SmartBeam (RET, RAS, and RAB)
[tilting + panning + fanning]

Introduction of the 3rd Dimension

A key innovation in SmartBeam antenna technology is the introduction of the 3rd dimension for remote modifications. The beamwidth range for each antenna goes from 35° up to 120°. This has a significant impact on the antenna pattern, as well as the gain in the main lobe, which varies in the range of 13.9 dBi for 120° pattern to 19.2 dBi for narrow 35° pattern (see Figure 3).

Figure 3



35° beamwidth
Gain: 19.2dBi

65° beamwidth
Gain: 16.1dBi

120° beamwidth
Gain: 13.9dBi

This SmartBeam antenna features variable electrical beamwidth in the range of 35° to 120° opening angle, hence the antenna gain is different for the various opening angles.

Use Cases of SmartBeam Antennas in 3G Networks

SmartBeam antennas can be used for multiple purposes, including coverage, quality, and capacity improvements. We explored several use cases with a focus on load balancing capabilities.

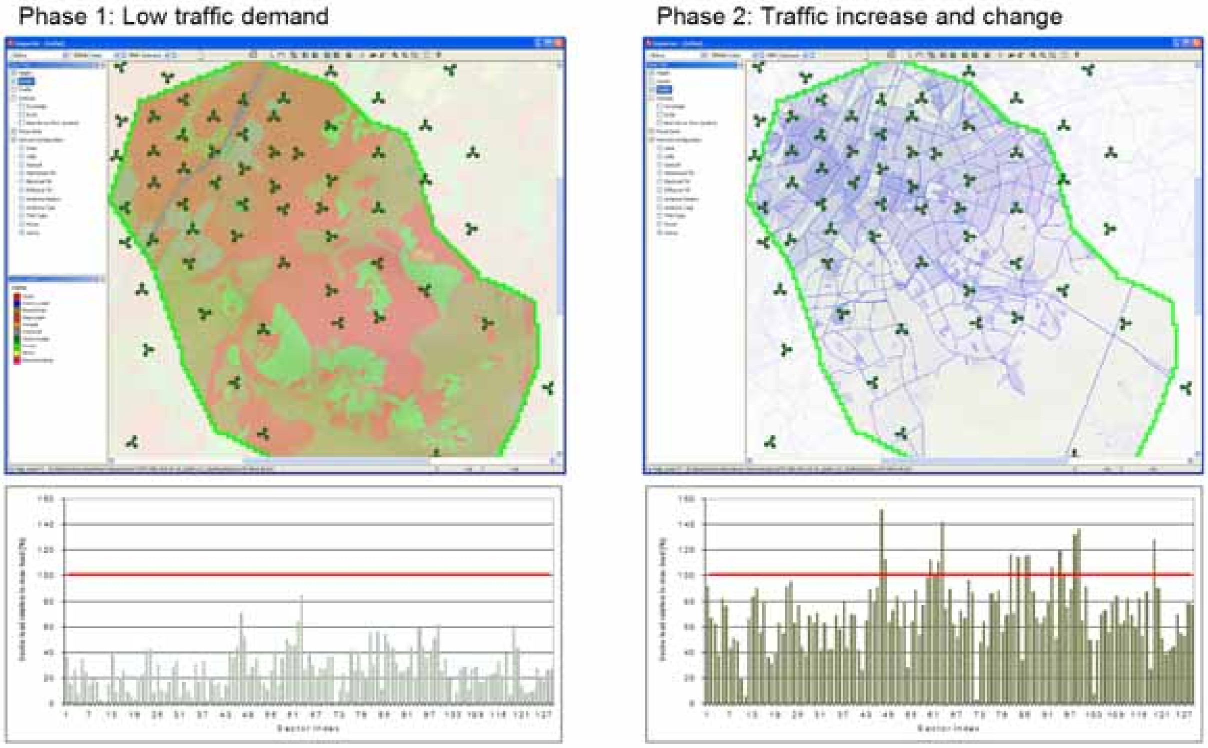
To gain better insight into the real value of advanced antenna technology, we used data from a 3G UMTS radio network in Brussels, Belgium (see Appendix A). The data is obtained from a leading radio network planning tool, including the data from the configuration data base, geo data, operational target values, and traffic distribution statistics[1].

In general, radio networks can be limited by coverage, interference, or radio resources. While networks in the first phase of their life cycle (and deployment cycle) are typically limited by coverage or bad interference design, mature radio networks are typically limited by capacity and radio resources. An example for these two cases is given in Figure 4.

Phase 1 shows the network where traffic demand due to mobile users in the network is very low. Networks are typically designed and deployed based on land usage information (clutter), as indicated on the left hand side in Figure 4. The loading of individual sectors is also well below the maximum traffic that can be handled in such cases (see Appendix A).

Phase 2 describes a more mature network where higher traffic demands occur. Once the number of subscribers and the data rates for the individual services increase, the cell utilization increases. This is shown on the right hand side of Figure 4. The traffic distribution in such cases is typically highly inhomogeneous within a network, which is indicated by the traffic density map. This results in many cells with a low load, while other cells are overloaded, i.e., exceed the nominal limit of 100% maximum traffic load.

