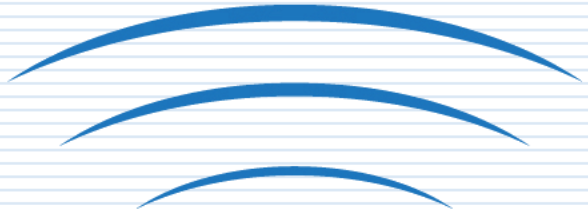

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Adaptive Array SDR Base Station for Commercial Cellular Applications

SDR Forum Technical Conference -- November 17, 2003

Michael Komara, Terry Williams -- AirNet Communications Corp.

Why Adaptive Arrays?

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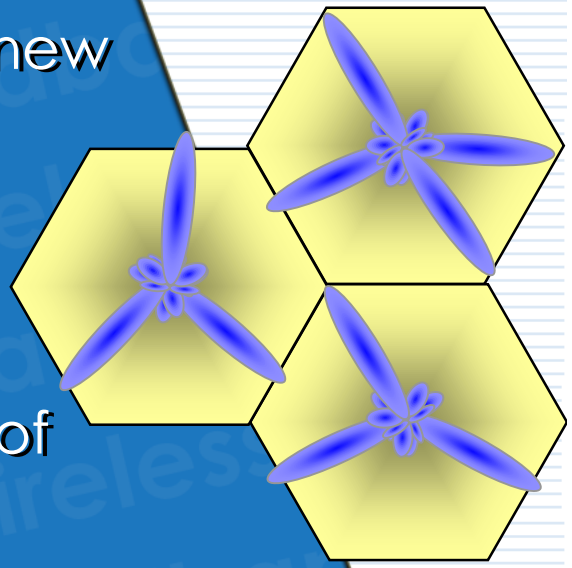
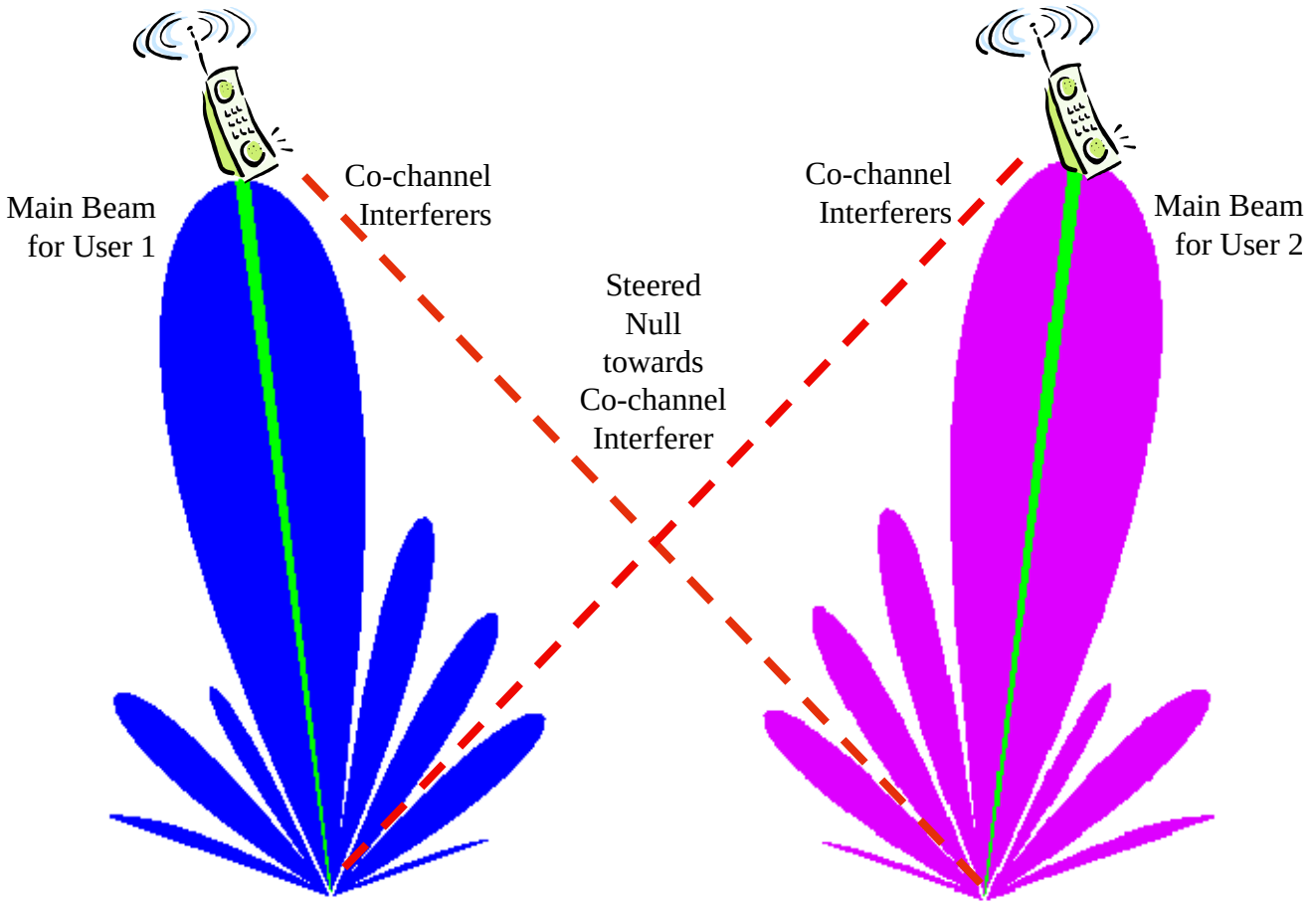
- Operators need more capacity to support new customer usage patterns:
  - Higher minutes of use per customer.
  - Wireline substitution.
  - High-speed data.
- Some urban areas are already running out of capacity:
  - No new frequencies available.
  - Must get more capacity from existing frequencies.
- Adaptive antennas dramatically improve capacity:
  - Narrow antenna beam "follows" the subscriber.
  - Dramatically reduces co-channel interference.
  - Significantly increases system capacity.



