GSM ADAPTIVE ARRAY TRIAL RESULTS USING AN SDR CELLULAR BASE STATION

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ABSTRACT

Broadband, multi-carrier, software-defined radio (SDR) mobile wireless network infrastructure is an excellent platform onto which Adaptive Array software can be efficiently applied. The first commercial SDR cellular base station was deployed in 1997 and the first fully adaptive, smart antenna GSM base station was deployed in early 2004. The Broadband, Software-Defined Base Station has provided the foundation for the software-centric realization of this adaptive array antenna system, enabling unprecedented spectral efficiency for network operators.

This paper summarizes the key trial results of the Adaptive Array (AA) solution for GSM, GPRS, and EDGE. This solution is a result of the successful integration of Adaptive Array software into the SDR Base Station, offering a commercially deployed broadband, software-defined BTS for the GSM/GPRS/EDGE market.

For the AA solution, integration of Adaptive Array software into the BTS represents the continued product development and technical innovation that have produced C/I improvements of up to 25 dB (nominal 16 dB) for downlink and up to 30 dB (nominal 22 dB) for uplink, capable of supporting N=1 frequency re-use. The Adaptive Array BTS was deployed successfully with a North American operator, and has received customer acceptance.

Knowledge gained from cost-effectively integrating smart antenna technology into a broadband, multi-carrier SDR base station and from commercially deploying digital cellular mobility using smart antennas provides an excellent foundation for the challenging high-speed mobile data requirements of WiMAX 802.16e.

1. EXECUTIVE SUMMARY

This white paper summarizes the key trial results of the Adaptive Array (AA) solution for GSM, GPRS, and EDGE. This solution is a result of the successful integration of Adaptive Array software with the commercially deployed broadband, software-defined BTS for the GSM/GPRS/EDGE market.

For the AA solution, integration of Adaptive Array software into the BTS represents the continued product development and technical innovation that have produced C/I improvements of up to 25 dB (nominal 16 dB) for downlink and up to 30 dB (nominal 22 dB) for uplink, capable of supporting N=1 frequency re-use. The Adaptive Array BTS was deployed successfully with a North American operator, and has recently received customer acceptance.

The software-defined radio architecture also means that it only takes a software upgrade to add GPRS and EDGE functionalities into the base station, which lowers the operators' cost to support wireless internet services. The evolution path to 3G and WiMAX is also made easier with the SDR architecture, through a software upgrade and minor hardware changes.

2. ADAPTIVE ARRAY TRIAL OVERVIEW

An Adaptive Array Trial was conducted in March 2005 to demonstrate the capacity improvements offered by AirNet's AA technology. As shown in previous trial phases, this technology can improve the C/I ratio of any particular user an average of 16 dB for the downlink and 22 dB for the uplink. This trial showed how these individual performance enhancements dramatically increase the overall capacity of a wireless network by allowing greater frequency reuse while maintaining acceptable call quality metrics.

3. FOUR CELL NETWORK

The AirNet wireless network cellular test system in the Melbourne Florida area is composed of 4 overlapping cell sites, all pointing towards a contiguous coverage area. This is the minimum network configuration that mimics real cellular deployments and allows the benefits of Adaptive Array technology to be quantitatively measured.

AirNet operates this network for test purposes under an experimental license on a non-interfering basis. As such, a block of the PCS-1900 spectrum has been chosen where there was no active commercial traffic in this spectrum in the Melbourne area. Consequently, AirNet users generate

Table 1
Melbourne AA 4 Cell Site Locations

Site	Lat	Long	Array Height	Array Azimuth
Dow	28° 6.284" N	80° 41.235" W	80'	180° (South)
Smith	28° 4.315" N	80° 40.342" W	80'	280° (West)
Barn	28° 2.546" N	80° 40.198" W	110'	320° (North)
Waffle House	28° 4.778" N	80° 42.306" W	110'	100° (East)

Table 2
Melbourne AA Cell Site–Distances in Miles

Site	Dow	Barn	Smith	Waffle
Dow	0	4.2	2.6	2.2
Barn	4.2	0	1.9	2.9
Smith	2.6	1.9	0	2.3
Waffle House	2.2	2.9	2.3	0

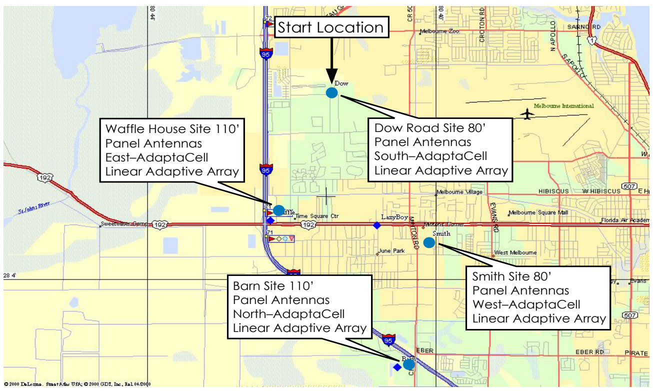


Figure 1
Melbourne AA 4-Cell Site Map Locations

all "live" traffic. Likewise, AirNet users or test equipment generate co-channel interference in the spectrum as well.

The four cell sites in AirNet's Melbourne Network are listed in Table 1 with their respective distances relative to each other listed in Table 2.

Figure 1 shows the four cell sites in a map of the area so that one can see their relative location. "Dow" is the northern site with antennas facing south; "Barn" is the southern site with antennas facing north; "Smith" is the eastern site with antennas facing west; "Waffle House" is the western site with antennas facing east.

Figure 2 shows the planned coverage from these 4 sites. The black oval represents the overlapping coverage area of these sites where the trial took place and the adaptive interference mitigation from adjacent cells can be measured. The downlink receive signal strength is displayed over a range of 7 levels from greater than -70 dBm to as low as -110 dBm.

Figure 3 illustrates the equal power boundary of the 4-cell network. This is approximately where inter-cell handovers should typically occur. There are 4 locations shown on the map where a signal from 3 of the towers is equal power. Without Adaptive Array technology, N=1 frequency re-use would not be possible since there are many areas where two or three signals are received at or near the same level.

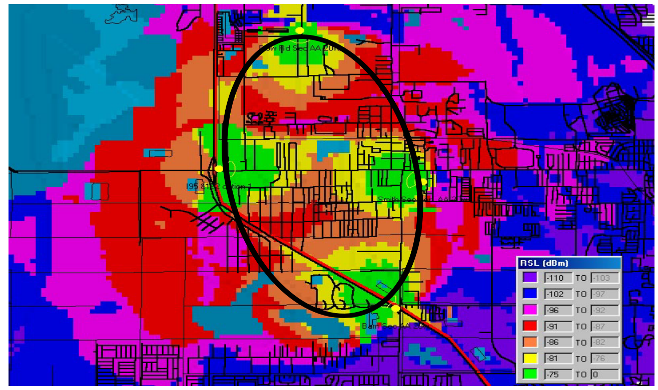


Figure 2
Melbourne 4-Cell Site Map Coverage Plot

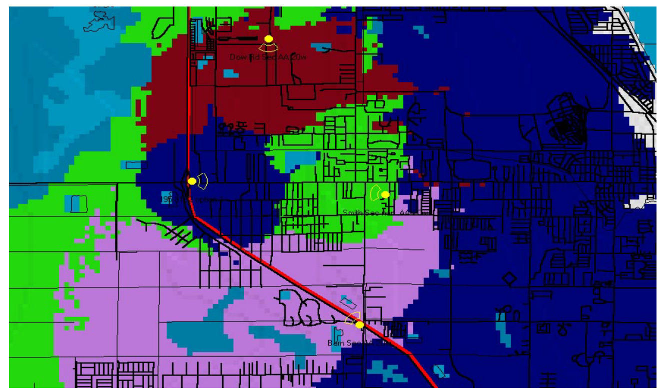


Figure 3
Melbourne AA 4-Cell Equal Power Boundaries

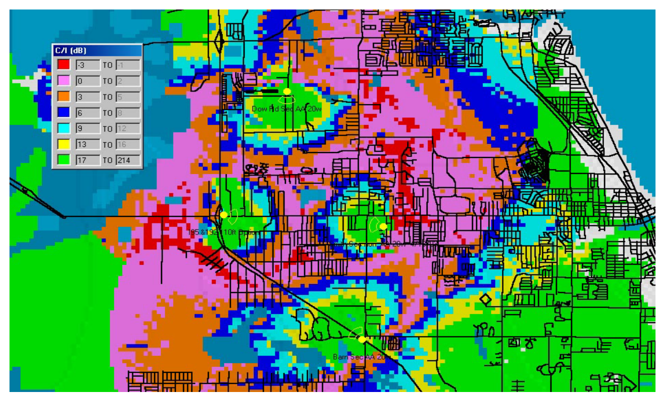


Figure 4
C/I Plot for N=1 Frequency Reuse–Non-Adaptive

Figure 4 shows the C/I plot given N=1 frequency reuse without adaptive array processing. The outer turquoise boundary C/I of 9 dB is the threshold for GSM voice. It is evident that without adaptive processing, this network would be severely interference limited, with only small areas of coverage nearby each tower that have +9 dB C/I or greater.

By enhancing the coverage with 16 dB of adaptive array C/I improvement, one can see that areas where C/I was zero or even negative now have C/I of 9 dB or greater. This trial

Figure 5
Adaptive Array with Calibration Network

phase will effectively demonstrate this improvement in C/I when using adaptive arrays.

4. BTS CONFIGURATION

Each BTS has a T1 connection back to AirNet's facility at Dow Road in Melbourne. This facility houses the AirNet BSC, TRAU, OMC-R, and a third-party MSC, which provides connectivity to the PSTN for mobile to land and land to mobile calls. Cell configuration can be remotely controlled from the OMC-R. Measurements reports are also collected on the OMC-R.

Each of the 4 cell sites was outfitted with an AirNet SDR base station. All were configured with 4 sectors of hardware (each sector has a 5 MHz broadband transceiver and associated digital processing) and AA software. Each base station was configured for operation in the PCS-1900 spectrum.

Specifically, each sector's broadband transceiver was tuned to operate in the 5 MHz band from 1977-1982 MHz for the downlink (BTS transmit) and 1897-1902 MHz for the uplink (BTS receive). The only additional hardware required for an AA deployment versus a standard deployment is a Calibration Mobile Station (CMS). The CMS is integrated into the BTS and is connected to the calibration network of the adaptive array for the purposes of automatic self-calibration. This CMS is installed in an EMI enclosure with antenna and power access.

The Smith, Barn, and Waffle House BTS systems are housed in outdoor enclosures. The Dow BTS (at AirNet's main facility) is housed in an indoor enclosure. Each BTS was configured to transmit an RF beacon carrier to match a 20 Watt beacon carrier in a traditional deployment. In an adaptive BTS, this is done by transmitting 5 Watts through each of the 4 TX paths using Multi-Element Broadcast, for a total of 20 Watts. The adaptive traffic channels will transmit just 1.25 Watts through each transmit path for a total of 5 Watts. The downlink processing gain accounts for the difference in total transmit powers by focusing energy to create the same footprint as the beacon — effectively providing 5-6 dB of additional antenna gain. This has been shown to be true through extensive drive tests.