Figure 4



Here is a comparison of two typical cases during the life cycle of a wireless network. In Phase 1 the traffic demand is well below the maximum traffic that can be handled by the network. The network is typically limited by coverage and interference rather than capacity. In Phase 2 the traffic increases and problems occur in the different cells as they get overloaded. Blocked and dropped calls are the result, leading to significant additional infrastructure investments to handle the offered traffic.

Therefore, one of the key questions is whether SmartBeam antennas can help balance the load between different cells, leading to a combination of coverage, interference, and capacity improvements.

Comparison of RET, 2D, and 3D SmartBeam Antennas

To investigate the impact of SmartBeam antennas on load balancing, we compared its performance with conventional antenna technologies, including RET antennas using the network and traffic scenario as shown in Figure 4, Phase 2 as the starting position.

This is a 3G UMTS network with 65° antennas. The mechanical tilts are used from the underlying 2G network. The initial electrical tilts were set to 2°. This is a typical deployment approach for a 3G overlay on an existing 2G network. We compare different antenna technologies:

- **RET antenna:** Fixed 65° horizontal pattern (as shown in Figure 3), elevation range of the remote tilt [0° to10°], no azimuth changes; → *Tilting.*
- **2D SmartBeam antenna:** Fixed 65° horizontal pattern, elevation range of 0° to 10°, remote azimuth changes in the range of [–30° to +30°]; → *Tilting + Panning.*
- **3D SmartBeam antenna:** Elevation range of [0° to10°], remote azimuth changes in the range of [–30° to +30°], flexible antenna beamwidth in the range of [33° to 120°]; → *Tilting + Panning + Fanning*.

Gaining Improvements in Coverage, Interference, and Load Balancing with SmartBeam Antennas

SmartBeam antennas provide multi-dimensional improvements in coverage, interference, and load balancing.

- Coverage improvements
    - Pilot coverage

      Sufficient signal coverage on the pilot (also called common control or broadcast signal) is the basis for all wireless communications systems. The received signal strength of the pilot tone at the mobile has to exceed the receiver sensitivity to ensure that a mobile can connect to the network. SmartBeam antennas can significantly help to increase the basic network coverage.
    - Service coverage

      Different services may require different received signal levels so that a successful service connection (a voice call or any data transmission) can be established between the mobile and the network. These service coverage requirements depend upon the received signal level and the received signal-to-interference ratio.
- Interference improvements
    - Improvements in C/I (Ec/Io)

      Interference is one of the key limiting factors in wireless systems. In order to work properly, every data transmission requires a minimum signal to interference ratio. This is usually expressed in terms of carrier to interference ratio (C/I), or by Ec/Io[2].

**Ec/Io = Average energy per chip over the total received power spectral density, including signal and interference in a CDMA system.

Improvements in the C/I (Ec/Io) result in better service coverage, services with higher data rate throughputs, and improved service quality in general. Improving the C/I (Ec/Io) also means that lower transmit power levels per connection are required for the same service, leading to significant improvements in the overall network capacity.

- Reduction in the cell overlap or “Soft Handover”

  Cell overlap in CDMA type systems is required for a smooth handover for a user moving from one service cell to another, also called “Soft Handover.” As mobile devices in Soft Handover mode receive the same, hence redundant, information from multiple base station transmitters simultaneously, a large cell overlap leads to significant capacity reduction. Cell overlap should therefore be kept as low as possible, but as large as required.

SmartBeam antennas can be used to control both interference, as well as cell overlap in a highly effective manner.

- Load balancing improvements

  As shown in Figure 4, the distribution of the sector load is typically highly inhomogeneous within the network. While some sectors experience very high traffic loads, the utilization of the majority of the sectors is well below the maximum load.

  - Improvements in sector utilization

    In an ideal network, the maximum system capacity can be achieved by equally balancing load between individual sectors. This means that load from highly loaded sectors should be shifted to those that can easily handle additional traffic.

  - Reduction of the number of overloaded sectors

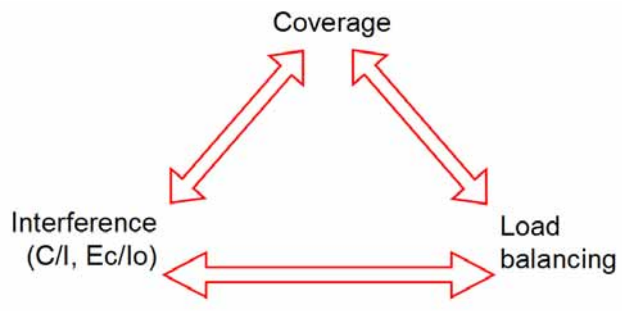
    The key benefit of load balancing is to increase sector utilization, which reduces the number of overloaded sectors. This leads to significantly improved overall network performance and capacity without additional CAPEX.

  SmartBeam antennas enable flexible, cost-effective balancing of individual sector loads by allowing remote tilting, as well as remote panning and fanning.

Balance Between the Different SmartBeam Benefits

Performance improvements in radio networks are a compromise of individual objectives, such as coverage, interference, and load balancing capabilities. These improvements can be achieved simultaneously, although optimization for each improvement may vary. This is schematically shown in Figure 5. Simply put, the network with the highest coverage will not have the highest capacity and best interference distribution at the same time.

