ALTAI
Super WiFi

THE ALTAI SMART ANTENNA TECHNOLOGIES AND THE LINK BUDGET AND DIVERSITY GAIN ANALYSIS

WHITE PAPER

When comparing with a standard AP, the A8n Super WiFi base station provides on average three times the range, two to four times the throughput, three times the user capacity, ten times the coverage area and significant improvements with interference mitigation. This white paper will explain the reasons behind by using link budget analysis.

1. Executive Summary

By employing multiple-branch smart antenna technology, the Altai A8n series Super WiFi Base Station can attain an improvement of more than 4 dB in antenna diversity gain over a 2x2 access point (AP). This significant improvement in diversity gain allows more flexibility in the link budget engineering. For instance, the Altai A8n can give 14 dB and 4 dB improvements in uplink and downlink link budgets when compared to a standard 200 mW AP with two omni antennas. The significant improvement in link budget provides a number of benefits including longer range, higher throughput at distance and higher user capacity.

2. Smart Antenna Architecture

Each Altai A8n base station has eight antenna ports for connection to four sector antennas, each with two cross-polarized antenna elements. Each sector antenna has a 14 dBi antenna gain, a horizontal beamwidth of 70° and a vertical beamwidth of 12°. Each sector antenna has a dedicated radio transceiver.

The A8n series use multiple antenna elements to receive multiple signals from users and the signal information from all the multiple beams will be processed using the Altai patented smart antenna technology to obtain the best signal path. Along with the A8n's smart antenna technology, it also has phase shifting networks to attain angular diversity in its array design. *This is particularly important in high multipath and high interference environments to have multiple antenna diversity with multiple independent radios.* By using the information collected from all the receiving paths, the A8n knows the best signal path for each user when transmitting and achieves the best signal performance as opposed to an omni broadcast. By only transmitting along the best signal path, the A8n series significantly reduce interference to other coverage areas in multi-site deployments and greatly increases the total system capacity.

The A8n antenna design is summarized in Figure 1.

Figure 1: A8n Antenna Design

	A8n
Configuration	 (Not in scale)
Antenna	External
Antenna Architecture	Each base station supports 4 sector antennas, each sector has 2 cross-polarized antenna elements
RF Connector Port	2 N-ports for each sector
Horizontal Beamwidth	Each sector is 70 °
Vertical Beamwidth	Each sector is 12°
Coverage Planning	4 sectors have 360° coverage
Antenna Gain (Peak)	14 dBi

By using a multiple-antenna array in the system with coordinated operation, a larger diversity gain can be attained. This diversity gain is more noticeable in non-line-of-sight (NLOS) environments and therefore the A8n performs particular well in NLOS environments. The increase in diversity gain will improve the link budget and this will be discussed in more detail in Section 4. The reason why diversity gain can improve NLOS performance and the extent to which diversity gain can improve will be discussed in Section 5.

3. Benefits of a Smart Antenna System

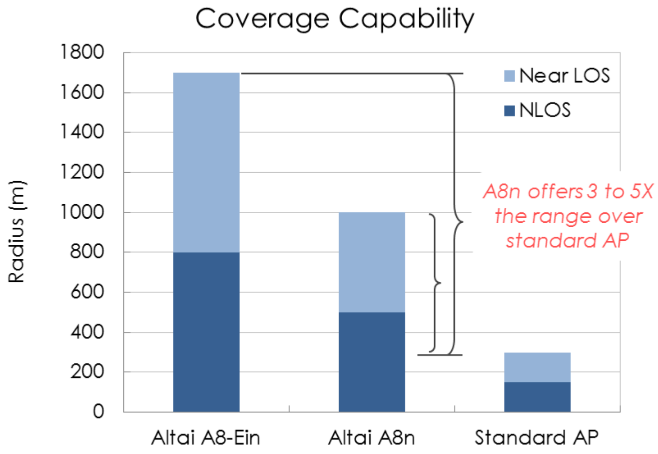
The smart antenna design of the Altai A8n offers a larger diversity gain, a higher receive sensitivity and provides a higher link budget. All these features lead to the following user benefits:

