



# Alvarion<sup>®</sup> Advanced Antenna Systems

Beamforming Teams Up with MIMO to  
Enhance Mobile WiMAX<sup>™</sup> Network Value

White Paper



SentieM



## Abstract

In today's competitive environment, operators are focused on improving the value of their network as well as the user experience. By enhancing the main components of any SLA (Service Level Agreement) – coverage, capacity and QoS (Quality of Service) – Mobile WiMAX provides operators with a highly reliable and affordable technology for delivering next-generation wireless broadband services.

AASs (Advanced Antenna Systems) – the use of multiple antennas on both subscriber terminals and base stations – typically utilize a range of diversity and MIMO (Multi-input, Multi-output) schemes for maximizing WiMAX™ network efficiency. Leveraging vast technological expertise and a deep understanding of mobile operators' needs, Alvarion offers leading, state-of-the-art AASs that include not only diversity and MIMO schemes, but also beamforming. An advanced technology that utilizes multiple antenna elements like its diversity and MIMO counterparts, beamforming further increases network coverage, capacity, data rates and QoS to help operators meet their SLAs efficiently and effectively. By offering operators flexible AASs in which beamforming is complemented by a range of diversity and MIMO schemes, Alvarion enhances the value of operators' networks while improving the overall user experience.

## AAS Enables WiMAX Network Efficiency

Beyond serving as a leading-edge technology, WiMAX has emerged as a key business driver addressing operators' ever-growing needs. One such need is the ability to deliver reliable and consistent wireless broadband services to mobile terminals such as cell phones, MIDs (Mobile Internet Devices), laptops, smartphones, and PDAs – while meeting consumers' expectations for low price points. This need has become more pressing given that operators today are looking to maximize ARPU (Average Revenue Per User) while lowering CAPEX (Capital Expenditures), ongoing OPEX (Operating Expenditures), and TCO (Total Cost of Ownership) to remain competitive.

One way operators can reliably deliver quality broadband services at a low cost is through AASs. Alvarion's AASs generate multi-channel systems, thereby increasing the CINR (Carrier-to-Interference-plus-Noise Ratio) and significantly improving the radio signal, which leads to higher QoS. By greatly enhancing WiMAX network performance, Alvarion's AASs reduce the number of required base stations and cell sites, translating to a lower TCO for operators. At the same time, this unique combination of technologies increases overall system reliability, improves data rates, and boosts capacity and coverage.

Providing operators with the technological differentiation they need to succeed, Alvarion's AASs are the only class of antenna technologies that enable Mobile WiMAX to meet and even exceed operator expectations.

## Diversity and MIMO Schemes

Playing a major role in WiMAX implementations, a number of schemes – including antenna diversity, DL (downlink) transmit diversity, and MIMO – improve the quality and reliability of a wireless link line by utilizing AASs<sup>1</sup>.

### Diversity Schemes

**Delay Diversity:** exploits an antenna array by applying different delays to each antenna element.

**CDD (Cyclic Delay Diversity):** carries out both a time delay and cyclic shifted version of the OFDM data transmission with every element.

**Delay Diversity over Beams:** represents Alvarion's implementation of CDD.

### MIMO Schemes

#### Downlink Technologies

**MIMO Matrix A:** transmits a single data stream from multiple antennas that is encoded with a STBC (Space Time Block Code).

**MIMO Matrix B:** leverages SM (Spatial Multiplexing) by utilizing two or more multiple antenna elements at the base station and MS (Mobile Station) for processing independent data streams.

#### Uplink Technologies

**MRC (Maximal-Ratio Combining):** multiplies each signal from a RX (receiver) antenna array by a weight proportional to the incoming signal level.

**CSM (Collaborative Spatial Multiplexing):** simultaneously sends transmission signals from multiple MSs, thereby acting like a multi-antenna transmitter.

## Beamforming Technology

### Overview

Beamforming utilizes multiple antenna elements, or arrays, as is the case with diversity and MIMO techniques. However, by sending radio signals at specific relative phases, beamforming creates a narrower antenna beam than that generated by a baseline fixed-beam antenna, with the beam acting as a powerful adaptive directional antenna. The signal with its transmitted energy is physically formed and directed to a particular subscriber, resulting in higher gain, greater throughput and less interference.