Adaptive Array Principles

- Uses Signal Processing Algorithms to Distinguish Between the Desired Signals, Multipath, and Interfering Signals.
- Tracks Users with the Main Beam and Tracks Interferers with Nulls to Maximize the Overall Link Budget.
- There are NO Predefined Antenna Patterns.



Adaptive Array Technology

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- Multiple transmit/receive antenna elements:
  - Advanced signal processing exploits spatial characteristics of signals.
  - Provides dynamic gain and interference mitigation for each subscriber… every frequency and every time slot.
- Spatial Optimization – Multipath environment:
  - Receive: Maximizes signal reception by weighting energy arriving from several directions.
  - Transmit: Transfers energy in different spatial directions such that energy is concentrated at the mobile receptor.
  - Concept of a "beam" in a traditional sense does not apply.
- Downlink solution is derived and continuously updated using uplink measurements.
- Improves C/I without the "diminishing returns" of static sectorization:
  - Static sectorization has poor trunking efficiency.
  - Static sectorization has sector overlap.
  - Static sectorization has increased "soft" handover.

Adaptive Array Enhances Signal Quality

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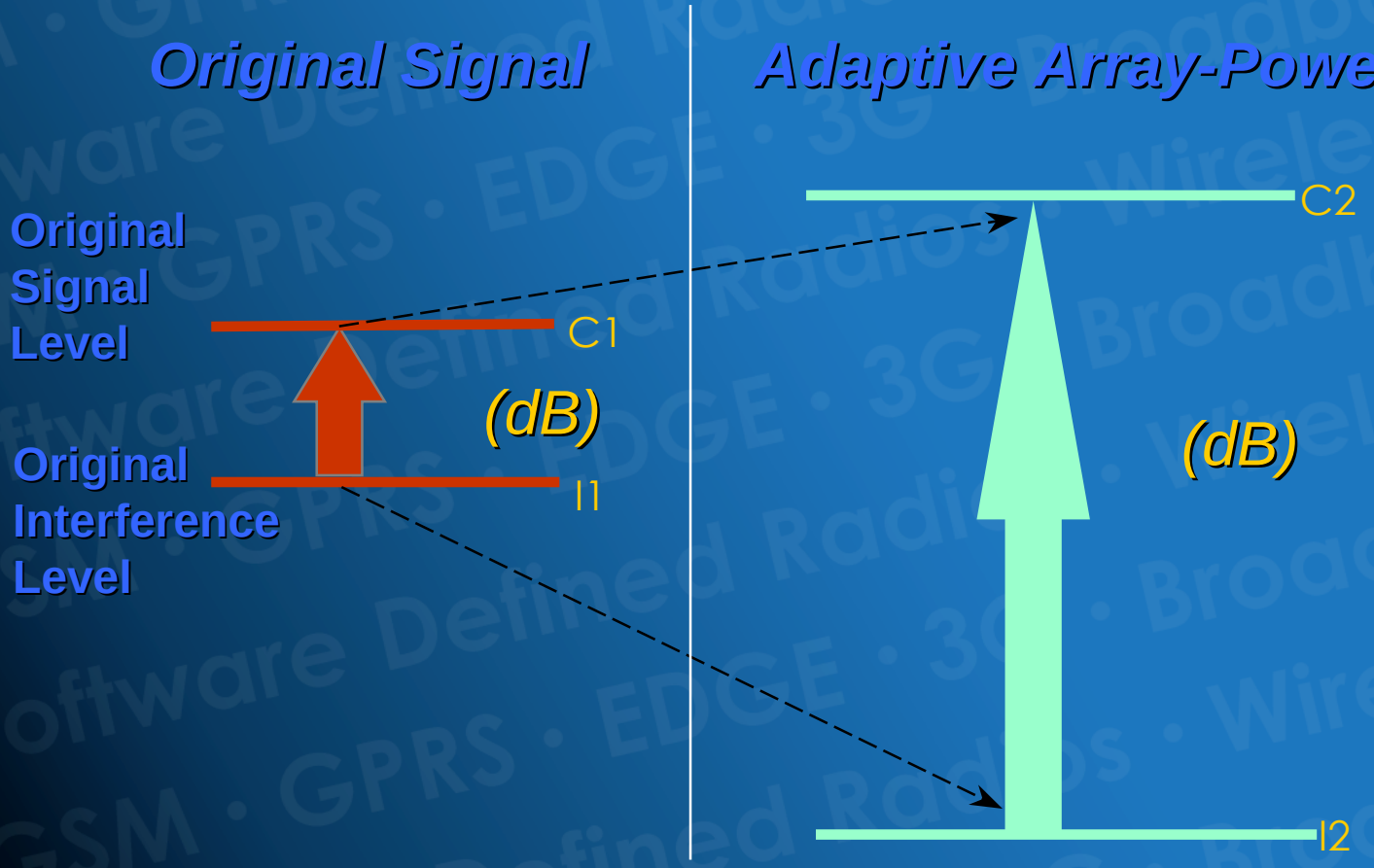
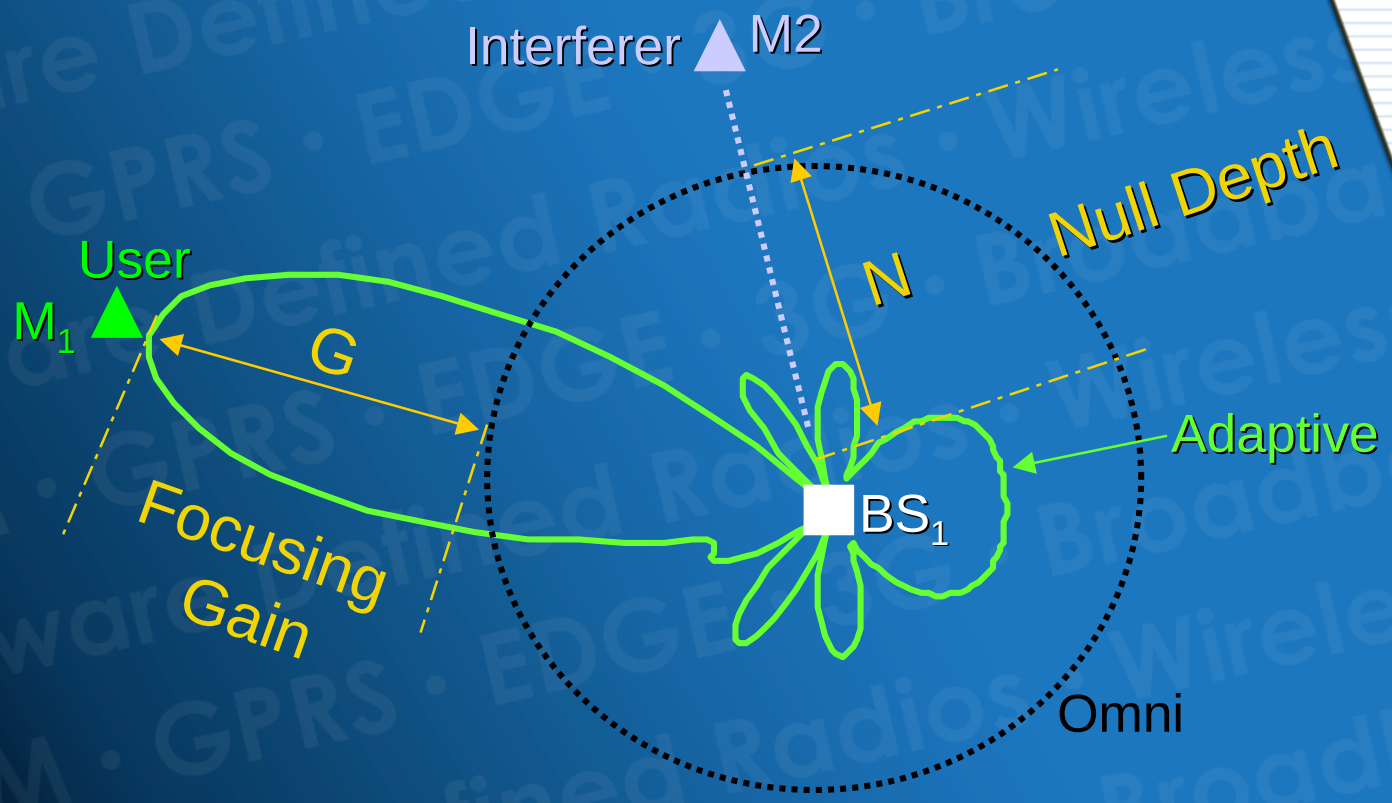