- Longer range
- Higher throughput at range
- Higher user capacity
- Better interference mitigation
- Causes Less interference
- Larger vertical beamwidth

Longer Range

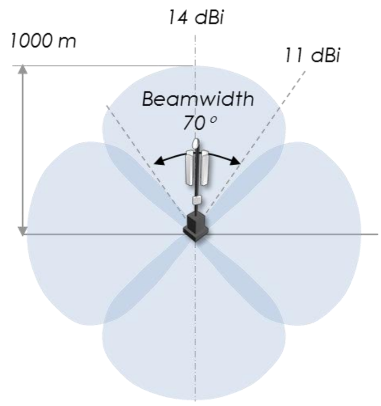
When comparing to a standard AP, the A8n provides up to three times the range and requires significantly fewer units and installation sites. The same saving can be applied to site acquisition, site engineering work, radio planning and maintenance work. The range comparison with a standard AP can be seen in the following figure.

Figure 2: Comparison of Coverage Capabilities of an A8n, an A8-Ein and a standard AP



The coverage pattern and range can be summarized below:

Figure 3: Coverage Capabilities of the A8n

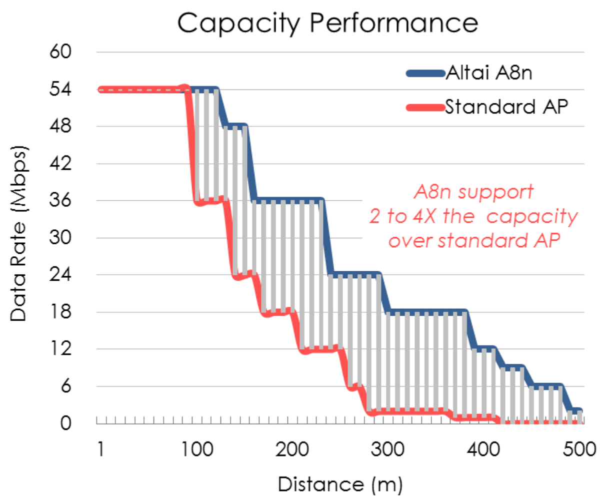


A8n omni coverage

Higher Throughput

The Altai A8n series can support higher data rates at all distances compared to a standard AP because of the improved link budget and superior interference mitigation. For instance, it supports up to two times the data rate at 100 to 200 m NLOS distance and up to four times the data rate at 250 m NLOS distance. This is illustrated in the following figure.

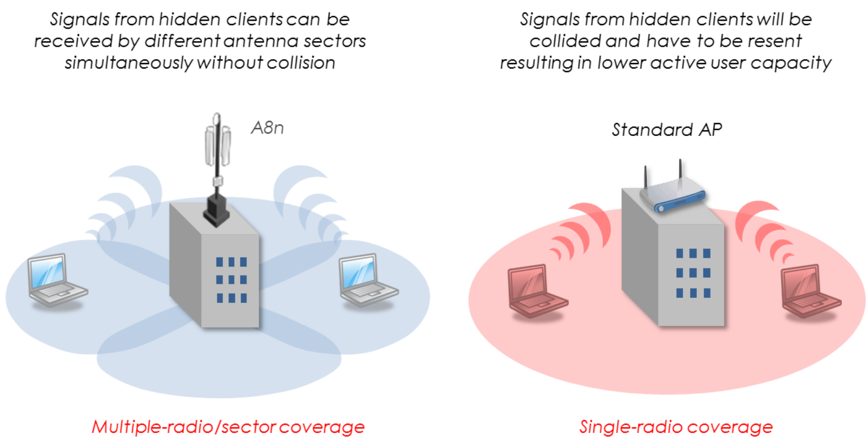
Figure 4: Capacity Performance of A8n as Compared to a Standard AP