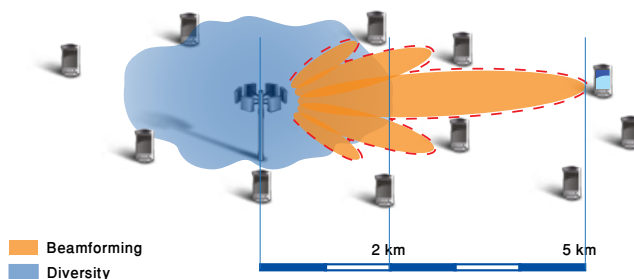


Figure 1  
Beamforming creates a narrow antenna beam directed to a particular subscriber while signal strength is retained along the signal edge

<sup>1</sup> Refer to the "Alvarion Advanced Antenna Systems: Leveraging MIMO and Diversity Schemes to Take WiMAX Infrastructure to the Next Level of Wireless Broadband," white paper for more detailed information about these schemes.

The difference between beamforming and diversity schemes is somewhat parallel to that between a flashlight and light bulb. By focusing, or narrowing a light toward one spot with a flashlight, the light emanating from it travels farther to, and is stronger at its destination than light emanating from a light bulb. Similarly, in the case of beamforming, by aiming radio signals from the source toward one specific point, signal quality is significantly enhanced compared to a fixed switching beam.

Due to its narrowing of the beam, beamforming requires knowledge of a subscriber's characteristics, making it more challenging to implement for users moving from the range of one cell site to another. However, while mobile subscribers often find themselves on the go, the majority remain in the range of a single cell site throughout the duration of an average session, according to cellular network statistics. In such cases, mobility and handoff are therefore not an issue. As a result, beamforming offers significant benefits for most practical usage models.

## Beamforming Techniques

The two prevalent beamforming techniques – AOA (Angle of Arrival) and intelligent (or mathematical) – differ from one another regarding the direction toward which energy is focused. AOA beamforming is based on physical direction, while intelligent beamforming (also known as Eigen-beamforming) is based on mathematical direction. Alvarion AASs carry out an intelligent understanding of network conditions, which are unique to the operator.

### AOA Beamforming Technique

In the case of AOA beamforming, users are characterized in terms of angle of arrival, or the physical angle from which the user energy arrives at the front of the beamformer antenna array. Similar to a compass, this technique determines in which direction relative to the beamformer, the subscriber is located. After the AOA is obtained for each received signal, the weights for each antenna element are calculated, enhancing the desired signal in the physical direction of the specific user at the time of transition.

### Intelligent Beamforming Technique

In contrast to AOA beamforming, intelligent beamforming does not utilize a physical interpretation such as a geometric angle. Rather, the technique uses the channel impulse response at each beamformer antenna element to calculate the array weights that satisfy desired criteria<sup>2</sup>, such as SINR (Signal-to-Interference-and-Noise Ratio) maximization. As long as the channel response is known at the beamformer, this technique focuses a beam in a mathematical direction, based on the mathematical decomposing of the channel array, toward the desired user.

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<sup>2</sup> Intelligent beamforming schemes generally transmit or receive the data in the direction of the eigenvectors of the channel covariance matrix. Beamforming carried out in the direction associated with the largest Eigen value is optimal for SINR maximization.

In addition to providing signal enhancement toward the desired direction, the beamformer can carry out null beamforming. With this technique, the beamformer calculates the weights in a way that suppresses the signal in the direction of undesired interferences (e.g. other users that utilize the same timing and frequency allocation associated with another base station).

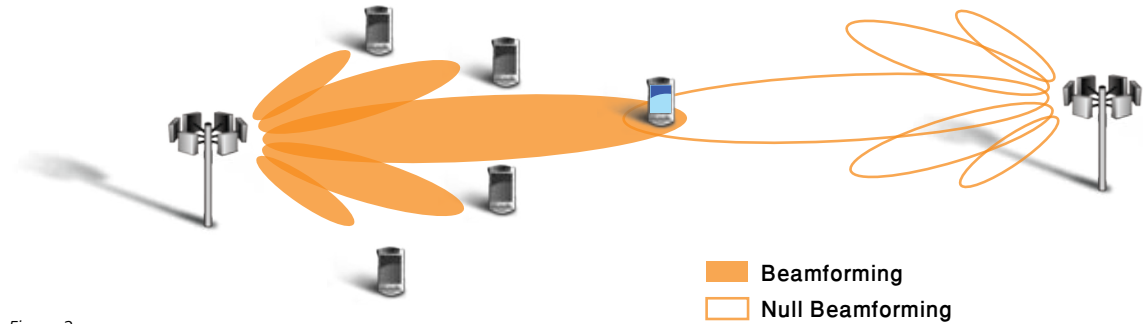


Figure 2  
In null beamforming, the signal is suppressed in the direction of undesired interference, improving reception to the MS.