Figure 5
Compromise between coverage, interference, and load balancing effects in radio network optimization



SmartBeam antennas can achieve different gains, depending on the actual limitations in the network, which helps improve coverage, interference (C/I and Ec/Io), and load balancing in a flexible way. This explains why SmartBeam antennas are an adaptive coverage system, an interference reduction system, as well as a flexible, adaptive capacity solution.

Network Optimization Versus Load Balancing

Although various improvements can be achieved simultaneously, the performance improvements that are achievable depend upon the available degrees of freedom of the SmartBeam system.

Coverage and interference improvements can be considered as classical optimization tasks. The results for these tasks are shown in Figure 6A, and include:

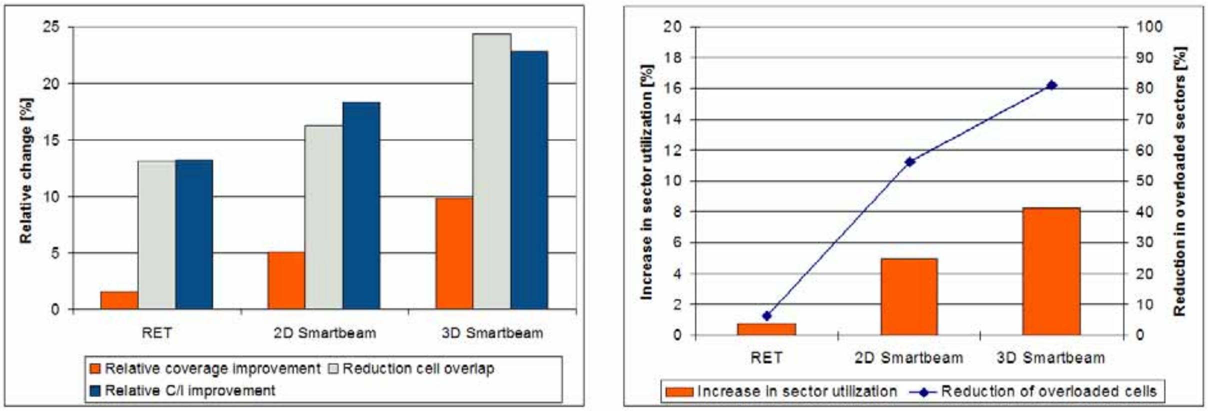
- Coverage improvement
- Reduction in cell overlap
- Relative C/I (Ec/Io) improvements

The results of load balancing are shown in Figure 6B, and include:

- Increase in sector utilization
- Reduction of overloaded cells

Figure 6A **Figure 6B**

Simultaneous improvements achieved by RET, 2D SmartBeam, and 3D SmartBeam antennas



In Figure 6A, the relative improvements in coverage, C/I (Ec/Io), and reduction in the cell overlap are shown. In Figure 6B, the relative increase in sector utilization and reduction of overloaded cells are shown as compared to the initial scenario. While RET antennas are good for interference optimization, their value for coverage improvements and load balancing are limited as compared to 2D and 3D SmartBeam antennas.

Starting from the initial settings, different antenna technologies have been used for both network optimization and load balancing, simultaneously:

- **Improvements by 1D RET antennas**
  a) Optimization gains: It can be observed that the key strength of RET antennas is the optimization of C/I (Ec/Io) performance in a network (see Figure 6A). Cell overlap can be controlled similarly to the interference in the network. However, RET antennas have a limited ability to improve the coverage of a network.
  b) Load balancing gains: As Figure 6B shows, RET antennas are of limited value with regard to load balancing. Modifying tilt is obviously not sufficient to move traffic effectively from one sector to another. This results in a small relative improvement of cell utilization. As a result, the number of overloaded cells can only be reduced slightly, see Figure 6B.
- **Improvements with 2D SmartBeam Antennas**
  a) Optimization gains: In cases where 2D SmartBeam antennas are used, all optimization objectives are improved when compared to the RET situation. C/I (Ec/Io) and cell overlap performance have been improved, and the relative coverage improvement has more than doubled compared to the RET case. See Figure 6A.

b) Load balancing gains: Since 2D SmartBeam antennas have the additional degree of freedom for remote changes of the boresight direction (panning), the offered traffic can be shifted more effectively between the individual cells. This results in better load balancing, higher cell utilization, and hence the ability to reduce the number of overloaded cells significantly, as shown in Figure 6B.

- **Improvements with 3D SmartBeam Antennas**

  a) Optimization gains: In addition to previous cases, now the beamwidth of the antenna can be modified remotely (fanning). All of the performance indicators related to optimization are significantly improved compared to the 2D SmartBeam. C/I and coverage are further improved. Compared to RET antennas, C/I improvements are almost doubled.