Increased Signal Level

C/I increase at mobile and basestation
C2 > C1
I2 < I1

Decreased Interference Level

Gain and Nulling Increase C/I



Uplink and Downlink – Adaptive Processing Gain = G + N

Benefits of Adaptive Array

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Feature	Benefits
Signal Gain – Inputs from multiple antennas are combined to optimize the power required to maintain a given level of coverage.	**Better Range/Coverage** – Focusing the energy increases base station range and coverage. Lower handset power requirements translate into greater battery life and smaller size.
Interference Rejection – Antenna pattern nulls can be generated toward co-channel sources, improving the C/I ratio of the received signals.	**Increased Capacity** – Lowering interference throughout the network leads to higher capacity and increased frequency reuse patterns.
Spatial Diversity – Composite information from the array is used to minimize fading and other undesirable effects of multipath propagation.	**Multipath Optimization** – Can reduce the effective delay spread of the channel, allowing higher bit rates to be supported.
Power Efficiency – minimizes the amount of broadcasted energy focusing multiple antenna elements.	**Reduced Expense** – Lower amplifier costs, power consumption, and higher reliability will result.

SuperCapacity BTS – Powered by ArrayComm IntelliCell Technology

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- Broadband SDR base station is an enabling technology.
- Addition of adaptive array software to base station DSP arrays.
- ArrayComm IntelliCell™ adaptive algorithms:
  - Weighting and combining done digitally at base band.
  - No expensive RF hardware and RF plumbing.
- Substantially higher performance than competing solutions.
- Utilizes off-the-shelf antenna elements.
- Built-in… NOT Bolted-on.