## AOA vs. Intelligent Beamforming Techniques

While both AOA and intelligent beamforming are more advanced than diversity schemes, a comparison of the two beamforming techniques shows that intelligent beamforming is usually preferable, since it delivers a better signal than via AOA.

### Number of Parameters

AOA takes into consideration only the user's direction, or measured angle, vis-à-vis the beamformer. Intelligent beamforming, meanwhile, is based on several parameters as shown in the figure below, and therefore, represents a more comprehensive and multi-faceted method than AOA.

The difference between the two is similar to the difference between a climate control system and standard air conditioning (a/c) system in a vehicle. A climate control system takes into account the temperature setting, amount of sunlight falling upon the sun load sensor, outside temperature, and vehicle velocity to create optimal climatic conditions. An a/c system, on the other hand, is based on the temperature setting alone. In the same way, intelligent beamforming takes into account both the overall radio system configuration as well as the subscriber's location to produce an optimal signal. AOA beamforming, meanwhile, considers only the user's direction to produce a less-than-optimal signal.

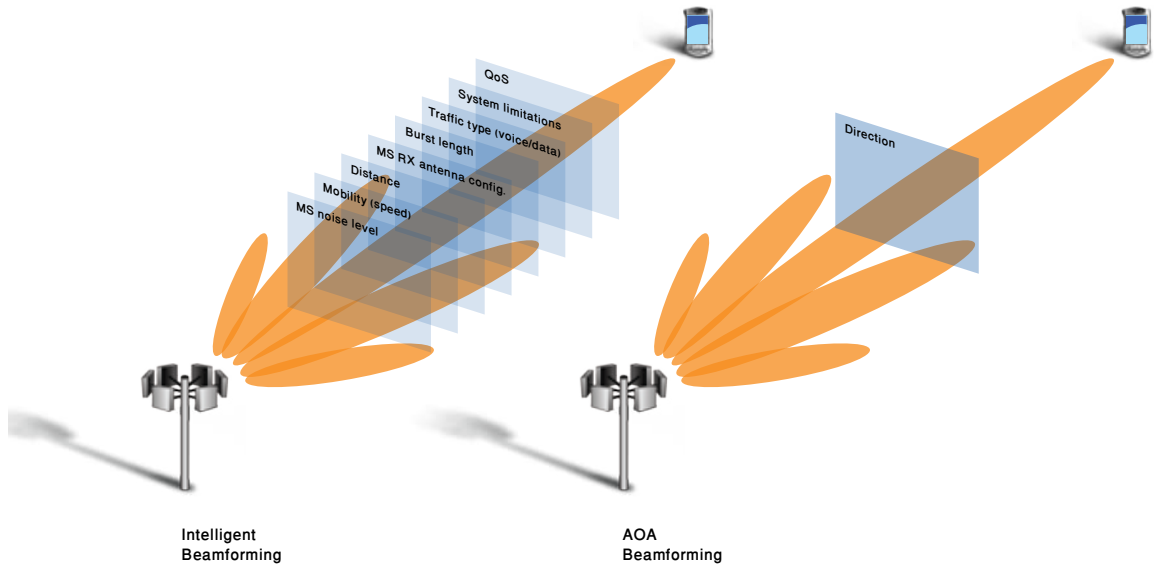


Figure 3  
AOA only takes user direction into consideration, whereas intelligent beamforming is based on several parameters.