Higher User Capacity

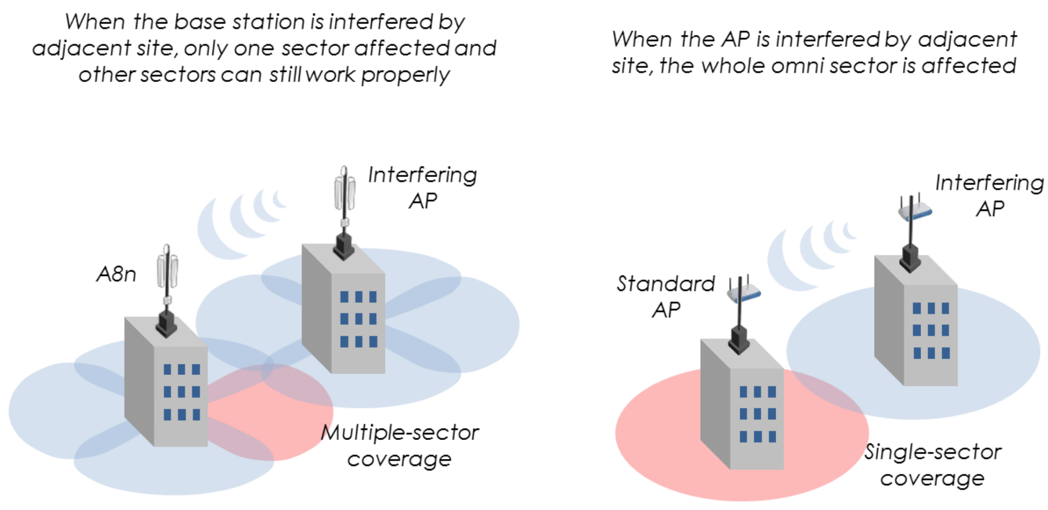
Another very important benefit of using multiple antennas with independent, coordinated radios is to minimize the harmful effects due to packet collisions from hidden nodes, as explained in figure 5 below. Packet collisions from hidden nodes happen very often in NLOS environments. For instance, when two hidden clients send signals to an A8n at the same time but from different directions, the A8n can receive both signals using multiple antennas and radios, and therefore both signals can be processed without collision. In this way, the lost packets and transmission retries are substantially minimized, meaning more time slots are reserved for other clients or additional packets. *This is a key reason* why the A8n can handle two to four times the user capacity of a standard AP, or even of multiple standard AP's co-located but not operating in a coordinated manner at the baseband and physical RF layer. Each A8n typically supports 50 to 100 concurrent users and up to a maximum of 256 users.

Figure 5: Higher User Capacity by Using the Altai A8n



Another important aspect of improving the user capacity is reducing the effects of co-channel interference. As is well known, in WiFi there are only three non-overlapping channels in the 2.4 GHz spectrum and it is highly likely that there will be other users sharing the same channel. Therefore, there is a reasonable probability that there will be other users transmitting on the same channel which will cause interference and reduce capacity. With a standard AP this will affect its reception for the entire cell, but with the A8n only the relevant direction of the interfering source will be affected as shown below in figure 6.