Table 3
Adaptive Site Configuration Parameters

Site	BCCH ARFCN	AA TCH ARFCN
Dow	747	755
Smith	749	755
Barn	751	755
Waffle House	753	755

Table 4
Common TCH Assignment for Each Cell

Site	ARFCN 755 TN0	ARFCN 755 TN1	ARFCN 755 TN2	ARFCN 755 TN3	ARFCN 755 TN4	ARFCN 755 TN5	ARFCN 755 TN6	ARFCN 755 TN7
Dow	Unlock	Unlock	Unlock	Unlock	Unlock	Lock	Lock	Lock
Smith	Unlock	Unlock	Unlock	Unlock	Unlock	Lock	Lock	Lock
Barn	Unlock	Unlock	Unlock	Unlock	Unlock	Lock	Lock	Lock
Waffle House	Unlock	Unlock	Unlock	Unlock	Unlock	Lock	Lock	Lock

5. ADAPTIVE ARRAY CONFIGURATION

Each cell site was equipped with an antenna array consisting of five off-the-shelf PCS-1900 panel antennas, namely Decibel DB948F85E-M. These are vertically polarized +14.5 dBd panels with an 85° azimuth beam width. Four of these antennas are closely spaced at half-wavelength spacing to form a uniform linear array. These four elements both transmit and receive. A fifth element, which is a diversity receive element, is placed at least 8-10 wavelengths away from the center cluster and is used to mitigate deep Rayleigh fades from the mobile.

A picture of the "Waffle House" adaptive array antennas, showing the 4 closely-spaced panel antennas, the fifth diversity panel antenna, and the calibration network is shown in Figure 5.

6. CAPACITY TEST CASES

The primary goal of this trial was to demonstrate that AA technology can achieve a 65% fractional load with an N=1 reuse plan for the adaptive traffic channels. Beacon channels were planned with a typical reuse as listed in Table 3. For the 4-cell network, each site had a unique beacon carrier ARFCN (Absolute Radio Frequency Channel Number) which was "locked" during the trial, i.e. it was prohibited from carrying any traffic. This forced all calls to be assigned to the adaptive traffic channels. In addition to a unique beacon carrier, a unique Broadcast Control Channel (BCCH) was assigned to each BTS (used by AA processing to distinguish between desired and non-desired users), and a common AA traffic ARFCN as listed in Table 3.

As previously discussed, there is no existing commercial spectrum traffic in the chosen portion of the PCS-1900, so AirNet personnel was used exclusively to load the network with traffic. To keep the number of users at a manageable level, yet still effectively demonstrate network loading, each cell was configured with the same adaptive

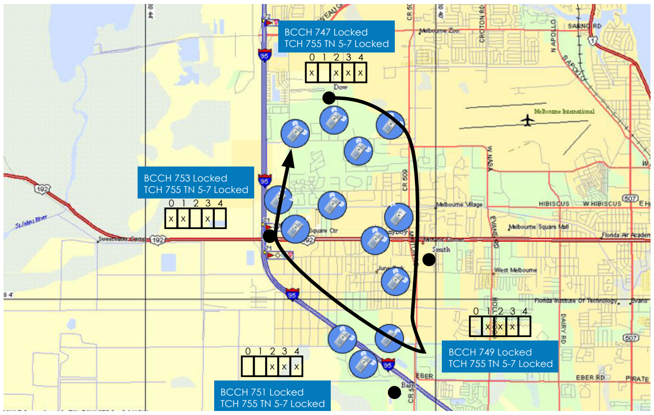


Figure 6
Test Drive Scenario for 4 Cell AA

TCH (Traffic Channel) carrier (ARFCN 755). This achieves N=1 frequency reuse.

Five out of the 8 timeslots were "unlocked" per cell, i.e., allowed to carry traffic. These were the same 5 timeslots in each cell, as listed in Table 4. Since the 4 BTSs are internally clocked by a GPS clock source, the transmitted outputs are synchronous and the timeslots on each of the BTSs transmitted carrier are temporally coincident; i.e., TN0 of the Dow site is broadcast at the same time as TN0 of the Barn site, Smith site, and Waffle House site.

To meet the loading target, 3 users made calls in each of the 4 cells (total of 12 users) using 3 out of the 5 timeslots available per cell. A fourth timeslot was used for a 13th user for inter-cell handovers–yielding 65% FL (Fractional Load), where 13 of the 20 timeslots were in use at all times.

Users were in-car with specific drive routes and constrained to the boundaries of their particular cell. (For safety reasons each user had a driver.) The drive routes were chosen to cover significant portions of each cell area, and users were dispersed randomly to ensure that a multitude of co-channel interference scenarios (angle of arrival, signal strength, multi-path) were encompassed in each test period. Test mobiles utilized the "BTS TEST" option so that they could only lock onto the desired control channel for the cell they were in.

7. AA TEST WITH 65% FRACTIONAL LOAD, N=1

For this test, the 4-cell network was configured as shown in Table 3 with the beacon ARFCN locked and 5 timeslots on the AA ARFCN unlocked as shown in Table 4. Each cell was using the same AA ARFCN. Three users were dispatched to each cell, made calls, and drove pre-determined drive routes. These users were continuously occupying 12 of the 20 available time slots.

A TEMS™ drive test mobile was dispatched to drive through each of the 4 cells, collecting downlink data from each cell in addition to the measurements continually being collected at the OMC-R. The TEMS drive test mobile was continuously operating as the 13th user of the 20 available time slots, resulting in a 65% fractional load (FL) of the system. Figure 6 shows an example of the Test Drive Scenario for 4 Cell AA with the 12 users and the TEMS unit driving among the 4 cells.

The exact same test was performed in both AA and non-AA modes. Data collection was performed during both drives and the measurements were post-processed, with the results compared. Then a third iteration of the test was performed with power control disabled and data collected and compared.

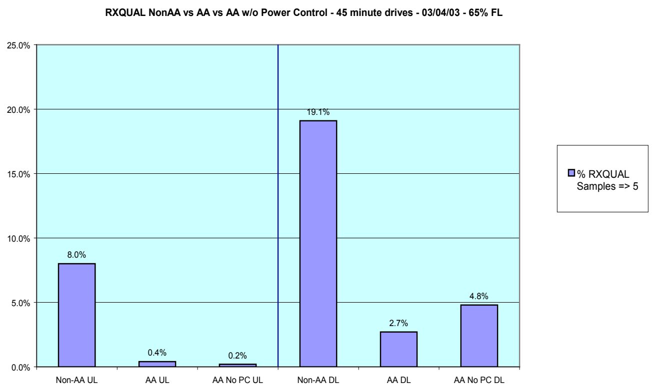
The following is a summary of the 65% FL test:

- Four Cells, N=1 Frequency Plan.
- Equivalent BTS TX Power (for AA and Non-AA):
  - 20 Watts at Dow, Smith, and Barn.
  - 5 Watts at Waffle House (TX power reduced to equalize coverage due to greater antenna height).
- VOCODER = EFR (Enhanced Full Rate).
- Three AirNet Users Per Cell:
  - Locked to Home Cell Using "Cell Test Mode" on the Test Mobile.
  - One TEMS Drive Test Mobile Moving Between Cells:

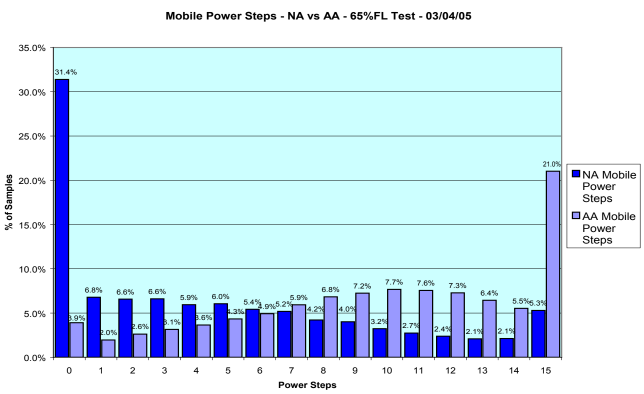
Table 5
Performance Summary for 4 Cell AA with 65% FL

3/4/2005 Drive Test Condition 65% FL*	Suc TCH Seizures	Atmp TCH Seizures	Dropped Calls Total	Unsuc In Intracell HO	Suc In Intracell HO	Atmp Intracell HO	Unsuc In Intercell HO	Suc In Intercell HO	Atmp In Intercell HO	Unsuc Out Intercell HO	Suc Out Intercell HO	Atmp Out Intercell HO	% Drop Call	% Successful Intra-Cell HO	% Successful Inter-Cell HO
Non-AA	1383	1635	109	168	1150	1318	5	9	14	5	9	14	7.9%	87.3%	64.3%
AA with PWR Control	80	82	0	2	66	68	1	11	12	1	11	12	0.0%	97.1%	91.7%
AA without PWR Control	260	273	3	12	243	255	5	7	12	5	7	12	1.2%	95.3%	58.3%

* 13 users on 20 timeslots throughout network
* Calls only re-initiated if dropped



Graph 1
RxQual Samples–Non-AA Versus
AA with and without Power Control



Graph 2
Mobile Power Steps–Non-AA Versus AA

- ▪ The TEMS unit is the Only Mobile Performing Inter-Cell Handover.
- 13 Total Users Using the Same 5 TCH Channels: 4 Cells x 3 Users + 1 TEMS = 13 Users.
- Equivalent Fractional Loading of 65%: (13 users / 20 channels = 65%).

The drive test procedure included:

- All Drivers Use Established Drive Routes in Cells.
- All Users Dialed into Common Bridge.
- TEMS user observes TEMS Report.
- TEMS user drives through All Four Cells Twice.
- Capture Peg Counts.
- Test 1: Configure Network Non-Adaptively.
- Test 2: Configure Network Adaptively.
- Test 3: Configure Network Adaptively, but Disable UL/DL Power Control

8. TRIAL RESULTS FOR 4 CELL AA

AirNet met or exceeded the success criteria for the 65% fractionally loaded 4-cell adaptive network. Table 5 shows the Performance Summary for 4 Cell AA with 65% FL.

Note that the results of the drive test show that without AA, there were 7.9% dropped calls, which did not meet a <2% pass criteria. When AA was enabled, there were NO dropped calls, which easily meets the pass criteria. Even without UL/DL power control enabled, with AA invoked, there were only 1.2% dropped calls – also meeting the <2% pass criteria.

Without AA, there were 87.3% successful intracell handovers – falling short of the 97.1% successful intracell handovers achieved when AA is enabled. With UL/DL power control disabled, there was a 95.3% success rate for intracell handovers when AA was used.

Without AA, there were 64.3% successful intercell handovers. This falls well below the 91.7% successful intercell handovers achieved when AA is enabled. Interestingly, with UL/DL power control disabled, there were only 58.3% successful intracell handovers with AA.

Based on these results, one can expect that in a market with 2x5 MHz of spectrum, the AA base stations with a 4/12 BCCH frequency plan can be deployed in a mixture of S8-7-8 and S7-8-7 configurations. This scenario provides a 64% fractional load on the adaptive TCH. This represents a 2.6X increase in capacity from that of a frequency hopping S4/4/4 configuration.

9. RXQUAL SAMPLES, NON-AA VERSUS AA

Graph 1 shows RxQual Samples greater than or equal to 5 during three sequential 45 minute drive tests with 65% fractional load. The 3 drives were Non-AA, AA with Power Control, and AA without Power Control. The test results clearly showed the benefits of Adaptive Array technology.

Without AA, the Uplink had 8% RxQual ≥5 and the Downlink had 19.1% RxQual ≥5. These numbers are very poor and would not be suitable for a commercial deployment. The pass criterion for this is less than 5% for both uplink and downlink.