### Implementation Limitations

AOA is also more limiting than intelligent beamforming, since in order for it to be effective, it requires:

- Exact measurement of the user’s angle, which is not always possible
- Detailed knowledge of the antenna array geometric configuration, which is not always easily accessible or correctly configured

### Local Scattering Propagation

In broadband wireless environments, especially urban ones, propagation from local scattering at the user’s surrounding area leads to the physical arrival of multiple paths from different angles. This increases angular spreading<sup>3</sup> as seen from the base station antenna array, making AOA estimation impossible. Since intelligent beamforming is not based on actual AOA, it better fits real-world broadband wireless environments, which typically have significant local scattering.

### Intelligent Beamforming Advantages

Since intelligent beamforming looks at each antenna as an individual channel, the technique provides WiMAX operators with a number of advantages compared to the AOA technique:

- 1. Agnostic to antenna configuration and vendor:** intelligent beamforming requires no knowledge of the system’s initial configuration or equipment, enabling it to work with any antenna configuration or vendor.
- 2. Immune to system expandability and adaptability:** intelligent beamforming automatically adjusts itself to configuration and equipment changes, enabling it to work when the antenna system is expanded or altered.
- 3. Indifferent to antenna array proximity:** intelligent beamforming individually isolates each of the system’s antennas, enabling it to be utilized when the antennas arrays’ elements are either close to, or far apart from one another.

<sup>3</sup> AS (Angular Spread) is a measure of the angular dispersion of the AOA and usually high in indoor scenarios compared to LOS (Line of Sight).

## Beamforming Benefits

Beamforming offers a number of clear business and performance benefits making it an attractive technique for WiMAX operators looking to improve the value of their network and enhance the user experience.

### Increased Coverage\*\*

By extending DL data transmission range, beamforming potentially covers a larger area with fewer base stations than alternative techniques, enabling operators to reduce CAPEX, OPEX and TCO.

Rate per single user (Mbps)	Covered users* (%)	MIMO cell radius (m)	BF cell radius (m)	Required # of cells per area lowered by:
1	80	500	700	2
2	60	500	1100	4.8
2.6	50	500	1200	5.8

\* Covered users refers to the probability of serving a single MS (at a single frame) at a peak rate.

### Increased Capacity\*\*

With beamforming, a cell can support more users while maintaining the same QoS, enabling operators to add subscribers without increasing CAPEX and TCO.

Cell Radius (m)	Rate per user (Kbps)	MIMO A+B # of users	BF # of users	BF gain (%)
500	200	10.8	23.3	130
500	500	4.2	9	120
1500	200	8.1	19.9	140
1500	500	3.2	7.6	145

### Increased Data Rates\*\*

With beamforming, a cell can deliver a higher data rate for a given number of users, enabling operators to upgrade their service without increasing CAPEX and TCO.

Cell radius (m)	# of users	MIMO A+B rate per user (Kbps)	BF rate per user (Kbps)	BF gain (%)
500	10	220	450	110
500	5	430	860	102
1500	10	160	390	135
1500	5	320	750	133

\*\* In real test areas results may vary from time to time

### Increased QoS\*\*

With beamforming, a cell delivers higher QoS for the same number of allocated users, enabling operators to maintain service quality without raising OPEX and TCO.

Cell radius (m)	Number of users	Minimal rate per user (Kbps)	MIMO A+B covered users (%)	BF covered users* (%)
500	5	700	46	90
500	5	500	58	98
1500	5	556	42	90
1500	5	468	50	98

\* Covered users refers to the percentage of users able to achieve a minimal bit rate.

To illustrate how these benefits translate into actual savings, a 4-antenna beamforming configuration can provide a 6dB signal enhancement while significantly improving transmission fade margin. By delivering greater range, higher throughput and improved indoor coverage compared to alternative technologies, beamforming enables a reduced number of base stations required for achieving specific system-wide capacity. As a result, TCO is significantly reduced with CAPEX potentially lowered by up to 50% and OPEX by up to 30%.