Figure 6: The A8n Capacity is Less Affected by Interference



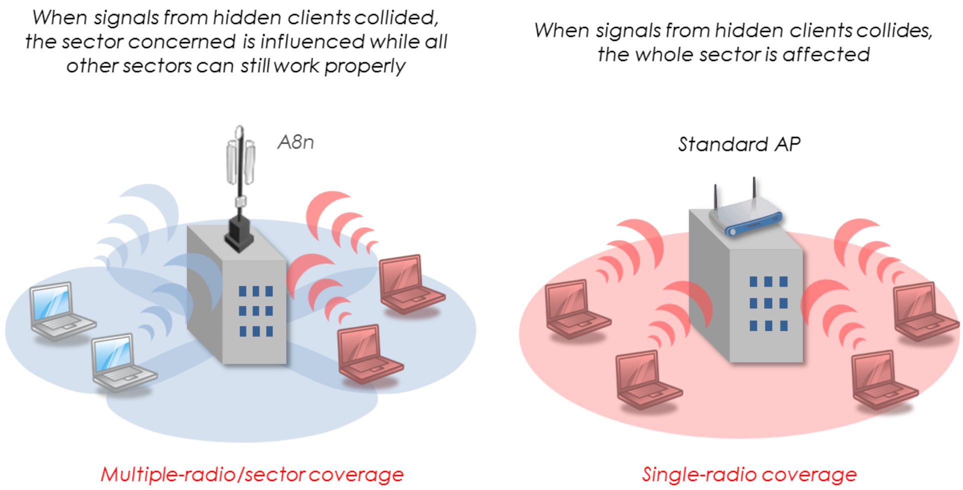
With the A8n, only the best signal path will be used for each client during the downlink transmission, reducing the amount of cell to cell interference by a factor of four when compared to a standard AP. Since WiFi is a shared medium, this will significantly increase the amount of air-time, or capacity, available to the network as a whole and therefore the user capacity and bandwidth capacity.

Better Interference Mitigation

There are two factors that lead the A8n to provide much better interference mitigation as compared to a single antenna standard AP. Firstly, the A8n platform has been designed from the beginning to be located outdoor among other high power radio systems, such as GSM, 3G, 4G, PHS etc. It has multiple high quality RF filters on each receive and transmit path. It has been extensively tested and proven to work efficiently in high interference and dense-urban areas, with different kinds of cellular systems operating nearby, even within a few meters. The A8n has been co-located with PHS systems, 3G, 4G, GSM and CDMA systems without having any degradation in performance. Also, the A8n is designed to ensure it does not create any harmful interference to those systems even when collocated on the same tower or rooftop.

Secondly, due to the multi-antenna and multi-radio coordinated architecture, even when one coverage sector may suffer from interference the other sectors will continue to operate normally. With a standard AP using a single antenna, any interference received to that AP will affect its entire coverage area. Figure 7 explains why the A8n is more robust in a high interference area.

Figure 7: Better Interference Mitigation by Using the A8n

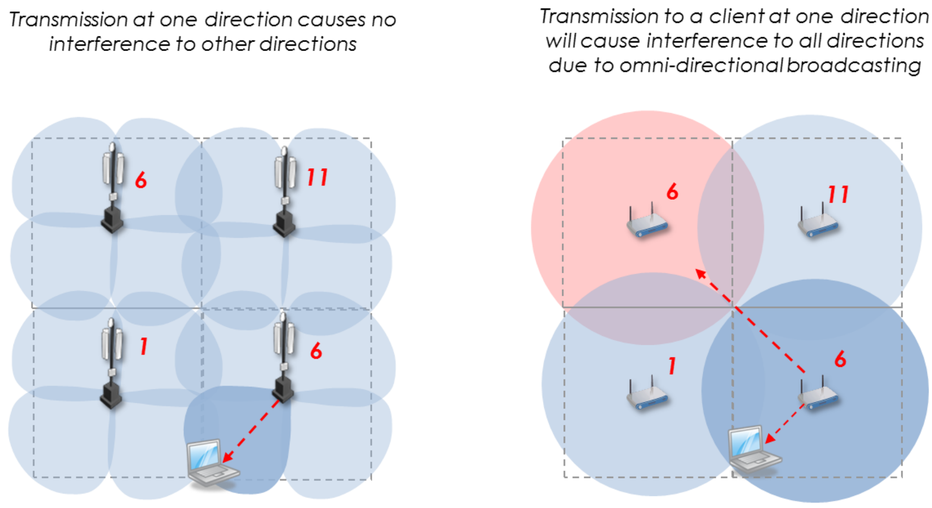


Causes Less Interference

When deploying a WiFi system in urban areas, all three non-overlapping frequencies will be used to reduce the interference between adjacent cell sites. However, even with this arrangement, interference to nearby cell sites using the same frequency is unavoidable.