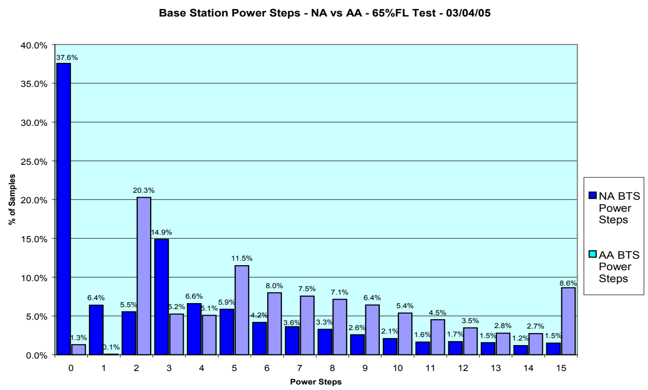
With AA enabled, the Uplink had only 0.4% RxQual ≥5 and the Downlink had only 2.7% RxQual ≥5. This is much more acceptable for a commercial deployment and meets the pass criteria (5%) for both link directions.

With AA enabled, but with UL and DL power control disabled, the Uplink had only 0.2% RxQual ≥5 and the Downlink had 4.8% RxQual ≥5. Even without UL and DL power control, the pass criterion was met when AA was employed.

10. MOBILE POWER STEPS, NON-AA VERSUS AA

Graph 2 shows Mobile Power Steps for Non-AA versus AA during 2 sequential 45 minute drive tests with 65% fractional load. The test results clearly showed the benefits of Adaptive Array technology.

In the drive test for Non-AA, the mobile power steps were very strongly weighted towards the highest uplink power level, with an astounding 31.4% of the power steps



Graph 3
Base Station Power Steps–Non-Aa Versus AA

at the highest setting-- level 0. When AA was enabled, the results were quite the opposite. With AA, the mobile power steps were very strongly weighted towards the lowest uplink power level, with an amazing 21% of the power steps at the lowest setting–level 15. This saves mobile battery power and greatly reduces co-channel interference.

11. BTS POWER STEPS, NON-AA VERSUS AA

Graph 3 shows Base Station Power Steps for Non-AA versus AA. The test results again show the benefits of Adaptive Array technology.

In the drive test for Non-AA, the base station power steps were very strongly weighted towards the highest downlink power level, with an astounding 37.6% of the power steps at the highest setting-- level 0. When AA was enabled, the results were much different. With AA, the BTS power steps were typically lower by 4 dB or more, with 20.3% of them at level 2, 11.5% of them at level 5, and 8.6% at level 15. This significant shift to lower BTS transmit levels saves power and reduces co-channel interference with other base stations.

12. AIRNET OVERVIEW

AirNet Communications Corporation first deployed the AdaptaCell Base Station for commercial GSM applications in 1997, achieving market successes both in North America and internationally. During the GSM Association conference in Cannes, France in February 1998, AirNet was honored to become the first manufacturer to be chosen to receive the coveted “Best Technical Innovation” Award for GSM infrastructure products based on the innovative broadband software-defined AdaptaCell and the Backhaul-free AirSite Base Station products together with our full BSS system.

The AdaptaCell base station supports the smooth migration from 2G GSM voice/data applications to 2.5G/3G data services, such as GPRS and EDGE, on the same platform.

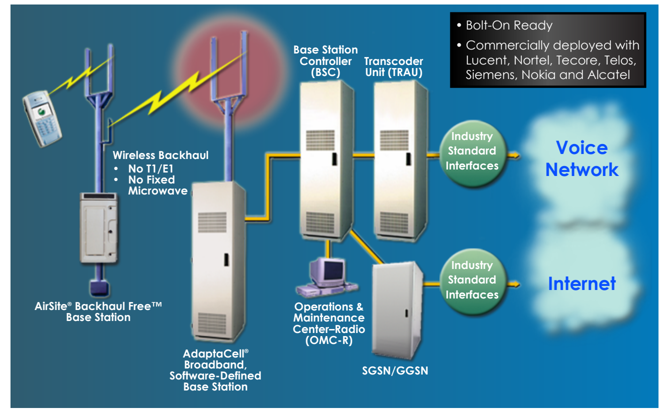


Figure 9
AirNet GSM/EDGE BSS System

This migration requires only minimal hardware modifications–not the forklift upgrade required by most other operators. Powerful digital processing for Adaptive Array technology can be added simply by upgrading the software. This system can be flexibly configured into a wide variety of topologies such as omni, bi-sectored, tri-sectored, omni adaptive array, and sectored adaptive array.

13. GSM/EDGE BSS PRODUCT PORTFOLIO

Founded in 1994, AirNet had commercialized the complete GSM BSS system in 1997 and has since deployed complete systems with more than 25 commercial customers around the world. Built on the broadband software-defined radio technology platforms, AirNet offers two base station types: the AdaptaCell Broadband software-defined BTS and the AirSite Backhaul-Free BTS. AirNet also offers the BSC (Base Station Controller) and PCU (Packet Control Unit), the TRAU (Transcoder Rate Adapter Unit), the OMC-R (Operations and Maintenance Center for Radio), which round out a complete BSS system (refer to Figure 9 for the complete system diagram).

AirNet is recognized by the GSM Association with the prestigious Award for Best Technology Innovation for its BSS system in 1998 in Cannes, France. Our customers recognize the CapEx and OpEx advantages of both our AdaptaCell BTS and AirSite BTS, which are the basis of the award.

Utilizing the open A-interface for voice and Gb interface for GPRS/EDGE, AirNet and its customers have successfully performed interworking tests with other major network suppliers of GSM/EDGE NSS and BSS systems. Detailed Key Performance Indicator (KPI) measurements, collected both in the field and in the lab, have confirmed that the AirNet BSS system exceeds industry standards such as Telcordia in terms of system robustness.

14. SUMMARY–AIRNET ADAPTACELL SUPER-CAPACITY BASE STATION

The AirNet implementation is the only viable and proven solution for adaptive array technology available for GSM/GPRS/EDGE. It is the key enabler for high capacity voice and packet data services, which is fundamental to success for GSM operators. AirNet has the only proven broadband software-defined radio platform that will support a seamless integration of Adaptive Array technology.

AirNet has accumulated more than 8 years of commercial in-service experience in the deployment of the AdaptaCell BTS, and has more than 4 years of experience in the Adaptive Array development and deployment. AirNet is now ready to deploy this system extensively in high voice and data environments to improve network performance and to reduce the number of sites drastically.

Recent trials in Melbourne, Florida have shown that the Adaptive Array system can be deployed with good results in 4 overlapping cells of coverage with an N=1 frequency reuse pattern at a 65% fractional load.

In summary, the AirNet AdaptaCell BTS, upgraded with Adaptive Array software has the following benefits:

- Up to 30 dB (22 dB nominal) of dynamic C/I improvement on a "per subscriber" basis for the uplink
- Up to 25 dB (16 dB nominal) of dynamic C/I improvement on a "per subscriber" basis for the downlink
- Improvement of RF network quality through C/I substantial gains.
- Improved spectrum utilization and Erlang capacity by a factor of as much as 300% for urban voice applications compared to traditional technology.
- Much higher data throughput for GPRS and E-GPRS (EDGE) by a factor of up to 500%.
- Reduced number of sites for both voice and data applications.
- Extension of the GSM network's viability many years further.
- Alternative to expensive and uncertain 3G plans.
- Improvement of GPRS and EDGE coverage by as much as 4 times.

AIRNET COMMUNICATIONS CORPORATION

GSM World Award for Technical Innovation

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AIRNET®

GSM Adaptive Array Trial Results Using an SDR Cellular Base Station

2005 Software Defined Radio Technical Conference

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November 16, 2005 – Orange County, CA

AirNet Overview

AIRNET®

- **Develops and Manufactures Complete Wireless Base Station Systems.**
- **Shipped First Commercial Products in May 1997.**
- **Base Station Technology Leader:**
  - GSM, GPRS, EDGE - w/ AA
- **1998 GSM World Award for Best Technical Innovation.**
- **First Commercially Deployed Broadband, Software-Defined, Base Stations in the World:**
  - Provides a software upgrade path to the wireless Internet
  - Delivers highest capacity and highest data rates
- **Only Backhaul Free™ Base Station:**
  - Eliminates T1/E1 or microwave
- **69 Patents (56 Issued).**
- **28 Customers Around the World.**
- **Shipped >1,000 Base Stations.**
- **ISO 9001:2000 certified.**
- **TL 9000 certified.**
- **Member:**
  - SDR Forum
  - WiMAX Forum

GSM World Award for Best Technical Innovation

1998

Software Defined Radio (SDR)
Who Benefits & How?

- The Network Operator:
  - A single platform solution:
    - Multiple system architectures.
    - Simultaneous radio protocols.
  - Upgradeability: software change - avoid “forklift” upgrades.
  - Flexibility and spectrum efficiency:
    - Transition to GPRS and EDGE completed.
    - Transition to 3G and WiMAX 802.16e where and when needed.
- The User:
  - Improved services: higher speed wireless multimedia.
  - Download new features (Internet model for wireless).

Software Defined BTS-4000XE

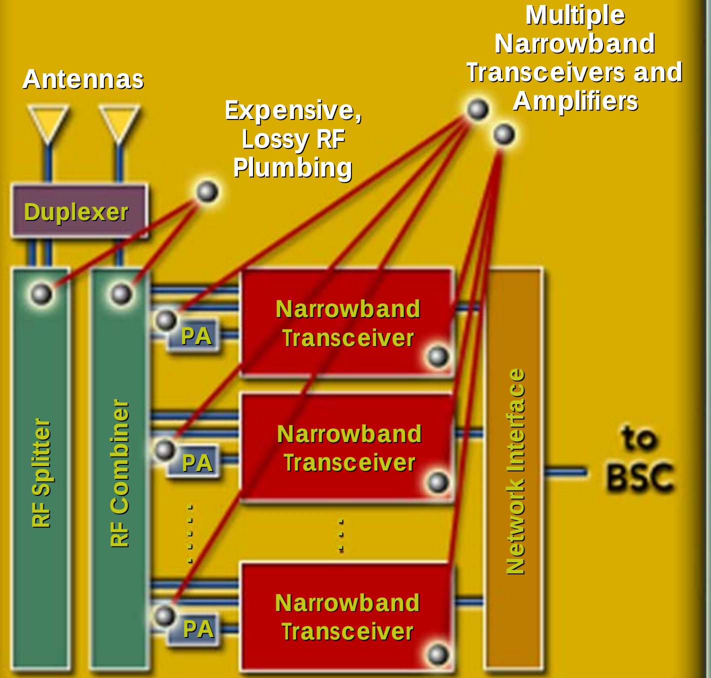
- Broadband, Multi-carrier, SDR, supporting high speed data and Adaptive Array processing.
- Compact, lightweight, rapidly deployable:
  - Pole, wall, and pad mountable.
- High powered, Multi Carrier Power Amplifiers:
  - Air breathing – No A/C required. Saves money.
- Superior power control software for better RF performance.
- Thermally hardened components.
- Software upgrade to SuperCapacity™ Adaptive Array:
  - **Up to 30 dB C/I improvement** – AA in UL and DL.
- OFDM, FFT/IFFT processing:
  - Deployed with GSM, GPRS, and EDGE.
  - Mobile WiMAX 802.16e ready.