## Alvarion SentieM Technologies

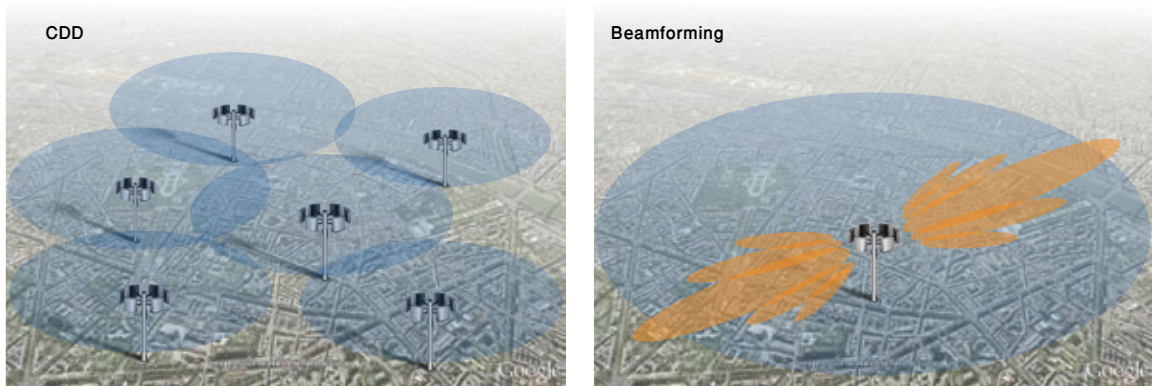


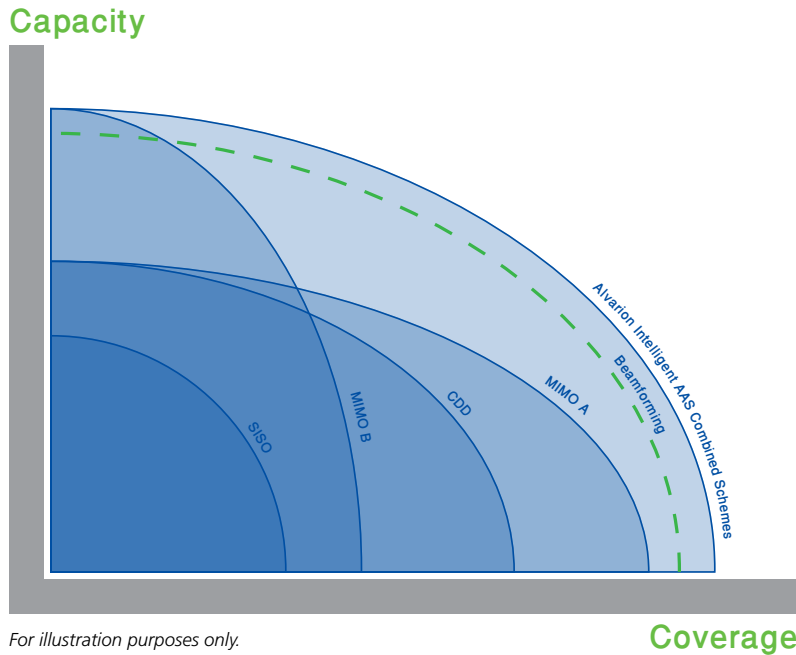
Figure 4  
With beamforming, operators require fewer base stations enabling reduced CAPEX and OPEX.

WiMAX networks are dependent on standards-based technologies that enhance both coverage and capacity. However, superior WiMAX networks require advanced technologies that extend beyond the standards to enable further enhanced coverage and capacity for better service quality, and in turn, an improved user experience. Alvarion's innovative SentieM technologies take into consideration the distinct characteristics of a WiMAX network to substantially improve coverage, capacity and QoS. These technologies enable such benefits by considerably improving the utilization of AAS technologies, RRM (Radio Resource Management), radio network architecture, and media technologies. Designed to comply with the IEEE 802.16e-2005 standard, SentieM technologies deliver and leverage superior technological advantages.

\*\* In real test areas results may vary from time to time

Alvarion's AASs leverage the widest range of technologies to achieve better capacity and coverage. Through SentieM technologies, Alvarion can intelligently determine whether wireless conditions call for the use of beamforming, diversity or MIMO schemes, or any combination of the three, for best-in-class wireless broadband TX/RX (transmit/receive) delivery.

One good example of Alvarion's technological AAS superiority is its mode selection algorithm. The algorithm selects the ideal AAS scheme by immediately learning MS noise level, signal strength, mobility (travel speed of device), distance from base station, MS RX antenna configuration (i.e. type, amount), burst length, traffic type (i.e. voice, data), system limitation, and QoS. Taking into consideration such critical factors, Alvarion is able to create best-in-class WiMAX networks. Alvarion's mode selection algorithm, along with other proprietary methods for combining and implementing AAS schemes, helps operators maximize overall WiMAX network spectral efficiency, potentially enabling a capacity increase of up to 70%.