By only transmitting along the best path, the A8n significantly reduces interference to other coverage areas. A standard AP will simply broadcast in all directions (omni broadcast).

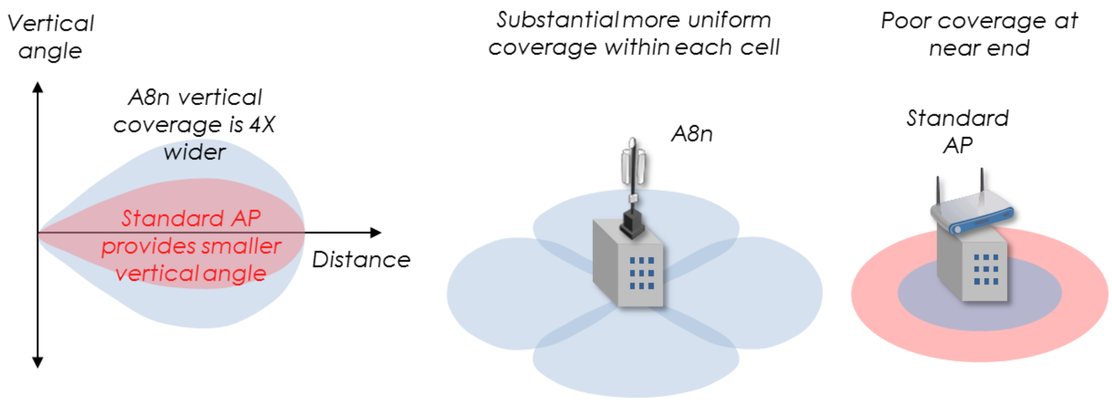
Figure 8: Less Interference Caused to Nearby Cell Site by Using the Altai A8n



Larger Vertical Beamwidth

The use of multiple co-ordinate antennas in an array allows the A8n system to have a much larger vertical beamwidth compared to a standard AP using a similar gain antenna as the A8n. The larger vertical beamwidth allows the A8n system to provide substantially more uniform coverage of the entire targeted cell area. This means the signal strength will not drop off as significantly when the vertical angle to the base station is large, as will happen with a standard AP. This allows higher data rates (stronger signal) between the user and the A8n and again improves the system capacity as compared to a standard AP.

Figure 9: A8 Provides Wider Vertical Beamwidth and Better Coverage Pattern



4. Link Budget Comparison between an A8n, a 200 mW Standard AP and a Cellular System

The link budget for a radio transmission system can be calculated as below:

Link Budget = Tx power + Tx antenna gain + Tx diversity + Rx antenna gain + Rx diversity gain + Receive sensitivity – Fade margin

The downlink and uplink link budgets for a standard AP with a Tx power of 200 mW as compared to an Altai A8n are shown in Figure 10 and 11 below. As these systems are operating at different frequencies, a path loss difference exists which is calculated as 20 log (Ratio of frequencies) and is included for adjustment. The standard AP is shown with omni antenna gains for 5dBi. The total diversity gain is the sum of the transmit diversity gain and receive diversity gain, both of which are related to the number of antenna available. The relationship between the diversity gain and number of antenna will be explained by using certain mathematical models in the next section.

For standard client, we can see that the A8n provides a better downlink link budget of 4 dB and a substantially better uplink link budget of 14 dB as compared to a 200 mW standard AP. In this case, the coverage of the A8n is downlink limited (downlink link budget smaller than uplink link budget) at a link budget of 124 dB. On the other hand, the coverage of the standard AP is uplink limited at a link budget of 113 dB. Therefore, the A8n has a better link budget of 11 dB, which means up to 3 times the coverage. *It is very important to note that only increasing the Tx power of a standard AP, as is often tried, does not improve the uplink performance, but does significantly increase the amount of interference created to adjacent cells.*

For applications that involve low power IoT devices that may only have around 10mW of transmission power due to battery life, we include another table for comparison. In this case, the coverage of the A8n is uplink limited at a link budget of 122 dB. The coverage of the standard AP is also uplink limited at a link budget of 108 dB. Therefore, the A8n has a significantly better link budget of 14 dB, which means that it has an even better coverage for IoT devices.