Wideband, Multi-Carrier SDR

Narrowband vs. Wideband Comparison

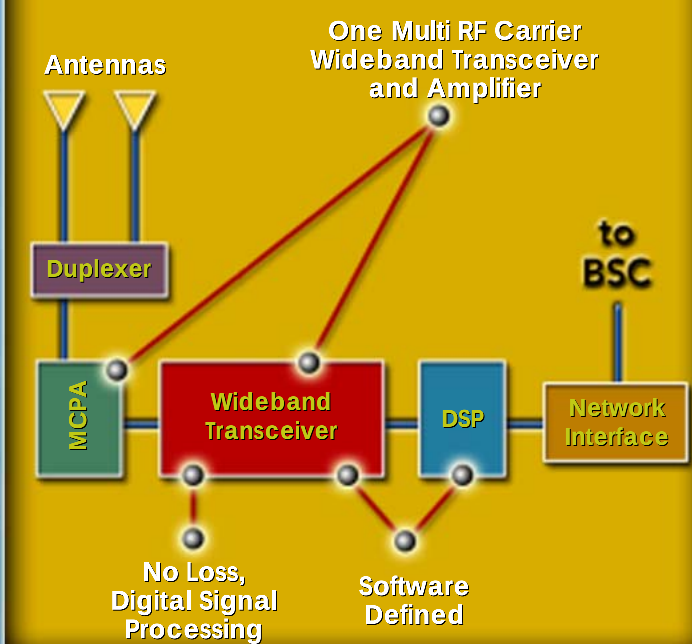
Traditional Base Station

- Narrowband, Hardware Centric
- Protocol Specific
- "Throw it Away for High-Speed Data"



AirNet SDR Base Station

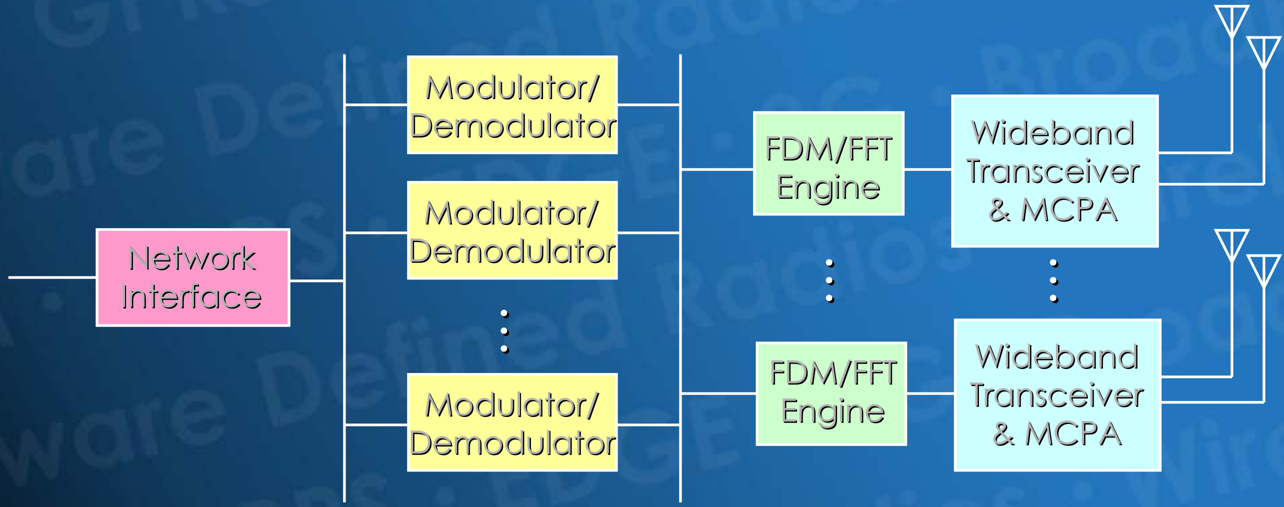
- Wideband, Software Centric
- Multi-Protocol
- "Supports High-Speed Data"



Software Defined BTS Features

AIRNET

- AirNet Broadband Base Station Technology
  - Uses FFT Engine to Separate/Combine Multiple Radio Channels.
  - Programmable Number of Channels (i.e. FFT Size).
  - Programmable Channel Center Spacing.
  - Programmable Channel Filtering Bandwidth.
  - Programmable Sub-Carrier Decimation and Interpolation Rates.
  - Multiple Independent (Orthogonal) Fully Software Programmable Modulation and Demodulation Processors Supporting any Modulation.
  - Supports Fully Adaptive Array Solution (Smart Antenna Technology).



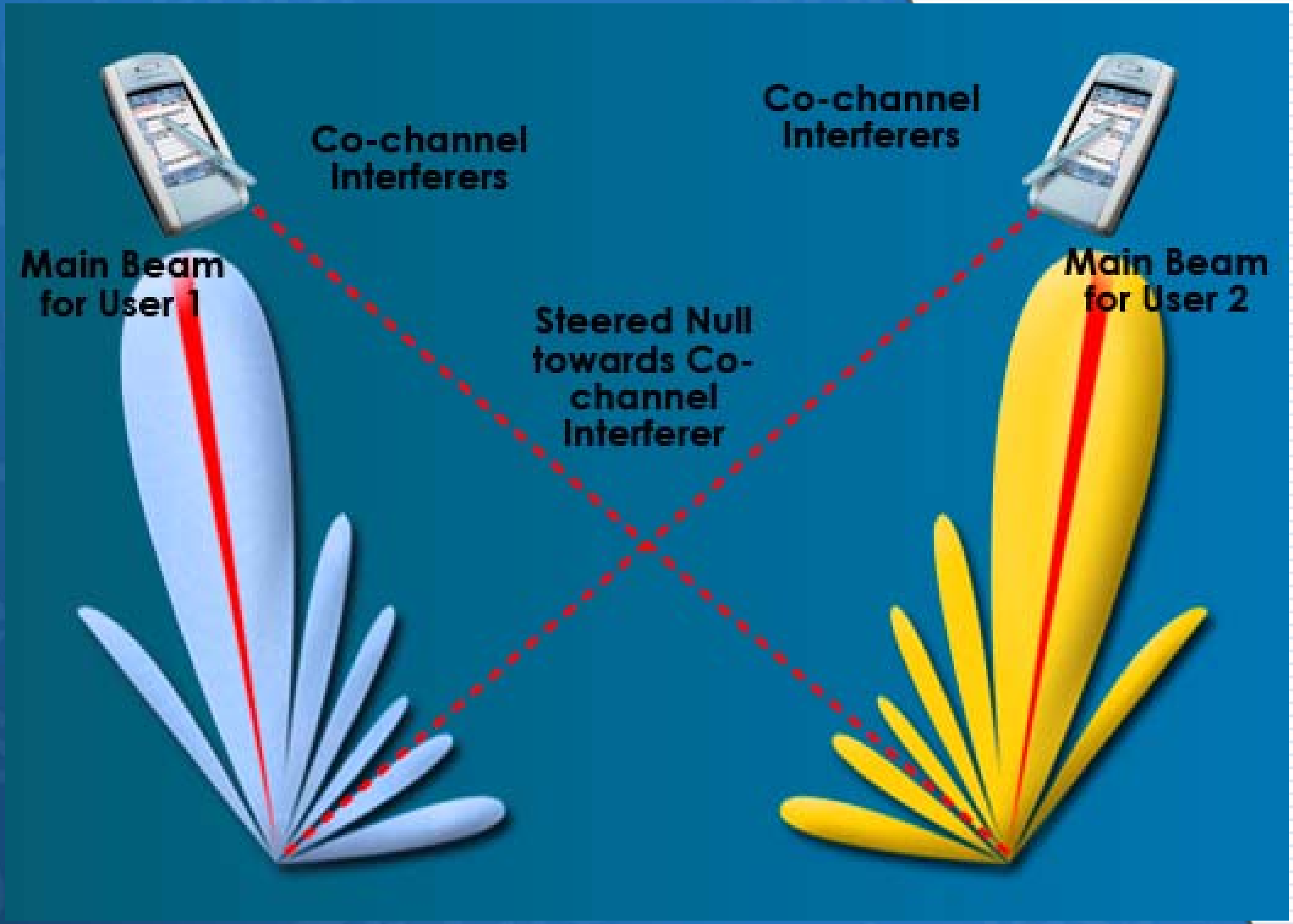
Super Capacity Adaptive BTS

AIRNET®

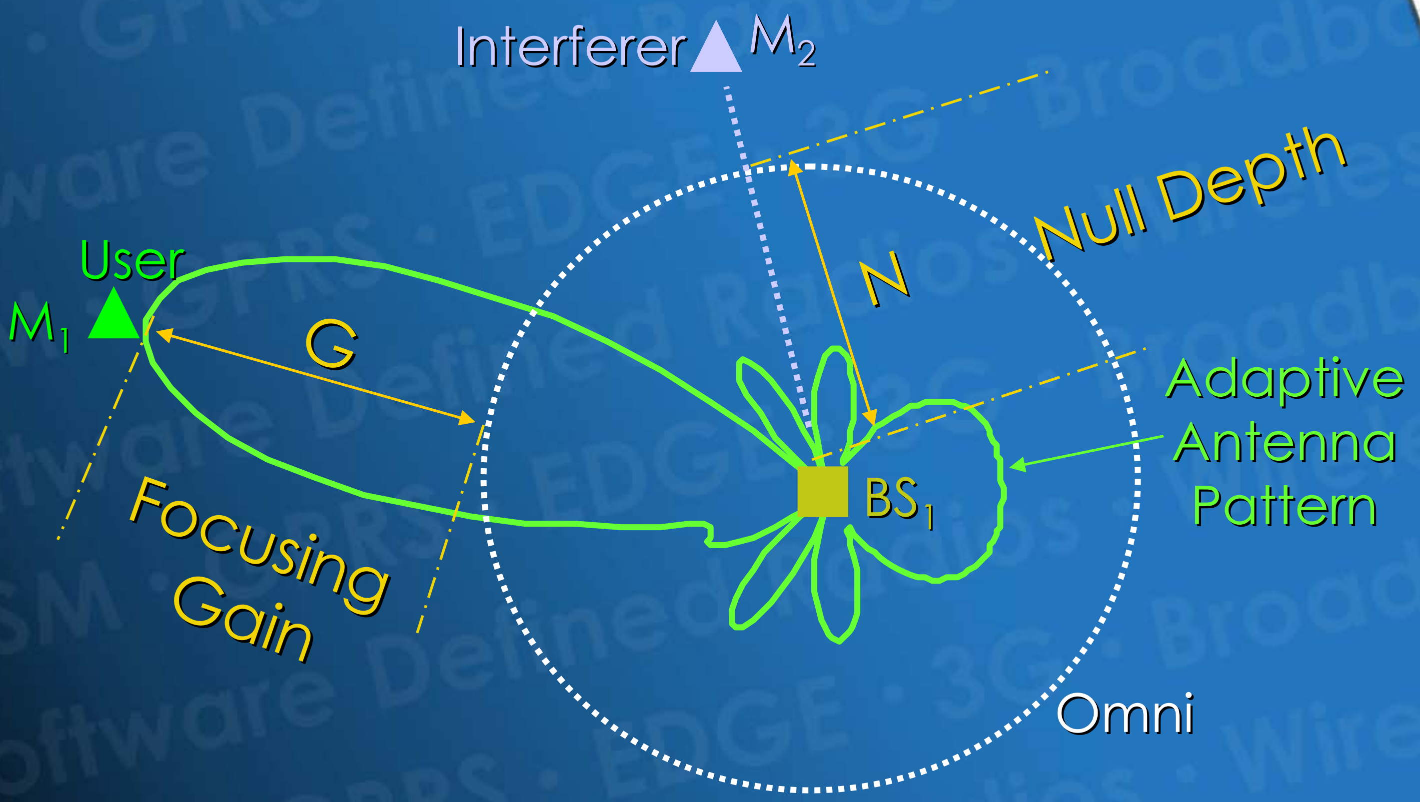
- Only proven broadband software-defined radio platform that supports a seamless integration of adaptive array antenna technology.
- AA implementation is a key enabler for high capacity voice and packet data services.
- The AdaptaCell® SuperCapacity base station, featuring adaptive array software, offers the following benefits:
  - Improvement of dynamic C/I on a "per subscriber" basis,
  - Improved quality throughout the network,
  - Improved frequency spectrum utilization (N=1 frequency re-use),
  - Higher data throughput and Quality of Service,
  - Overall cost reductions in both capital and operations, and
  - Software upgradeability for evolving standards.