AdaptaCell Base Station Adaptive Array Implementation

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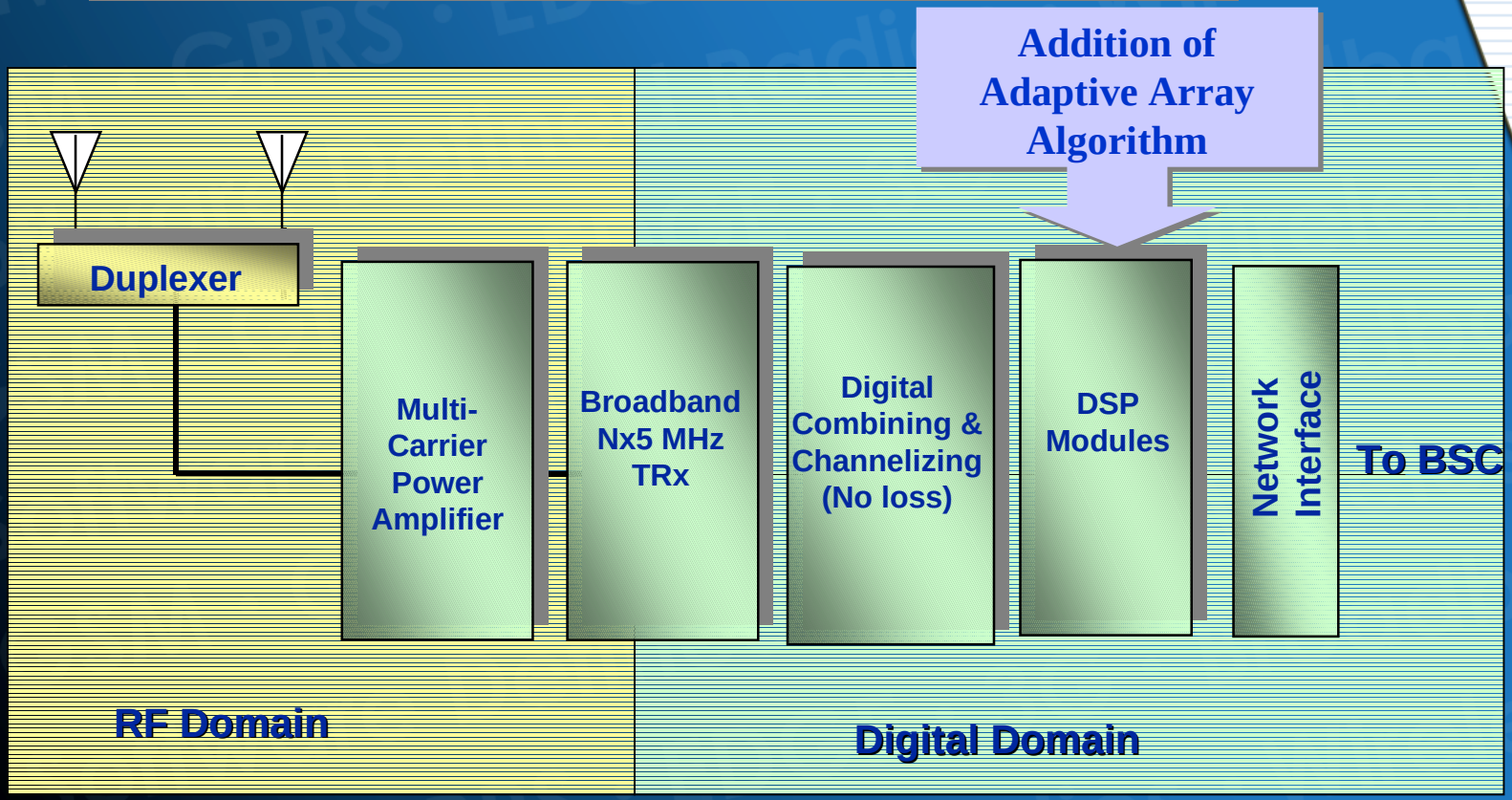
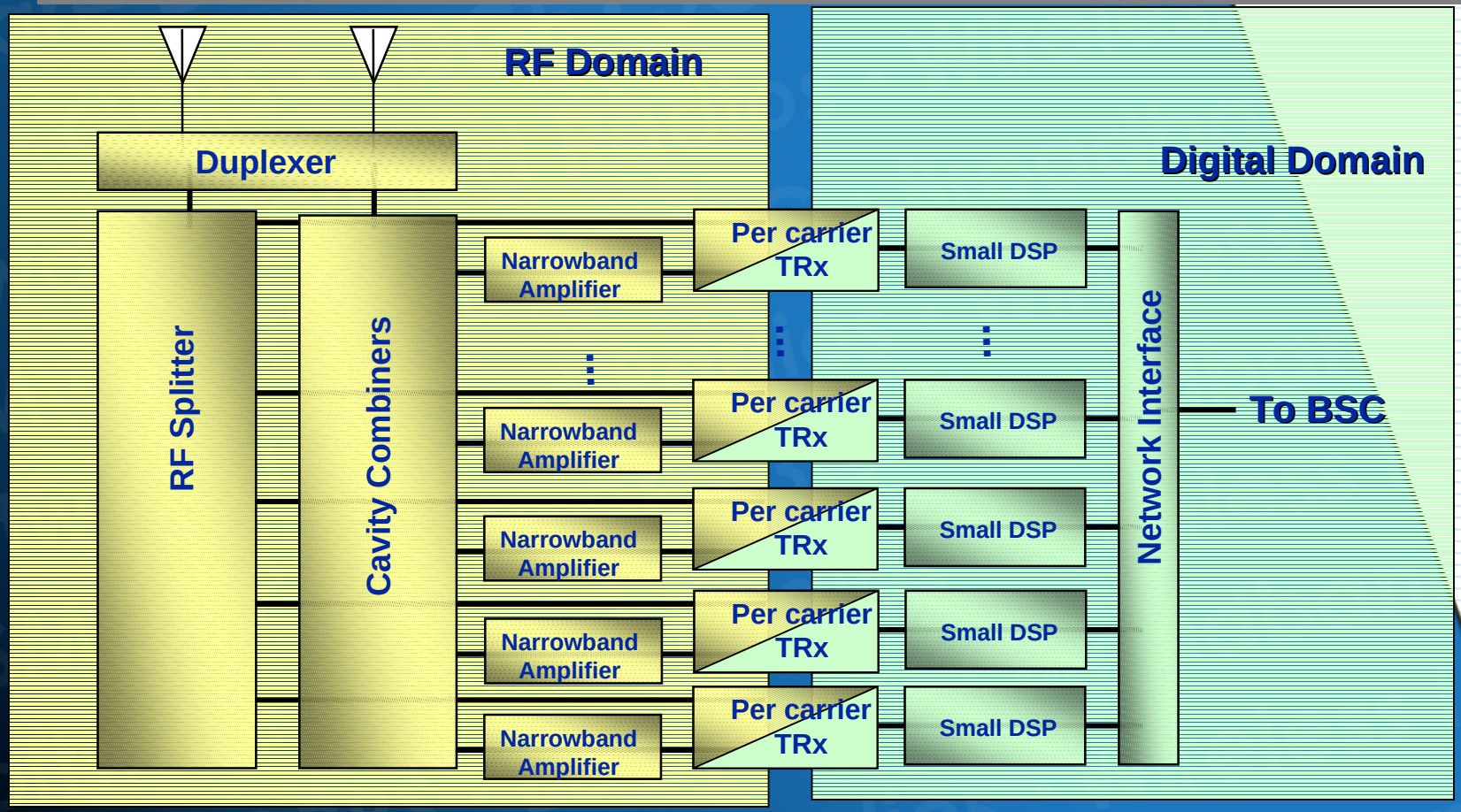
- No additional hardware.
- Standard antennas.
- No appliqué circuits.
- Powerful DSP processing to support Adaptive Array.



Narrowband – Unsuitable for Adaptive Arrays

- Standard specific hardware and software.
- Limited programmability.
- Lots of components.
- Lossy cavity combiners, cables, etc.

- Only way to implement adaptive solution is to add expensive hardware appliqué.
- Dramatic increase in RF component count.
- More expensive and less reliable.