Figure 10: Downlink Link Budget Comparisons

	200 mW Standard AP	A8n
Frequency (GHz)	2.4	2.4
Peak Tx Power (dBm) of AP (a)	22	13
Tx Antenna Gain (dBi) of AP (b)	5	14
Rx Antenna Gain (dBi) of client (c)	0	0
Tx Diversity of AP	2-tx-selection	4-sector x 2-tx-selection
Rx Diversity (Relative to 1-branch Rayleigh) of AP	2-rx-selection	2-rx-selection
Total Diversity Gain (dB) of AP (d)	17	21
Fade Margin (1-fading vs AWGN) (e)	17	17

Receive Sensitivity (dBm) of client (f)	-95 @1Mbps	-95 @1Mbps
Path Loss Difference (dB) (g)	2	2
Downlink Link Budget (dB) (a)+(b)+(c)+(d)-(e)-(f)-(g)	120	124

Figure 11a: Uplink Link Budget Comparisons (Standard Client)

	200 mW Standard AP	A8n
Frequency (GHz)	2.4	2.4
Peak Tx Power (dBm) of client (a)	15	15
Tx Antenna Gain (dBi) of client (b)	0	0
Rx Antenna Gain (dBi) of AP (c)	5	14
Tx Diversity of client	2-tx-selection	2-tx-selection
Rx Diversity (Relative to 1-branch Rayleigh) of AP	2-rx-selection	4-sector x 2-rx-selection
Total Diversity Gain (dB) of AP (d)	17	21
Fade Margin (1-fading vs AWGN) (e)	17	17
Receive Sensitivity (dBm) of AP (f)	-95 @1Mbps	-96 @1Mbps
Path Loss Difference (dB) (g)	2	2
Uplink Link Budget (dB) (a)+(b)+(c)+(d)-(e)-(f)-(g)	113	127

Figure 11b: Uplink Link Budget Comparisons (Low Power IoT Client)

	200 mW Standard AP	A8n
Frequency (GHz)	2.4	2.4
Peak Tx Power (dBm) of client (a)	10	10
Tx Antenna Gain (dBi) of client (b)	0	0
Rx Antenna Gain (dBi) of AP (c)	5	14
Tx Diversity of client	2-tx-selection	2-tx-selection
Rx Diversity (Relative to 1-branch Rayleigh) of AP	2-rx-selection	4-sector x 2-rx-selection
Total Diversity Gain (dB) of AP (d)	17	21
Fade Margin (1-fading vs AWGN) (e)	17	17
Receive Sensitivity (dBm) of AP (f)	-95 @1Mbps	-96 @1Mbps
Path Loss Difference (dB) (g)	2	2
Uplink Link Budget (dB) (a)+(b)+(c)+(d)-(e)-(f)-(g)	108	122

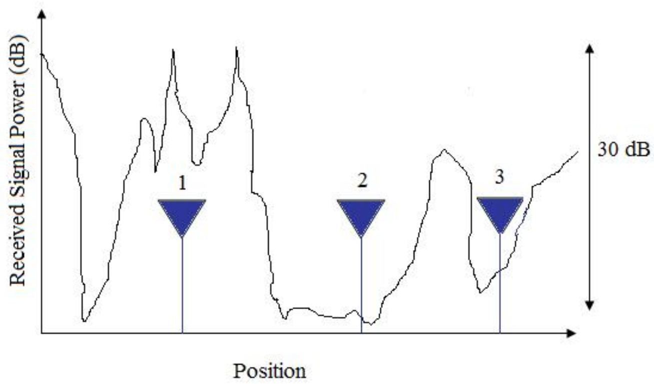
5. Diversity Gain Analysis

Concept of Diversity Reception

Using antenna arrays for diversity reception is one of the most straightforward uses of antenna arrays. Because the power level of a received signal can vary significantly with small changes in distance, a diversity array uses a set of antennas and selects the antenna with the maximum signal.