## AAS Features and Business Benefits

Alvarion's AASs include several features that can lead to significant business benefits for WiMAX operators.

### Technical Features

- **Robust, MIMO-based transmission schemes:** reduces fading and interference, while adaptively managing air interfaces
- **On-demand collaborative MIMO and beamforming:** enhances coverage and capacity by intelligently selecting the right operator-specific, multi-antenna technology
- **Optimal SNR (Signal-to-Noise Ratio) performance:** improves QoS
- **UL MRC employment at base station receive chain:** increases UL link budget while enhancing coverage
- **Spectral efficiency maximization:** increases aggregate sector capacity, especially in small cells
- **Proprietary CDD:** improves network coverage, while decreasing outages close to the cell edge
- **STC (Space Time Code):** robustly delivers extensive diversity gain

### Business Benefits

- **Enhanced base station coverage and capacity:** leads to better performance and reduced system costs and TCO
- **SLA fulfillment:** increases probability that subscribers will receive service as delineated in their SLA
- **Increased system reliability:** enables retention of SLAs even in hard-to-reach areas
- **Dynamic system:** delivers on-the-fly solutions to meet the dynamic needs of wireless environments
- **Enhanced performance:** substantially improves performance for even the most basic receivers

## Summary

AASs play a strategic role in ensuring the delivery of best-in-class WiMAX solutions for operators. Typically comprised of diversity and MIMO schemes, these systems improve network coverage, capacity and QoS. Alvarion takes AASs one step further by adding AOA and intelligent beamforming techniques to the mix. By focusing radio signals from the source toward one specific point, beamforming intelligently overcomes interference and fading effects. This, in turn, improves signal quality compared to diversity and MIMO schemes, thereby further enhancing network value and the user experience.

As a WiMAX world leader, Alvarion understands that for networks to operate most efficiently, they need to optimally utilize the various antenna element technologies at their disposal. Alvarion's innovative SentieM technologies intelligently determine the optimal use of beamforming, together with diversity and MIMO schemes, under various wireless conditions. In this way, Alvarion enables operators to maximize coverage, capacity and QoS, and, in turn, lower TCO, increase revenues and enhance profitability.

## Headquarters

International Corporate HQ  
corporate-sales@alvarion.com

North America HQ  
n.america-sales@alvarion.com

## Sales Contacts

Australia:  
anz-sales@alvarion.com

Asia Pacific:  
ap-sales@alvarion.com

Brazil:  
brazil-sales@alvarion.com

Canada:  
canada-sales@alvarion.com

Caribbean:  
caribbean-sales@alvarion.com

China:  
cn-sales@alvarion.com

Czech Republic:  
czech-sales@alvarion.com

France:  
france-sales@alvarion.com

Germany:  
germany-sales@alvarion.com

Italy:  
italy-sales@alvarion.com

Ireland:  
uk-sales@alvarion.com

Japan:  
jp-sales@alvarion.com

Latin America:  
lasales@alvarion.com

Mexico:  
mexico-sales@alvarion.com

Nigeria:  
nigeria-sales@alvarion.com

Philippines:  
ph-sales@alvarion.com

Poland:  
poland-sales@alvarion.com

Portugal:  
sales-portugal@alvarion.com

Romania:  
romania-sales@alvarion.com

Russia:  
info@alvarion.ru

Singapore:  
asean-sales@alvarion.com

South Africa:  
africa-sales@alvarion.com

Spain:  
spain-sales@alvarion.com

U.K.:  
uk-sales@alvarion.com

Uruguay:  
uruguay-sales@alvarion.com

For the latest contact information  
in your area, please visit:  
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## About Alvarion

Alvarion (NASDAQ: ALVR) is the largest WiMAX pure-player with the most extensive WiMAX customer base and over 250 commercial deployments around the globe. Committed to growing the WiMAX market, the company offers solutions for a wide range of frequency bands supporting a variety of business cases. Through its OPEN WiMAX strategy, superior IP and OFDMA know-how, and proven ability to deploy end-to-end turnkey WiMAX projects, Alvarion is shaping the new wireless broadband experience.