Comparison of AirNet BTS with Legacy Systems

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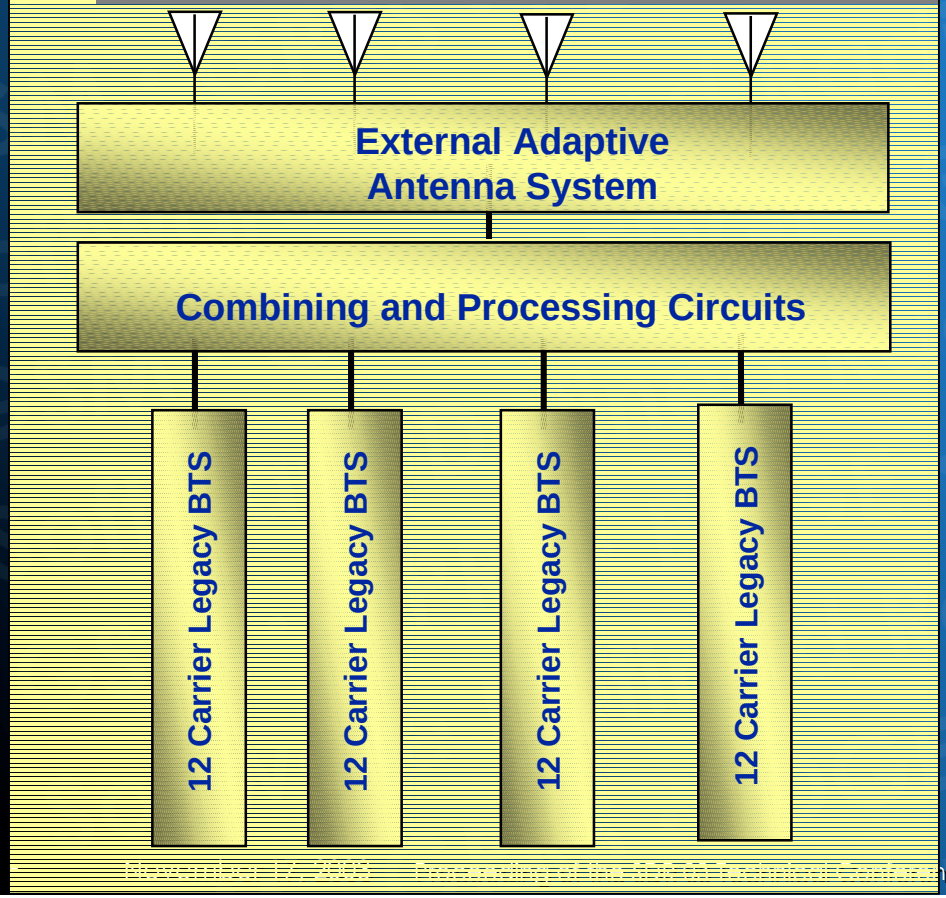
- **Narrow-band Legacy System**
  - Lack of Integration.
  - High Cost.
  - Lack of Real-time Processing Power.
  - May Require Non-standard Antennas.



- **AirNet Super-Capacity Base Station**
  - Software Integration of Adaptive Array Algorithm.
  - Cost-effective Solution.
  - 2.5G and 3G Enabler.
  - Uses Standard BTS Antennas.

The Need for Calibration

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- All TX and RX signal paths have amplitude and phase offsets at installation and exhibit some drift over time, temperature, and voltage.
- Different cable lengths, path delays, antenna placements, SAW filter delays vs. temperature.
- Receive-only systems do not need calibration if the direction-of-arrival is not required.
- Both TX and RX paths must be calibrated if the RX weights are used to calculate the TX weights.
- Calibration of all paths to better than 5 degrees and 0.1 dB of accuracy is desired.
- Digital compensation is done at baseband for the full TX and RX paths from antenna to DSP.

Automatic Calibration

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- Isolated "test mobile" cabled to a near-field calibration antenna or coupler assembly.
- A periodic call to the test mobile allows calibration of uplink RX and downlink TX paths.
- Base station forms transmit nulls at the calibration mobile and receives uplink data from mobile.
- The AA BTS system auto-calibrates periodically.
- Transparent to normal basestation operation – borrowing unused time slots.
- Digitally corrects for entire TX and RX paths from beyond the antennas to the DSP.

Capacity Increase Summary

- 5+5 MHz spectrum allocation assumed for all examples

Site Configuration	Tri-Sectored	Tri-Sectored	Tri-Sectored	Tri-Sectored	Omni	Omni	Tri-Sectored	Tri-Sectored	Omni	Tri-Sectored
Method	Non-Hopping	Freq Hopping	Freq Hopping	Freq Hopping	Adaptive	Adaptive-FH	Adaptive-FH	Freq Hopping	Adaptive	Adaptive
Traffic Reuse	4/12 Reuse	1/3 Reuse	MRP Reuse	1/1 Frac Reuse	2 Reuse	1 Reuse	1/1 Frac Reuse	1/1 Frac Reuse	1 Reuse	1/1 Frac Reuse
AMR	No AMR	No AMR	No AMR	No AMR	No AMR	No AMR	No AMR	With AMR	With AMR	With AMR
Erlangs per cell (2% blocking)	**9**	11	12	16	62	88	63	**30**	128	**91**
Erlangs per site (2% blocking)	**27**	33	36	48	62	88	189	**90**	128	**273**
Capacity Improvement over non-FH sectored	**0%**	22%	33%	78%	130%	226%	600%	**233%**	374%	**911%**
Capacity Increase over non-FH sectored	**1.0x**	1.2x	1.3x	1.8x	2.3x	3.3x	7.0x	**3.3x**	4.7x	**10.1x**
Capacity Improvement over FH sectored				0%	29%	83%	294%	**88%**	167%	**469%**
Capacity Increase over FH sectored				1.0x	1.3x	1.8x	3.9x	**1.9x**	2.7x	**5.7x**