As Figure 12 illustrates, the received power can change by 30 dB (a factor of 1000) by moving to position a relatively small distant apart. This strong variation in signal power is caused by the reflections and diffractions of all surrounding objects (buildings, terrains, water surface, etc) and the signal power pattern varies with time caused by the movement of user terminal and surrounding objects (the user, cars, windy trees, etc) and creates multipath, whereby there are various different paths the signal travels from the transmitter to the receiver and depending on the time (phase) they arrive at the receiver will determine if they add together to form a strong signal, or subtract to create a weak signal.

Figure 12: Uplink Link Budget Comparisons



To combat this effect (known as fading), an array of antennas can be used. For instance, if three antennas are placed in the above situation, as shown in Figure 12, the antenna with the maximum signal (antenna 1) can be selected and used. In this manner, the effects of fading are greatly reduced, and the probability of having a signal too weak to work with decreases as the number of antennas increases.

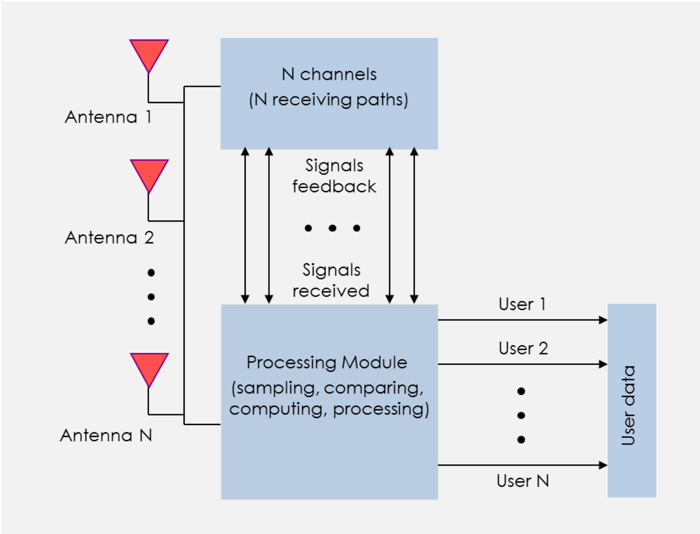
Finally, diversity reception can also occur for two antennas not separated in distance, but by receiving orthogonal polarizations. If one antenna receives vertically polarized waves, a second antenna can be placed near the first that receives horizontally polarized waves (which in a fading environment, are not strongly correlated). In this manner, polarization diversity can be achieved.

The Altai A8n uses four groups of antennas and each group consists of 2 antenna elements cross-polarized at plus and minus 45 degrees for maximum diversity, thereby utilizing both space diversity and polarization diversity in a single system.

General Antenna Array Model

The improvement of user capacity and receive sensitivity can be explained using the following general antenna array model as shown in Figure 13 below.

Figure 13: General Antenna Array Model



The total signal received by using N-antenna array for M users at the same time can be expressed below:

$$E_1 = A_{11}X_1 + A_{12}X_2 + . \; . \; . + A_{1M}X_M$$
$$E_2 = A_{21}X_1 + A_{22}X_2 + . \; . \; . + A_{2M}X_M$$
$$. \; . \; . \; .$$
$$E_N = A_{N1}X_1 + A_{N2}X_2 + . \; . \; . + A_{NM}X_M$$

where:

E = signal received from antenna 1 to N, which is a known value in the above matrix through measurement

A = interference between M different signals received from N antennas, which is a known value through test and estimation

X = user information from user 1 to M, which is required to be solved in the matrix

From the above matrix, we can see that:

- When number of antenna N is greater than or equal to the number of user M, all the user information from M users can be solved.
- When the number of antenna N increases, the user information that can be solved simultaneously will increase. This implies the number of concurrent users supported by the system can be increased.
- When the number of antenna N increases, the user information that can be solved become more accurate. This implies the receive sensitivity of the antenna array can be improved.