Adaptive Array Principles

- Utilizes Signal Processing Algorithms to Distinguish Between Desired Signals, Multi-path, and Interfering Signals.
- Tracks Users with the Main Beam and Interferers with Nulls to Maximize the Link Budget in UL and DL.
- There are NO Predefined Antenna Patterns.



AA Gain and Nulling Increase C/I

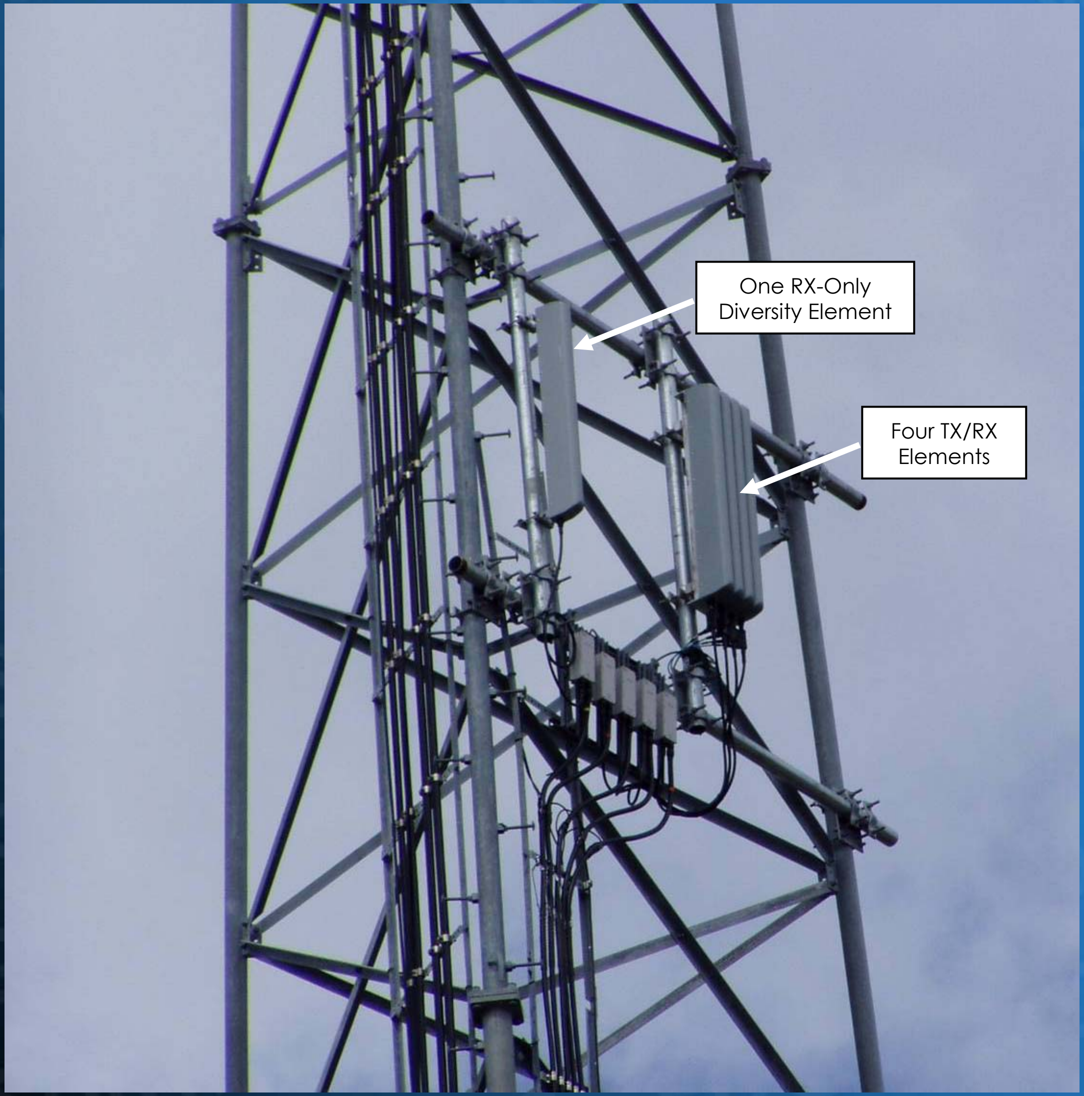


Uplink and Downlink – Adaptive Processing Gain = G + N

Adaptive Array C/I Gains

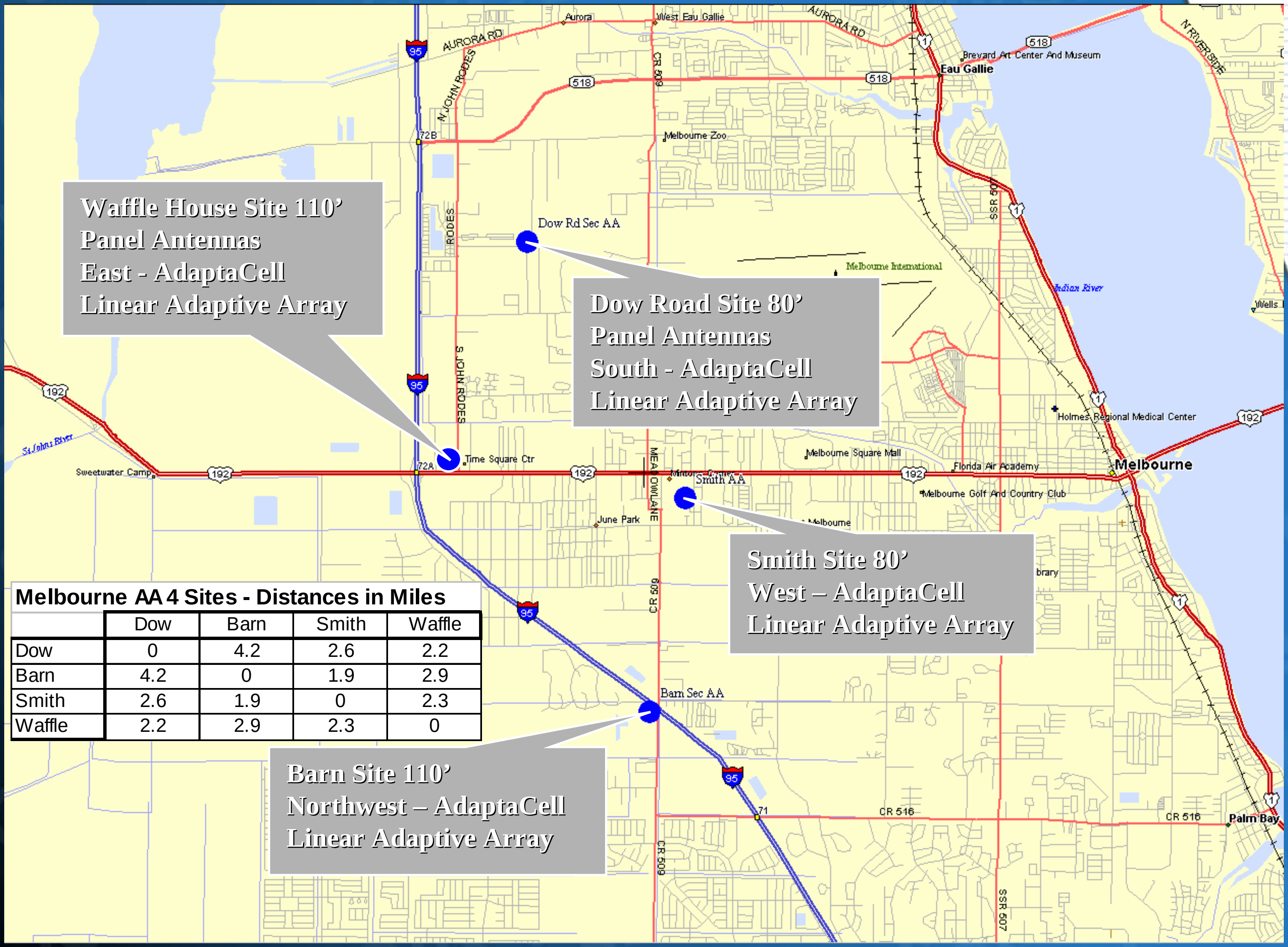
- Adaptive Array Antennas
  - Continuously updates its beam pattern based on changes in both the desired and interfering signal locations.
  - Smoothly tracking the users with main lobes and the interferers with deep nulls while constantly optimizing the link budget C/I ratio.
- Adaptive Array C/I Gain
  - Combination: Main loop focusing gain and reduction of interference.
- Downlink spatial and amplitude information is derived from analysis of uplink information
  - Relative C/I gains for the uplink typically exceed those for the downlink.
- Multiple field trials and commercial deployments using GSM cells operating at the same frequency and time slot
  - **Dynamic C/I gains of up to 30 dB** were achieved.
  - 22 dB in the uplink and 16 dB in the downlink continuously demonstrated.
  - Most of the C/I improvement was from interference rejection nulls, while focusing gain from 4 antennas provides approximately 5 dB.

Adaptive Array Antennas



- Actual Adaptive Array Antennas at "Waffle House" site.
- Linear array uses off-the-shelf antennas:
  - 4 TX/RX at $\lambda/2$
  - 1 RX-only ~8λ
- Omni array uses off-the-shelf antennas.