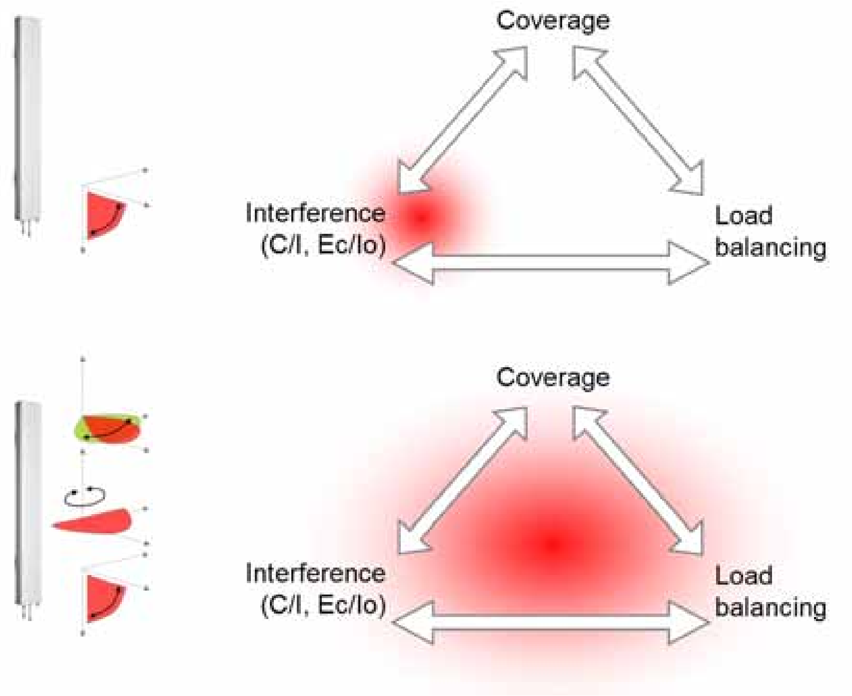
  b) Load balancing gains: Since 3D SmartBeam antennas have the highest flexibility to balance the load between sectors, i.e., to shift traffic among the cells, the increase in the average cell utilization is boosted. This leads to a dramatic reduction in the number of overloaded cells, as shown in Figure 6B.

From the results in Figure 6, the following can be summarized and concluded:

- RET antennas are ideal for interference and cell overlap optimization. RET antennas do not provide significant gains when used as adaptive coverage systems. Furthermore, RET antennas have very limited capabilities to balance the load in a network. As indicated in Figure 7, RET antennas provide the most value for interference optimization.
- SmartBeam antennas achieve significant gains in the optimization objectives when compared to the RET antennas. Furthermore, SmartBeam antennas achieve simultaneous gains in both coverage, as well as load balancing. SmartBeam antennas provide full flexibility to adapt the network to meet specific needs.

Figure 7

Schematic of the operational area of RET and SmartBeam antennas



The Value of Load Balancing

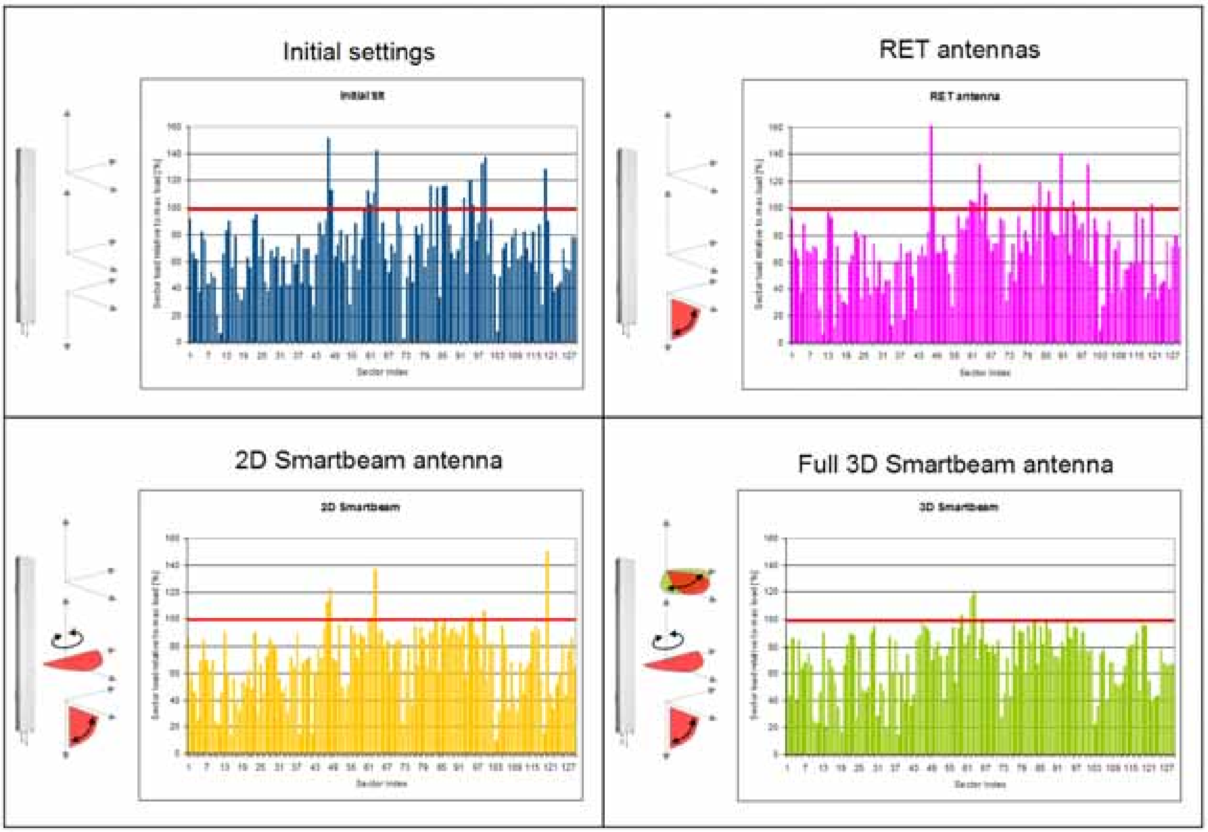
The key value of load balancing is to shift traffic from overloaded sectors to sectors with free capacity. By doing so, the general utilization is increased and the number of overloaded sectors is reduced.