SOURCE: AirNet/ArrayComm White Paper

Capacity Improvement Techniques - Comparisons

- FHOP, AMR, and Adaptive Array all improve network capacity.
- Each of these is complementary – benefits are additive.
- AirNet solution supports all three:
  - Also compatible with DTX and power control.
- Sectored AA w/AMR provides:
  - **3x** capacity over conventional sectored FHOP with AMR.
  - **10x** increase in capacity compared to conventional sectored w/o FHOP.
- "Switched beam" smart antenna solutions only offer modest capacity gains with significant added hardware.

Packet Data Limitations with Frequency Hopping

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- GSM Frequency Hopping:
  - Distributes noise from low C/I cells to high C/I cells.
  - Averages C/I of the network.
  - Improves voice quality of low C/I cells.
- GPRS and EDGE have much lower tolerance of noise compared to voice:
  - FHOP will degrade C/I -- worse BER of majority of cells.
  - Can trigger excessive data block re-transmissions due to bit error distribution amongst users.
  - Most vendors recommend putting GPRS/EDGE on BCCH carriers only.
- Can put GPRS/EDGE on any carrier with AirNet solution!

Up to 14x Sites Required Using Legacy Systems for EDGE

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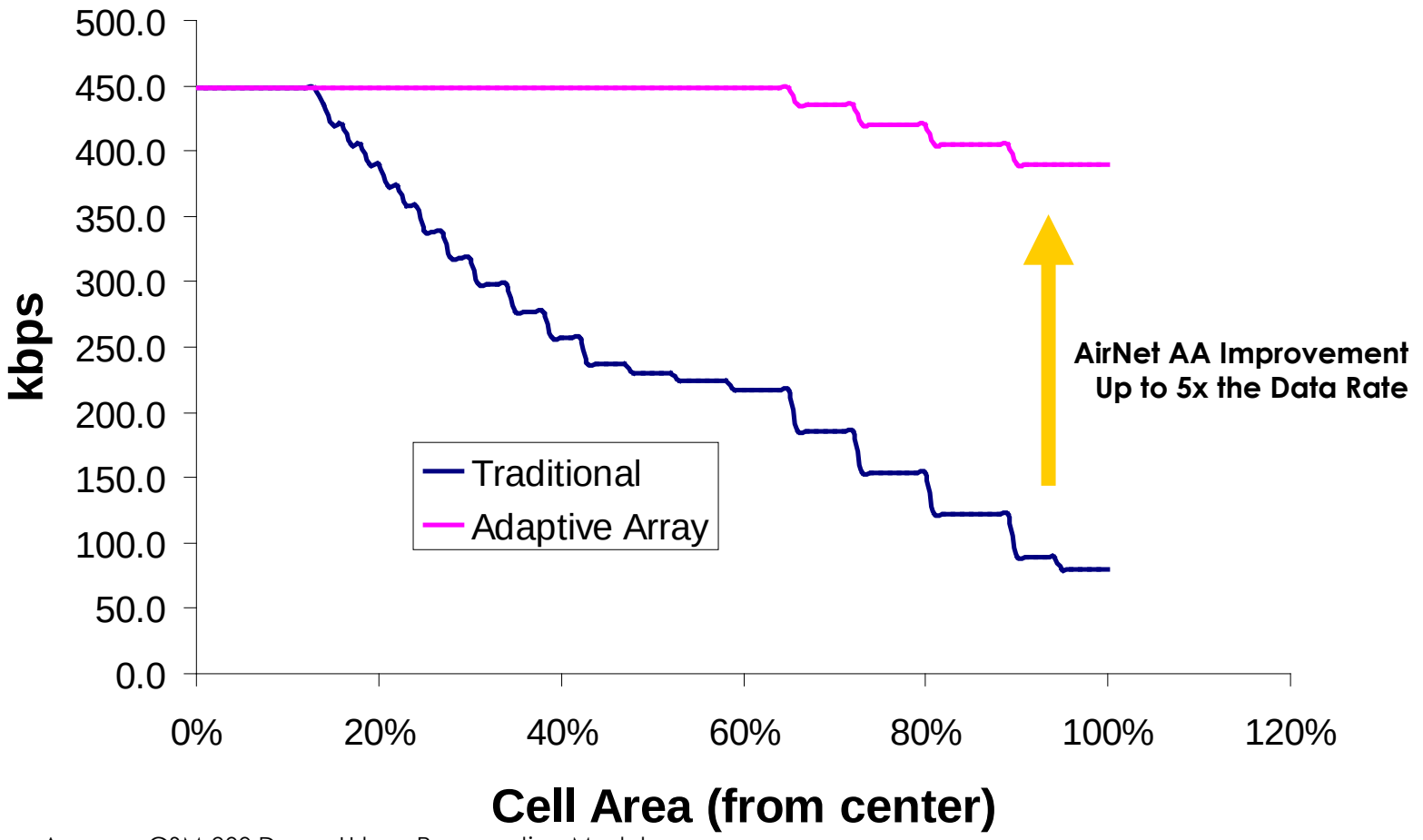
Modulation	Coding	Data Rate per time slot (kbps)	Data Rate per Carrier (kbps)	Required Co-Channel C/I (dB)	Deficit from GSM 9 dB C/I	Dense Urban Coverage Area (x GSM)	Suburban Coverage Area (x GSM)	Dense Urban Sites (x GSM)	Suburban Sites (x GSM)
GSM	CSD	9.6	57.6	9	0	100.0%	100.0%	100%	100%
GPRS	CS-1	9.05	72.4	13	4	65.2%	61.9%	153%	162%
GPRS	CS-2	13.4	107.2	15	6	52.7%	48.7%	190%	205%
GPRS	CS-3	15.6	124.8	16	7	47.3%	43.2%	211%	231%
GPRS	CS-4	21.4	171.2	19	10	34.4%	30.1%	291%	332%
EDGE	MCS-1	8.8	70.4	8	0	100.0%	100.0%	100%	100%
EDGE	MCS-2	11.2	89.6	10	1	89.9%	88.7%	111%	113%
EDGE	MCS-3	14.8	118.4	15	6	52.7%	48.7%	190%	205%
EDGE	MCS-4	17.6	140.8	20	11	30.9%	26.7%	324%	375%
EDGE	MCS-5	27.2	217.6	14	5	58.6%	54.9%	171%	182%
EDGE	MCS-6	29.6	236.8	17	8	42.5%	38.3%	235%	261%
EDGE	MCS-7	44.8	358.4	23	14	22.4%	18.7%	446%	535%
EDGE	MCS-8	54.4	435.2	28	19	13.1%	10.2%	763%	980%
EDGE	MCS-9	59.2	473.6	31	22	9.5%	7.1%	1053%	1408%