Melbourne 4-Cell AA Trial
Cell Site Locations

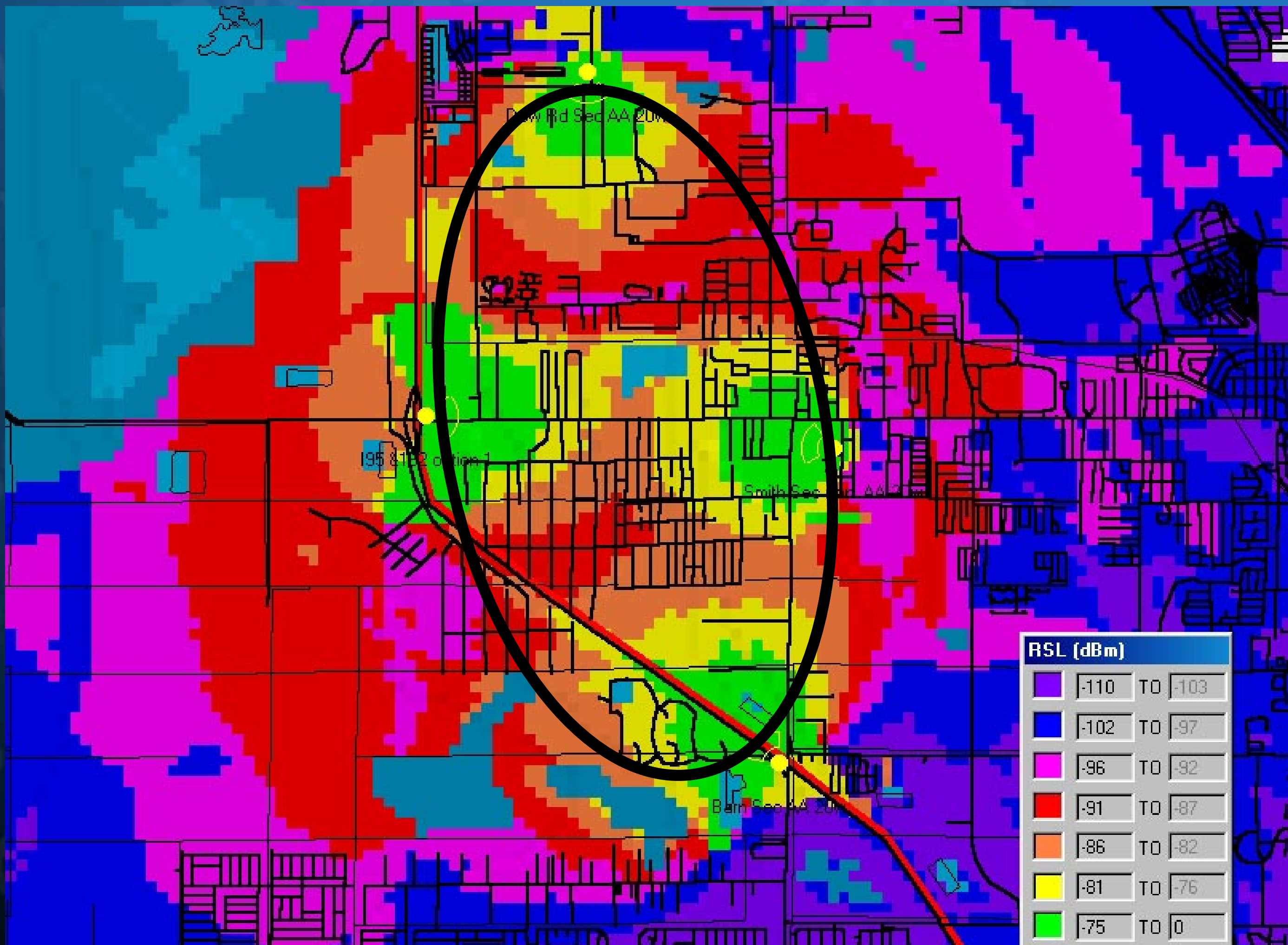


Melbourne AA 4 Sites - Distances in Miles

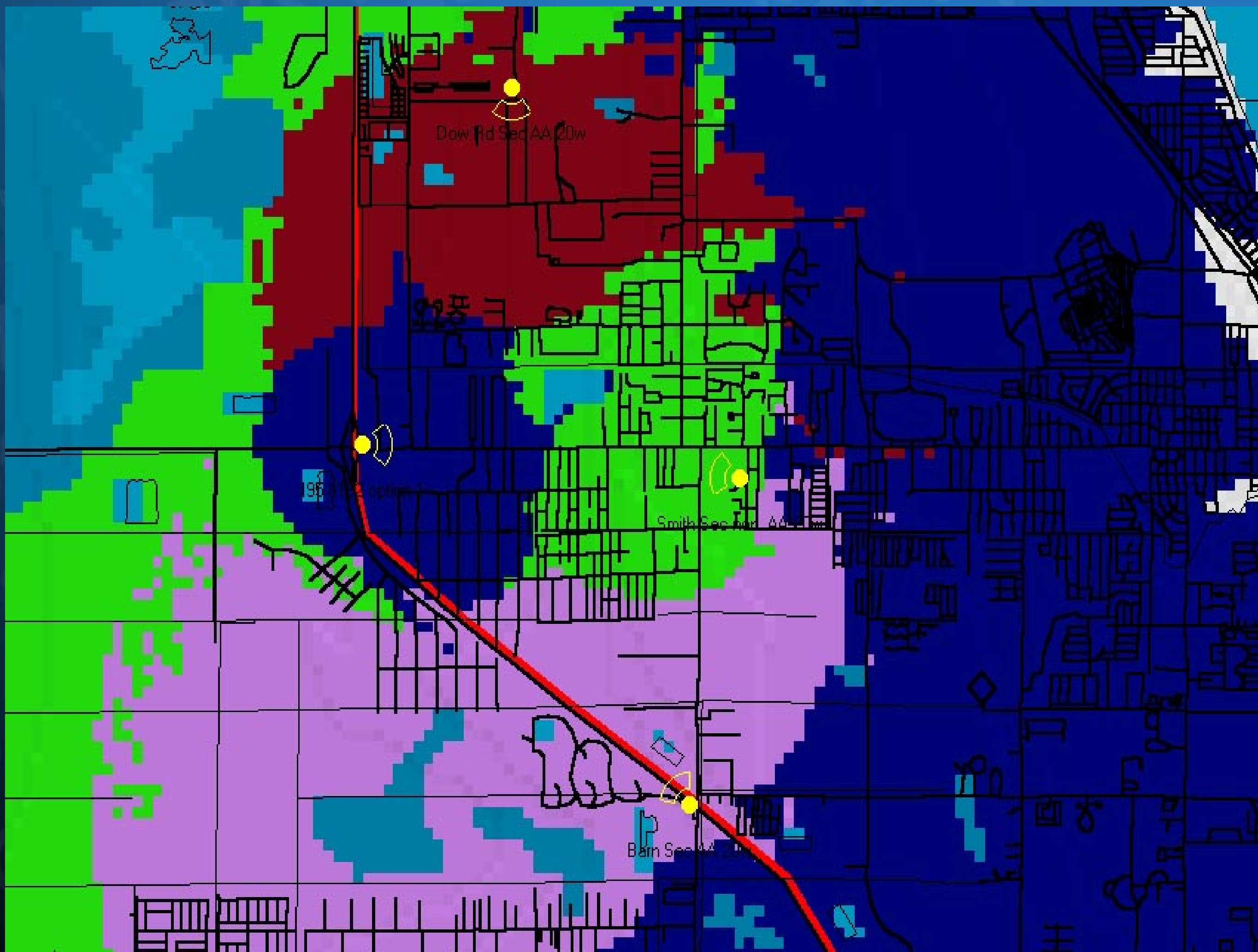
	Dow	Barn	Smith	Waffle
Dow	0	4.2	2.6	2.2
Barn	4.2	0	1.9	2.9
Smith	2.6	1.9	0	2.3
Waffle	2.2	2.9	2.3	0

AIRNET

Melbourne 4-Cell AA Trial
Signal Level Coverage Plot (dBm)



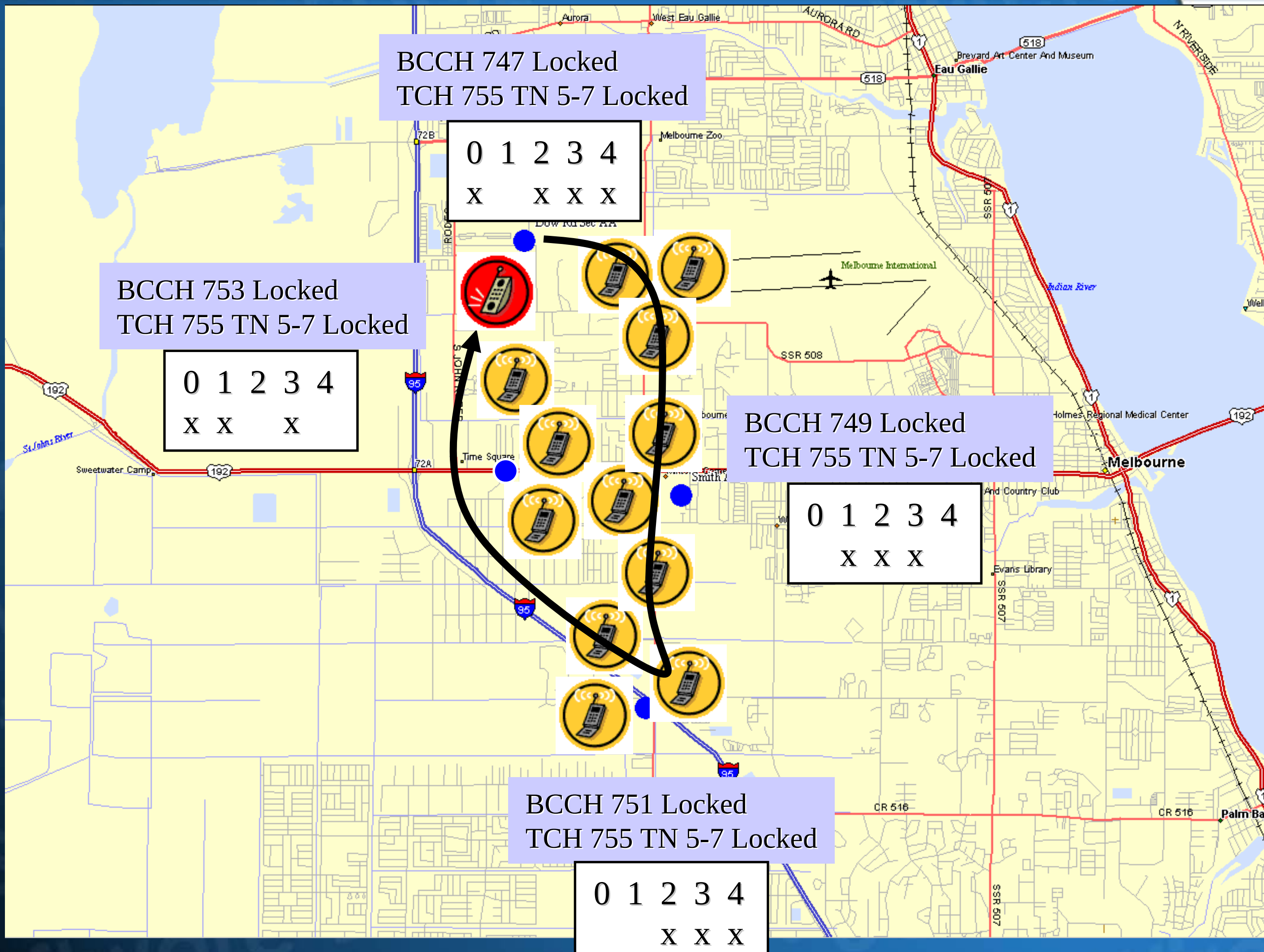
Melbourne 4-Cell AA Trial
Equal Power Boundaries (0 dB C/I)



Melbourne 4-Cell AA Trial N=1 Frequency Re-use Drive Test

- 65% Fractional Load Drive Test:
  - Four Cells, N=1 Frequency Plan.
  - Equivalent BTS TX Power (for AA and Non-AA):
    - 20 Watts at Dow, Smith, and Barn.
    - 5 Watts at Waffle House (TX power reduced to equalize coverage due to greater antenna height).
  - VOCODER = EFR (Enhanced Full Rate).
- Three AirNet Users Per Cell:
  - Locked to Home Cell Using "Cell Test Mode" on the Test Mobile.
  - One TEMS Drive Test Mobile Moving Between Cells:
    - The TEMS unit is the Only Mobile Performing Inter-Cell Handover.
  - 13 Total Users Using the Same 5 TCH Channels:
    - 4 Cells x 3 Users + 1 TEMS = 13 Users.
- Equivalent FL of 65%: 13 users / 20 channels