The differences in the actual cell utilization are shown in Figure 8. Based on the initial settings, different antenna technologies are compared. It can be observed that RET antennas have a limited ability to shift traffic among different cells. Hence, the number of overloaded sectors does not change significantly.

Comparing results from 2D and 3D SmartBeam antennas clearly demonstrates the key advantages of these technologies, particularly the 3D SmartBeam antenna. It can be observed from Figure 8 that cells with loads above the 100% mark (indicated by the red line) are almost eliminated. The additional loading is now covered by other sectors in the network, so that the overall captured traffic has been increased.

From a cost perspective, significantly lower CAPEX is needed to handle the overloaded sectors (in both the initial, as well as the RET case). As indicated in Figure 6B, more than 80% of the additional costs for fixing the sectors can be saved.

Figure 8



Cell loads of different scenarios with RET, 2D and 3D SmartBeam systems. Each bar represents the load of a particular sector. The overall improvements and reduction in overloaded sectors is limited with RET antennas and highest with 3D SmartBeam systems.

Antenna Beamwidth Distribution

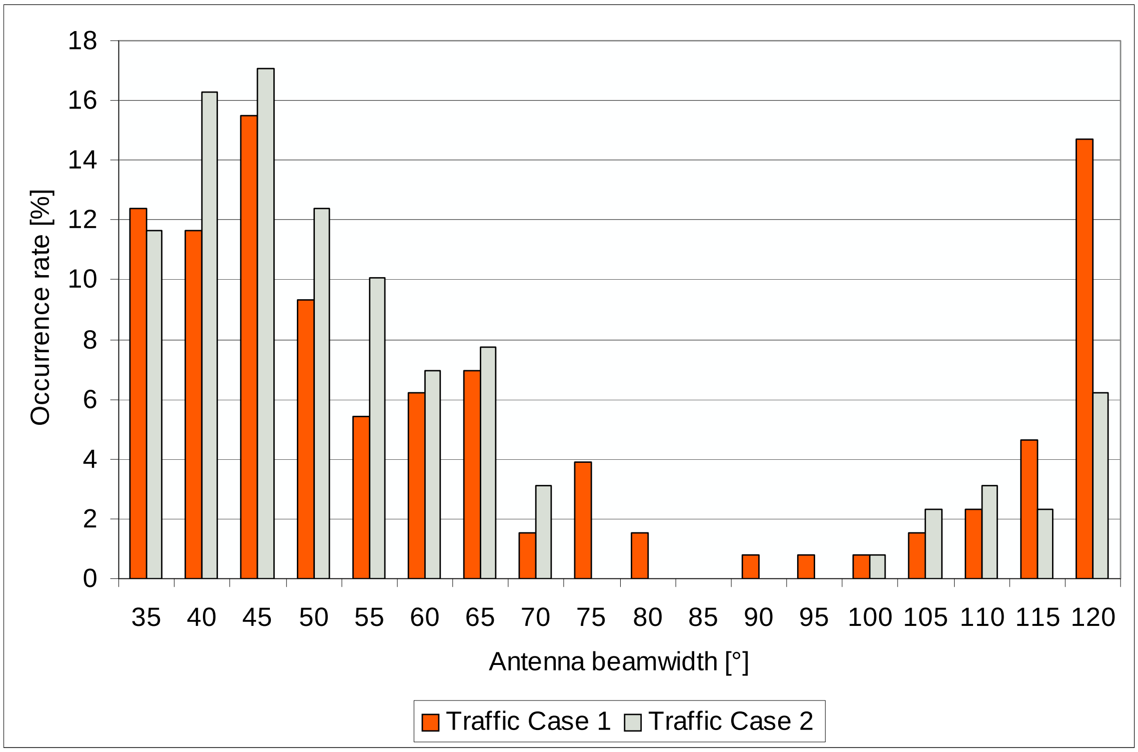
Most existing wireless networks use a fixed choice for antenna beamwidth, that is, the 65° antenna which is the most widely used antenna pattern worldwide. In contrast, our analysis shows that significant gains can be achieved with the flexible beamwidth provided by the 3D SmartBeam antenna.

To give insight into the most appropriate antenna beamwidth, Figure 9 shows the statistical distribution of the antenna beamwidth using the 3D SmartBeam antenna from the case above. Two beamwidth distributions are shown for different traffic scenarios. The traffic scenarios are taken from different network cases in the morning and late afternoon. This is indicated in Figure 1A by traffic cases 1 and 2.

From the first look, it can be seen that the “65° pattern fits all” maxim is no longer valid. We have already seen from the results of the 3D SmartBeam antenna in Figure 4 that significant improvements of coverage, C/I (Ec/Io), as well as a large reduction in the number of overloaded cells, are achieved by the use of a flexible beamwidth. Figure 9 gives an insight into the reasons behind this.

A narrow antenna beamwidth results in a higher antenna gain in the main lobe direction, as compared to a wider antenna beamwidth with a significantly lower main lobe gain (see Figure 3). This is why a mixture of different antenna beamwidths provides the best performance.