- GSM900 Dense Urban and Suburban In-building models used
- Derived from ETSI SMG2 Studies

Non-Starter

Adaptive Array Data Advantage



Assumes GSM-900 Dense Urban Propagation Model

AdaptaCell Data Rate Comparison

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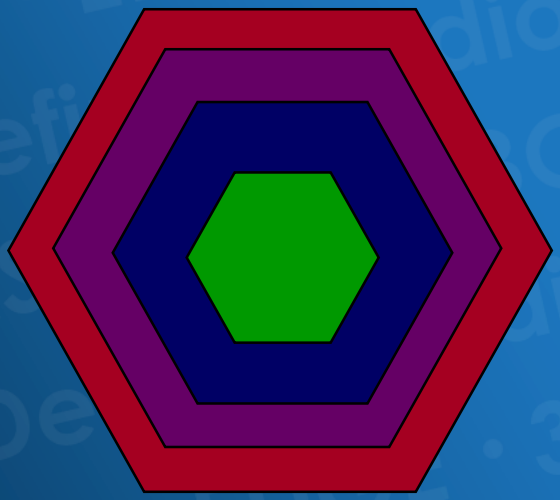
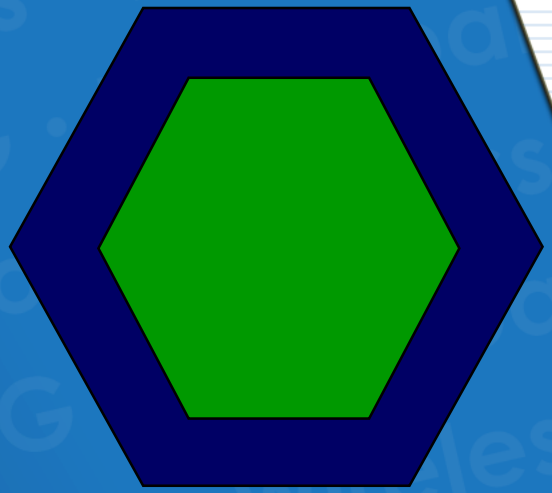
Peak Data Rate

- 70 kbps (MCS 1)
- 140 kbps (MCS 4)
- 240 kbps (MCS 6)
- 470 kbps (MCS 9)

GSM Base Line



AdaptaCell



Adaptive Array Summary

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- AirNet's AdaptaCell base station is the only broadband software-defined radio technology in commercial service:
  - Enabling technology for adaptive array.
- AirNet's AdaptaCell base station united with ArrayComm's IntelliCell AA software provides the only cost effective solution to achieve maximum network capacity.
- Dramatic voice capacity and data throughput improvements:
  - 3 to 10 times the voice capacity.
  - Up to 5 times higher packet data throughput.
  - Up to 6 times fewer sites.
- Will help in migration from IS-136 to GSM by reducing spectrum requirements.
- Utilizes standard antenna elements.