Melbourne 4-Cell AA Trial
N=1 Frequency Re-use Drive Test



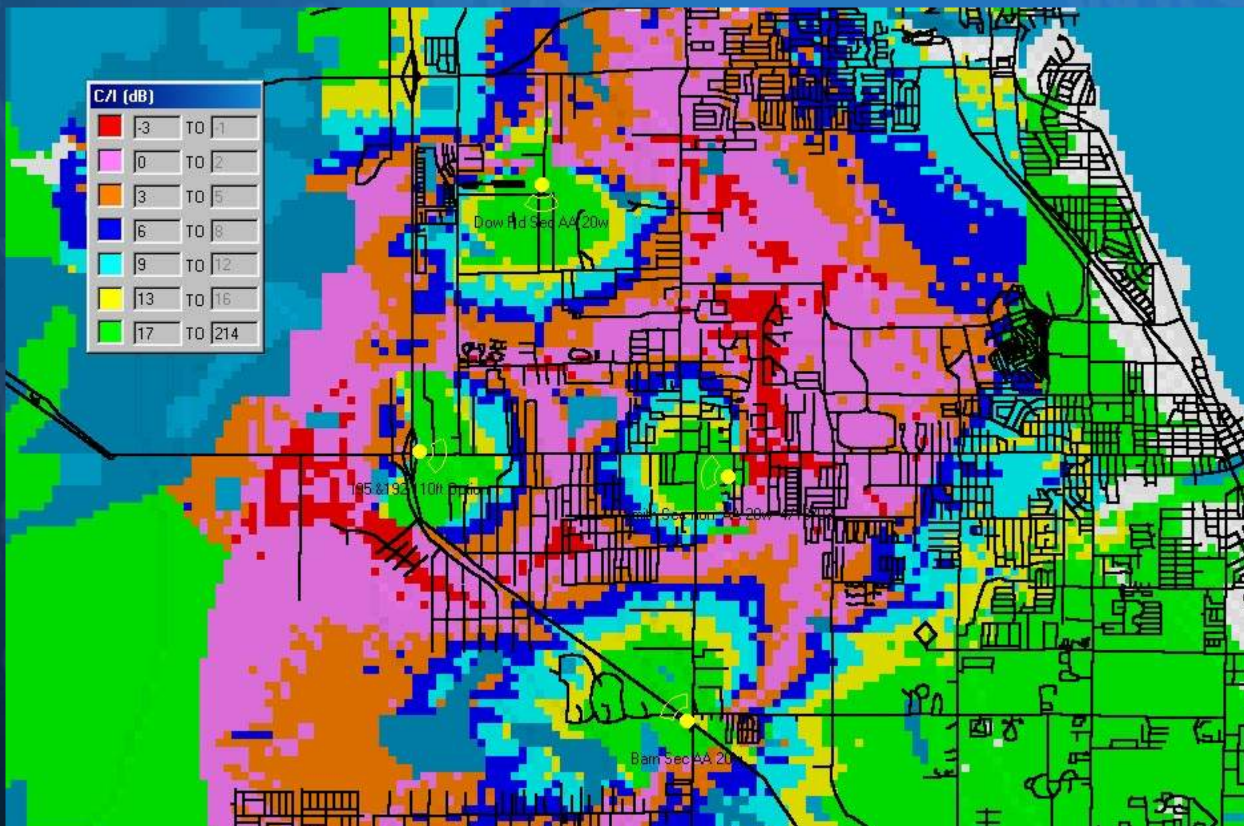
- *13 Users on 20 Timeslots throughout Network (65% Fractional Load)*

Melbourne 4-Cell AA Trial Drive Test Procedure

- The Drive Test Procedure Included:
  - All Drivers Use Established Drive Routes in Cells.
  - All Users Dialed into Common Bridge.
  - TEMS User Observes TEMS Report.
  - TEMS User Drives through All Four Cells Twice.
  - Capture Peg Counts.

- Test 1: Configure Network Non-Adaptively.
- Test 2: Configure Network Adaptively.
- Test 3: Adaptive, but Disable UL/DL Power Control.

Melbourne 4-Cell AA Trial
N=1 Frequency Re-use Destroys C/I



- Melbourne 4-Cell Adaptive Array Trial:
  - Plot Shows C/I without AA is Not Adequate for N=1
  - Must have >6 dB for <u>Minimal</u> GSM Reception (>9 dB Spec.)

Melbourne 4-Cell AA Trial
N=1 Freq Re-Use, Drive Test Results

3/4/2005 Drive Test Condition 65% FL*	Suc TCH Seizures	Atmp TCH Seizures	Dropped Calls Total	Unsuc In Intracell HO	Suc In Intracell HO	Atmp Intracell HO	Unsuc In Intercell HO	Suc In Intercell HO	Atmp In Intercell HO	Unsuc Out Intercell HO	Suc Out Intercell HO	Atmp Out Intercell HO	% Drop Call	% Successful Intra-Cell HO	% Successful Inter-Cell HO
Non-AA	1383	1635	109	168	1150	1318	5	9	14	5	9	14	7.9%	87.3%	64.3%
AA with PWR Control	80	82	0	2	66	68	1	11	12	1	11	12	0.0%	97.1%	91.7%
AA without PWR Control	260	273	3	12	243	255	5	7	12	5	7	12	1.2%	95.3%	58.3%

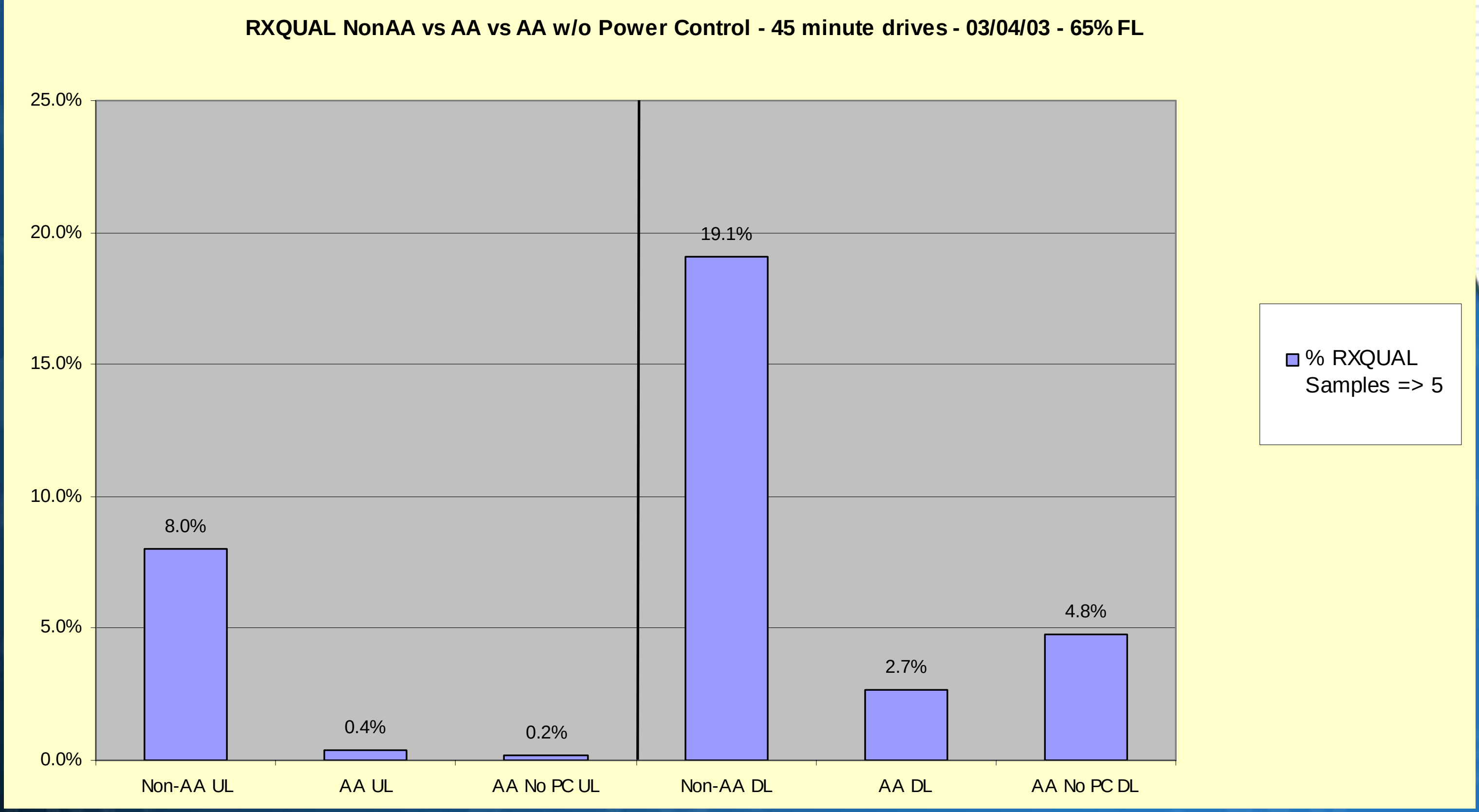
* 13 users on 20 timeslots throughout network
* Calls only re-initiated if dropped

- Without AA: 7.9% Dropped Calls
- With AA: NO Dropped Calls

- Without AA: 87.3% Successful Intracell Handovers
- With AA: 97.1% Successful Intracell Handovers

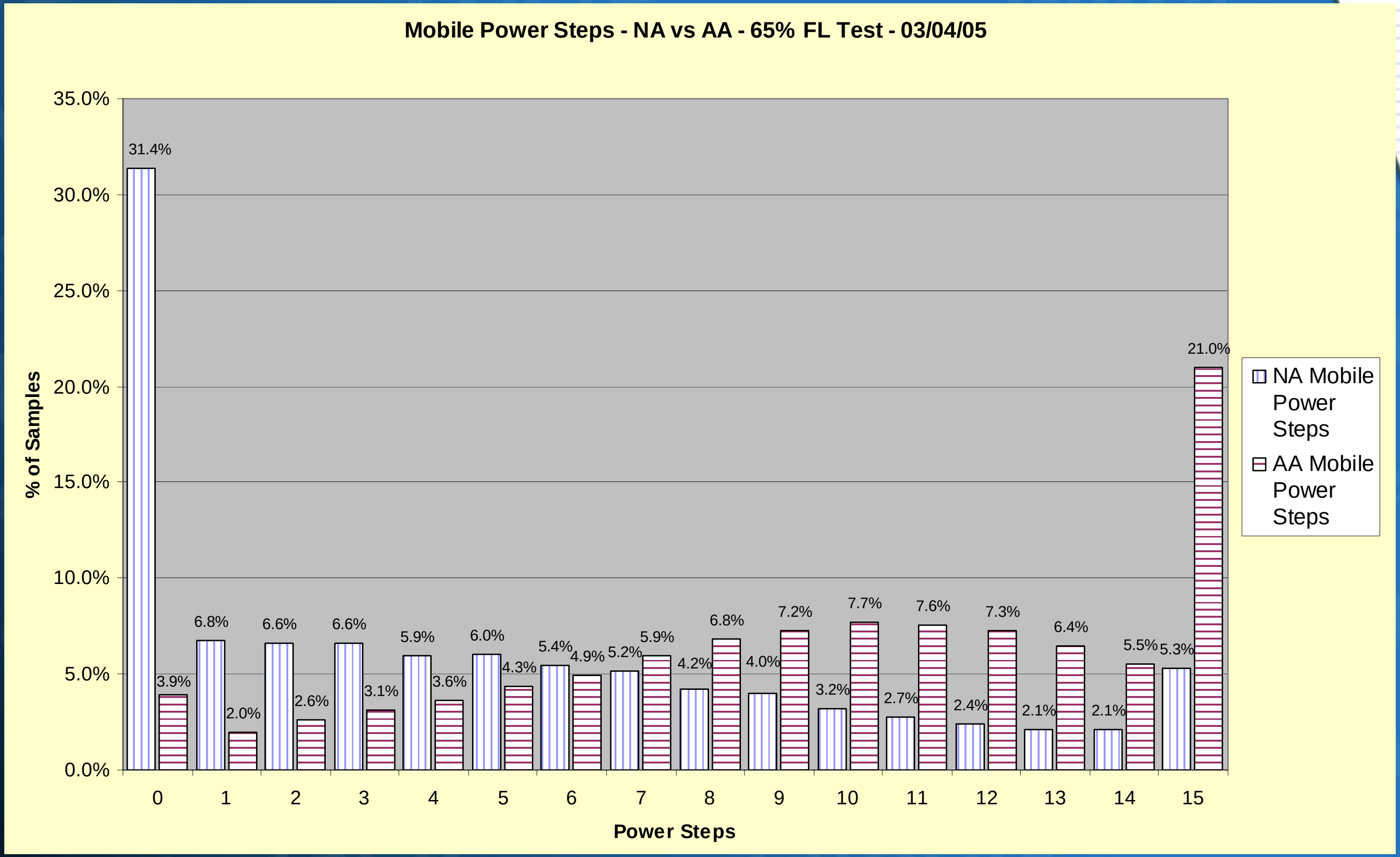
- Without AA: 64.3% Successful Intercell Handovers
- With AA: 91.7% Successful Intercell Handovers