Figure 9
Distribution of the antenna beamwidth after the optimization



Distribution of the antenna beamwidth shown in Figure 9 shows some clusters around 45° and at the upper end above 100°. The distribution depends on various input parameters, such as the scenario itself, the traffic distribution, as well as the desired focus on the optimization objective, as indicated in Figure 5.

One might think that wide beamwidth pattern will cause higher sector-to-sector interference. The results in Figure 6A show a different picture: The actual sector-to-sector interference has been significantly reduced by the use of variable beamwidth. This is due to the fact that it is not just the beamwidth, but the combination of beamwidth and azimuth changes that provides substantial improvements.

How SmartBeam Antennas Manage Cyclical Traffic Patterns

Measurements in wireless networks show a clear cyclical behavior. An example for the traffic pattern of a single sector, over a 24-hour, 7-days a week period is shown in Figure 1A. It can be observed that the traffic pattern repeats over time.

Keeping in mind that the overall traffic will increase over time, as indicated in Figure 1B, the total traffic will be a combination of a cyclical pattern combined with an increasing average value.

By using smart RF technologies that can remotely adapt to these continuously changing, and permanently increasing, traffic situations, both CAPEX and OPEX for wireless networks can be reduced.

Saving CAPEX and OPEX with SmartBeam Antennas

Due to the unique capability of SmartBeam antennas to provide adaptive coverage, flexible interference mitigation, and advanced load balancing, both CAPEX and OPEX can be significantly reduced.

CAPEX Reduction

Potential CAPEX reductions with SmartBeam antennas are tightly related to the reduced investments needed to fix overloaded sectors. Conventional methods to fix these overloading situations include the construction of new and additional base station sites, the addition of channel elements, and the instruction of advanced power amplifiers, cell splitters, etc.

By increasing the average sector utilization, these additional investments can be avoided. Our results show that up to 80% of overloaded sectors can be fixed with SmartBeam antennas, which can lead to a significant reduction in CAPEX required to fix the sites.

OPEX Reduction

Historically, the permanently changing and growing nature of wireless traffic has required a continuous network extension. Network extensions in CDMA and OFDMA networks imply that the interference situation has to be continuously adapted. As shown in Figure 5, this influences additional coverage and capacity requirements.

To ensure good overall network performance, radio parameters need to be modified continuously over the life cycle of the network. The ability to perform this task remotely with tilting, panning, and fanning capabilities can reduce operational expenditures.

Conclusion

Modern and future wireless networks will require more flexible capacity management than 2G, GSM, and IS95 radio networks. The increasing demand for high data rate services results in creating highly inhomogeneous traffic patterns, which vary over time and space.

In order to satisfy customer expectations, wireless network operators can accommodate this traffic demand by either massively overbuilding network capacities for peak situations, or by better utilizing their existing investments: their current infrastructure.

The latter case implies a need for intelligent antenna and radio infrastructure, which enables the remote balancing of the traffic. This capability relieves overloaded cells by remotely shifting the load to cells with more free capacity.

SmartBeam antennas from Andrew are a key enabler for flexible, next generation, wireless network management.

This paper provides an overview of the benefits of SmartBeam antennas as compared with conventional RET antennas in a 3G CDMA-based radio network. The following conclusions can be drawn from our research:

- RET antennas have a significant impact on the improvement of C/I and Ec/Io in CDMA based 3G radio networks.
- The ability of RET antennas to increase cell utilization by balancing load between different cells is rather limited.
- 2D SmartBeam antennas enable significant improvements in all performance indicators when compared to a network optimized with RET antennas. This includes coverage and C/I (Ec/Io) improvements, as well as higher cell utilization.
- Higher cell utilization allows 2D SmartBeam antennas to shift traffic from overloaded sectors to those that can carry extra load, reducing the number of overloaded cells by up to 50%.
- 3D SmartBeam antennas easily generate the highest performance gains of all available antenna technologies. This is the case for coverage and C/I (Ec/Io) objectives, as well as for cell utilization and the balance of cell loads.
- In the case of load balancing capability and improvements, for this typical example, 3D SmartBeam antennas outperform RET antennas by more than a factor of five.
- The distribution of the antenna beamwidth confirms a distinct that the singular use of a 65° pattern is far from ideal for wireless networks.
- SmartBeam antennas can reduce the number of overloaded cells by approximately 80%. Higher utilization of existing sites reduces future CAPEX and OPEX.
- 3D SmartBeam antennas allow highly increased flexibility, enabling operators to realize greater cost reductions to satisfy ever-changing capacity requirements.