So, comparing an Altai A8n which uses 8-antenna elements with a standard AP which uses 2 omni antennas elements, the number of concurrent users supported can be greatly improved, in the range of 2 to 4 times due to improved signal strength and reduced interference.

Diversity Gain Model

As explained in a previous section, as the number of antenna elements in an antenna array increases, the number of signal processing options increases. The diversity gain attained can be explained by using the following simplified selection diversity (SD) model. How much diversity gain can be attained is shown below.

The symbol error probability (SEP) of a 1 out of N selection diversity (SD) system in a multipath-fading wireless environment can be obtained by averaging the conditional SEP over the channel ensemble. This can be expressed analytically as follow:

$$P_{e,\mathrm{SD}}^{\mathrm{MPSK}} = \frac{1}{\pi} \int_0^{\Theta} \prod_{n=1}^{N} \left[\frac{\sin^2\theta}{c_{\mathrm{MPSK}}\Gamma\frac{1}{n} + \sin^2\theta} \right] d\theta$$

where:

P = symbol error probability for MPSK modulation for N independent Rayleigh fading diversity branches with equal signal-to-noise ratio averaged over the fading

C_{MPSK} = a constant related to modulation

$\Theta = \pi(M - 1)/M$, for M-ary phase-shift keying

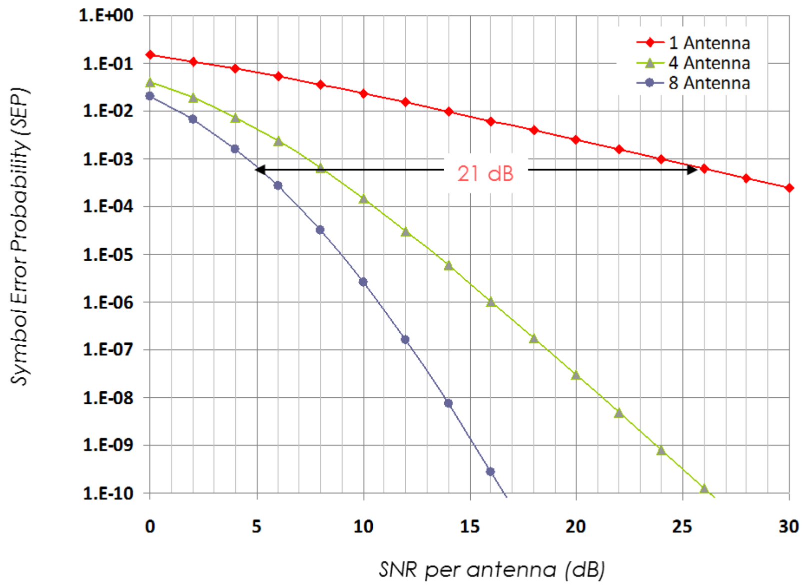
$\mathbf{\Gamma} = \mathbf{E}\{\gamma_i\} = \mathbf{E}\{\gamma_j\}$

γ_i and γ_j = instantaneous SNR of the *i* th and j th diversity branches

Using the above formula, the SEP values are plotted against SNR received by an antenna array, for selection diversity systems of one, four and eight diversity branches, as shown in Figure 14 below.

Figure 14: Diversity Gain Improvement for Different Antenna Branches

In between 1.E-03 and 1.E-04 SEP, a SNR improvement of ≥21 dB can be attained using 8 antennas



From Figure 14, if we check the SNR values for a range of SEP between 1.E-03 to 1.E-4, we can see that the improvement of SNR from 1-antenna to 8-antenna could be more than 21 dB, as indicated by the arrow in the figure. The improvement from 1-antenna to 2-antenna (which is the case for a 200 mW standard AP with 2 omni antennas in our previous sections) is not shown here, but by calculation a value of 17 dB is used in the link budget analysis.

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