Melbourne 4-Cell AA Trial
RxQual: AA vs. Non-AA



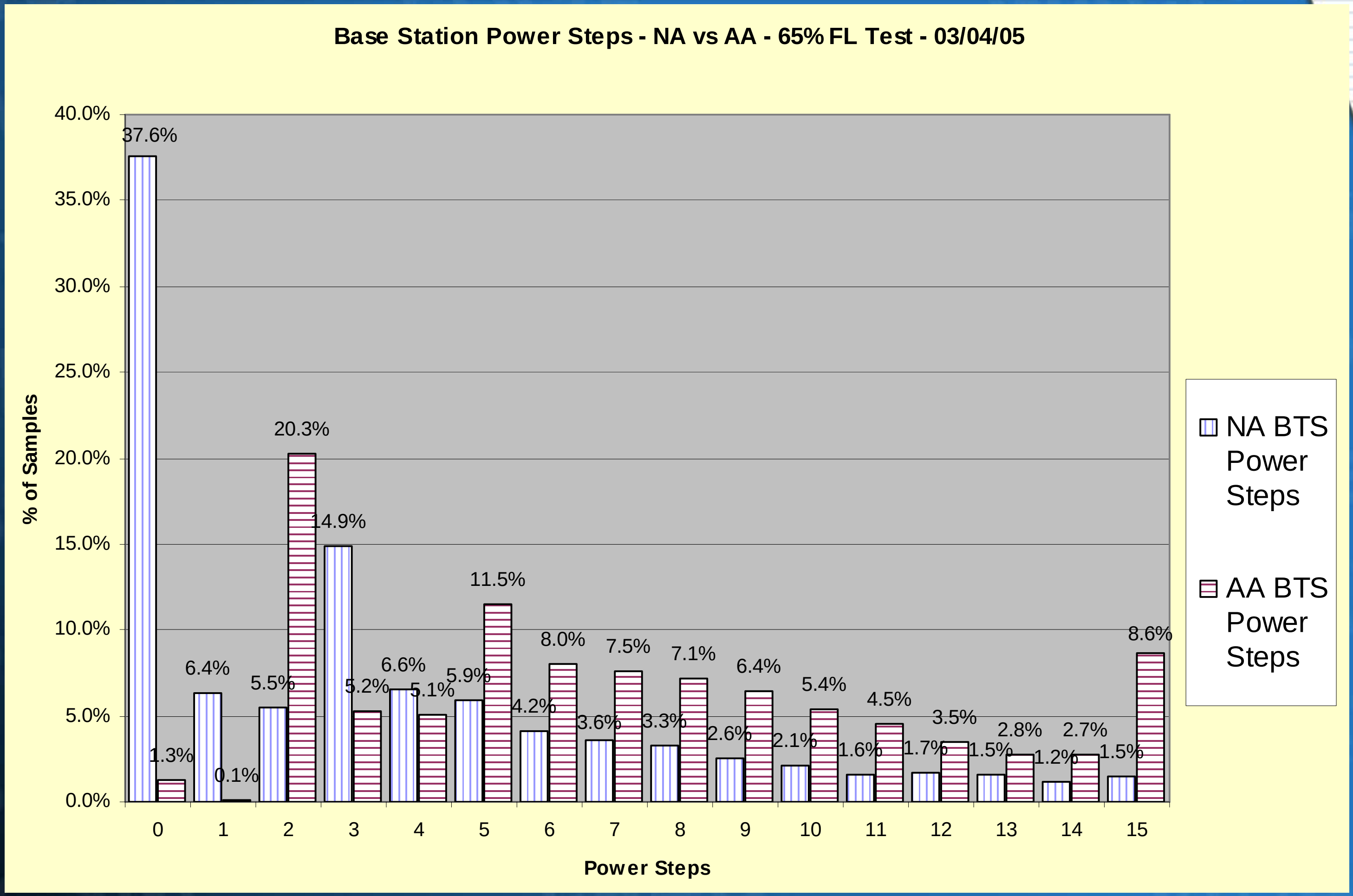
- Without AA: 8% Uplink RxQual ≥5, 19.1% Downlink RxQual ≥5
- With AA: 0.4% Uplink RxQual ≥5, 2.7% Downlink RxQual ≥5
- With AA (But with UL and DL Power Control Disabled):
  - 0.2% Uplink RxQual ≥5 and 4.8% Downlink RxQual ≥5

Melbourne 4-Cell AA Trial
Mobile Power Steps: AA vs. Non-AA



- Without AA: 31.4% of Mobile Power Steps at Highest Setting – Level 0
- With AA: 21% of Mobile Power Steps at Lowest Setting – Level 15
  - AA Saves Mobile Battery Power. AA Offers Longer Talk Time.
  - AA Greatly Reduces Uplink Co-channel Interference.

Melbourne 4-Cell AA Trial
BTS Power Steps: AA vs. Non-AA



- AA Saves BTS Transmit Power.
- AA Reduces DL Co-channel Interference.

- Without AA: 37.6% of BTS Power Steps at Highest Setting – Level 0
- With AA, BTS Power Steps Drop: Only 1.3% at Highest Setting
  - 20.3% at -4 dB Lower 11.5% at -10 dB Lower 8.6% at -30 dB Lower.

Adaptive Array Benefits

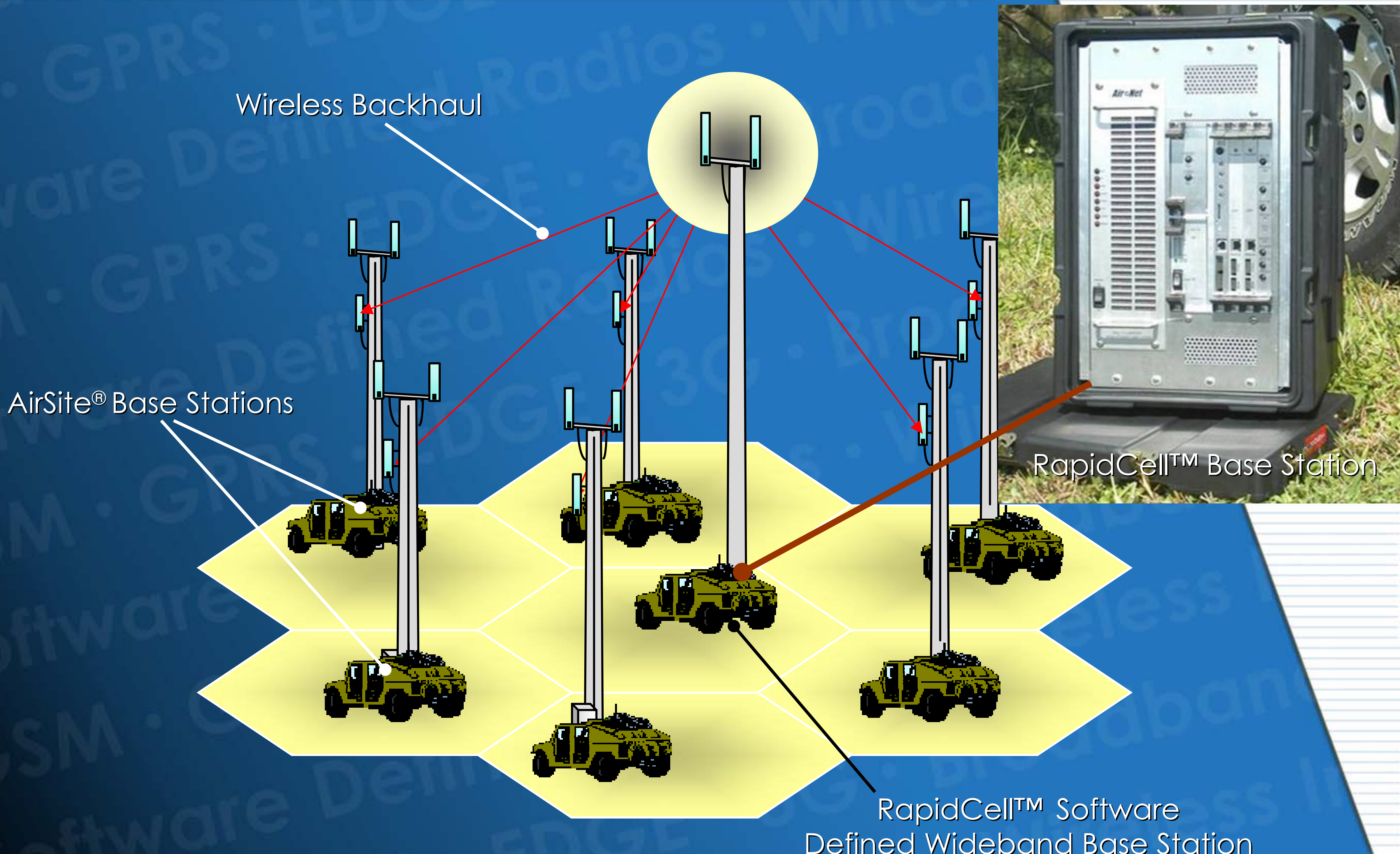
AIRNET

- Up to 30 dB (22 dB nominal) of Dynamic C/I Improvement on a "Per Subscriber" Basis for the Uplink.
- Up to 25 dB (16 dB nominal) of Dynamic C/I Improvement on a "Per Subscriber" Basis for the Downlink.
- Improvement of RF Network Quality through C/I Gains.
- Improved Spectrum Utilization and Erlang Capacity by up to 300% for Urban Voice Applications vs. Traditional Technology.
- Much Higher Data Throughput for GPRS and E-GPRS (EDGE) by up to 500%.
- Reduced Number of Sites for Voice and Data Applications.
- Extension of GSM Network's Viability Many Years Further.
- Alternative to Expensive 3G Plans.
- Improvement of GPRS and EDGE Coverage up to 4 times.

AA Mobile-to-Mobile Drive Pass

- Drive Test Using 2 Cells:
  - Mobile-to-Mobile, Same Frequency, Same Time Slot.
  - 2 Cars Approaching Each Other on Same Road.
  - Talking with Each Other, Monitoring Call on TEMS Units.
  - Cars Passed Each Other and Maintained Call without Drop.
  - Major Carrier Found this to be "Very Impressive".

Rapid Deployment System for Tactical Communications



RapidCell™ BTS

- **Standalone Features:**
  - Inter-mobile Calls.
  - ISDN Connectivity to PBX.
  - ISUP Connectivity to PSTN.
  - Satellite Connectivity.
  - Data Capabilities.
  - Secure Communications.
- **Sized to Deploy in Vehicles.**
- **Shock Mounted – Robust Packaging.**
- **Interfaces with Containerized Backup Power, Microwave, and Encryption Equipment.**
- **Many Uses:**
  - Private Networks, Military, or Agency.
  - Emergency First Responders.