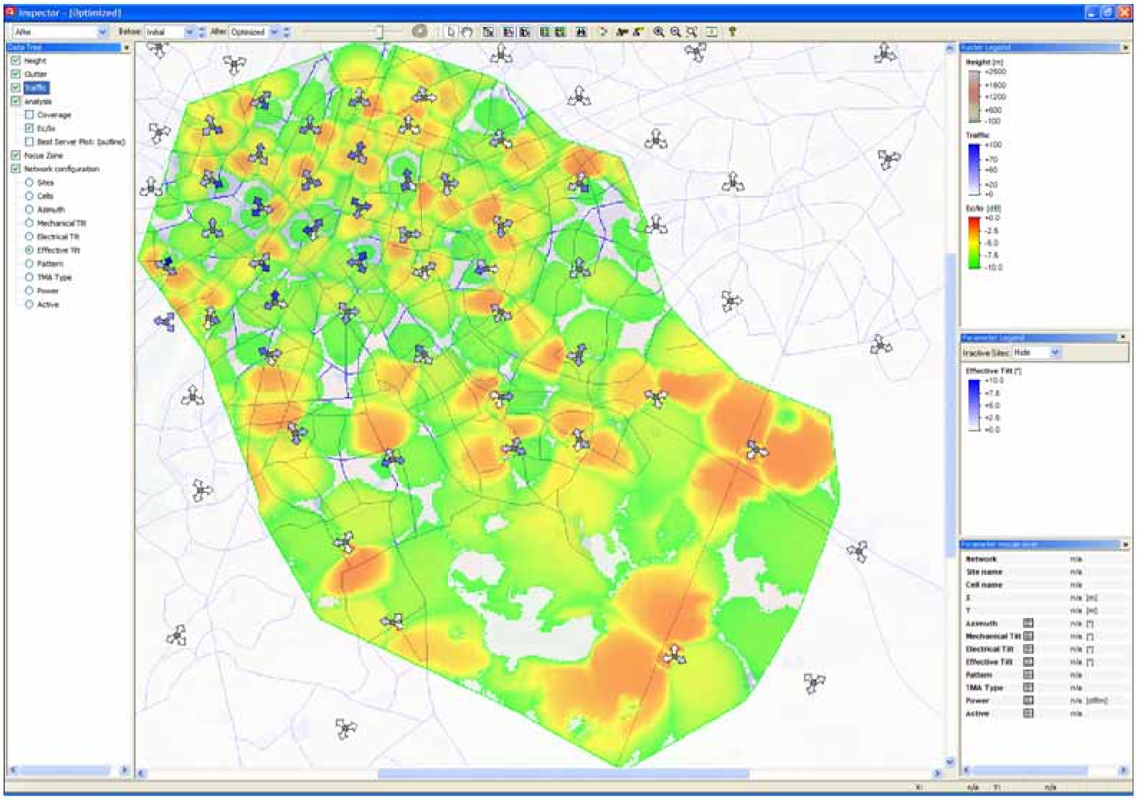
Visit our Web site at www.commscope.com/andrew or contact your local Andrew Solutions representative for more information.

- With cyclically changing traffic patterns, a scheduled network adaptation achieves the best network performance at the lowest cost. SmartBeam antennas, in combination with the network management systems provided by Andrew, are well suited for this application.

Appendix A

- The network example used for this white paper is shown in Figure 10. It includes a cluster of 129 UMTS sectors in southeast Brussels, Belgium. The data target area of interest is defined by a polygon. All analyses are conducted within this area.

Figure 10



After ▾ Before: Initial ▾ After: Optimized ▾

☑ Height
☑ Clutter
☑ Traffic
☑ Analysis
  ☐ Coverage
  ☑ Ec/Io
  ☐ Best Server Plot: (outline)
☑ Focus Zone
☑ Network configuration
  ○ Sites
  ○ Cells
  ○ Azimuth
  ○ Mechanical Tilt
  ○ Electrical Tilt
  ● Effective Tilt
  ○ Pattern
  ○ TMA Type
  ○ Power
  ○ Active

Inactive Sites: Hide ▾

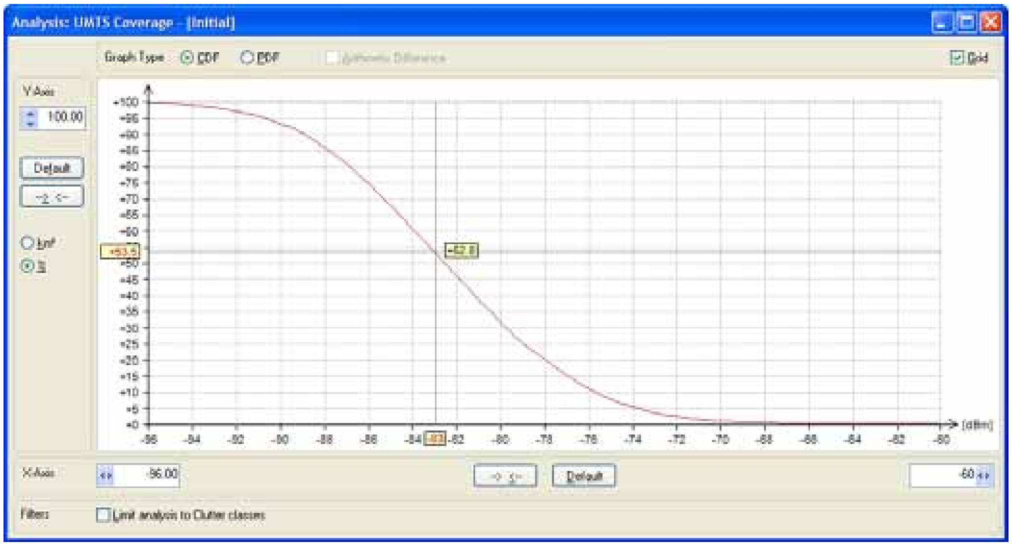
Network	n/a
Site name	n/a
Cell name	n/a
X	n/a [m]
Y	n/a [m]
Azimuth	n/a [°]
Mechanical Tilt	n/a [°]
Electrical Tilt	n/a [°]
Effective Tilt	n/a [°]
Pattern	n/a
TMA Type	n/a
Power	n/a [dBm]
Active	n/a

Visualization of the area of interest, including clutter data, site information, terrain data, coverage plot, and traffic density map.

- The scenario uses state-of-the-art radio network technologies and data. This includes geo data, land usage data (clutter information), traffic density maps describing the service probability, etc.

- All base station and link budget-related parameters (power levels, operating frequencies, mobile service requirements, transmit and receive properties of both the base station, as well as the mobile equipment, etc.) are based on typical examples used by operators to plan and optimize their UMTS radio network.
- Each of the arrows represents a base station sector, while the associated color shows individual parameters that can be selected by planning tool user.
- Figure 10 also shows a coverage plot for pre-defined thresholds, as typically used by UMTS operators. Areas inside the target polygon that are not covered appear white (or transparent). These are areas that should be covered by using optimization techniques and/or advanced antenna technologies.
- Coverage plots can be shown and analyzed, as well as statistics of these values. An example is given in Figure 11. The CDF (cumulative distribution function) of the coverage levels are shown. This can be used to analyze what the problems are in the network. If all coverage levels satisfy the requirements of the operator, coverage is not a limiting factor.

Figure 11
Statistics of the coverage distribution in the target area



Analysis: UMTS Coverage - [Initial]

Graph Type ● CDF ○ PDF

☐ Arithmetic Difference

☑ Grid

Y Axis 100.00

○ km² ● %

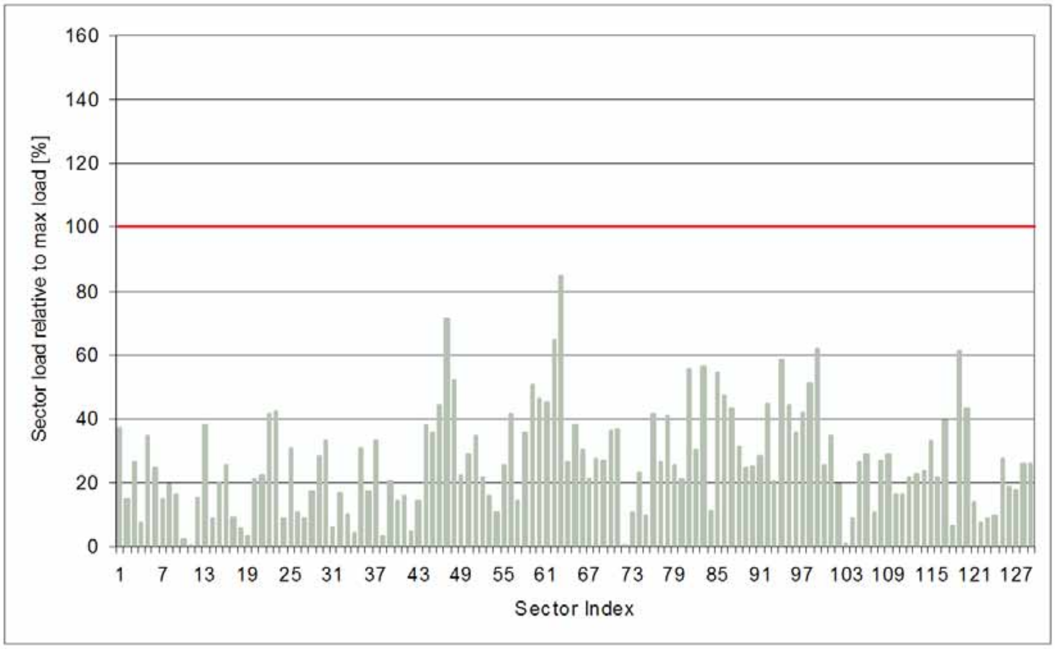
X-Axis -96.00 -60

Filters: ☐ Limit analysis to Clutter classes

- Coverage plot and statistics are shown in Figure 10 and Figure 11, respectively; plots on C/I and Ec/Io are computed as well. In combination with the coverage analysis, one can then easily analyze if the limitation in the network is on coverage or C/I (Ec/Io), or both.

- Considering that coverage and interference are not the only limitations in a wireless network, other factors are taken into account as well. An important parameter is the actual utilization of individual sectors. This helps determine if a particular sector can easily handle the offered traffic in the area or if the sector is overloaded.
- An example for a network where all sectors operate well below their maximum capacity is shown in Figure 12. The maximum traffic load is indicated by the red line at the 100% mark. Since different base stations may use different radio equipment, and hence have different absolute capabilities for maximum traffic, relative numbers are shown.

Figure 12



Relative load of individual sectors in the network

- In Figure 12, all sectors have sufficient flexibility to handle extra traffic; hence, there is no overloading situation. Networks like this are considered coverage or interference limited, but not capacity limited.

References

[1] *Final report on Semi-Smart Antenna Technology Project*, Ofcom Contract No. 830000081, Document No. 830000081/04, July 2006.

[2] *Automatic antenna tilt control for capacity enhancements in UMTS FDD*, M. Pettersen et al, IEEE 2004, 0-7803-8521-7/04, 2004.

Visit our Web site at www.commscope.com/andrew or contact your local Andrew Solutions representative for more information.