Improving Capacity in 5G Sub-6 GHz and mmWave Systems

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Blue Danube Systems Company Summary

OPPORTUNITY	Address explosive mobile data growth by dramatically improving wireless network capacity
MARKET & PRODUCT	4G-LTE and 5G-NR Massive MIMO with High Definition Active Antenna System (HDAAS™)
TEAM	52 Regular Employees, Industry experience across Antennas / RF / IC design / Systems / SW
FUNDING & INVESTORS	$43M raised, Sequoia, Northgate, AT&T and TBA top 3 global tech investment firm
FOUNDATIONAL TECHNOLOGY	Circuit-based solution to extract a highly phase-accurate clock along an arbitrary serial path

- Named a Top Start-Up in Both Semiconductor and Wireless Industries
- "Most Innovative Cellular and Enterprise System Start-Up" IEEE WCNC 2017

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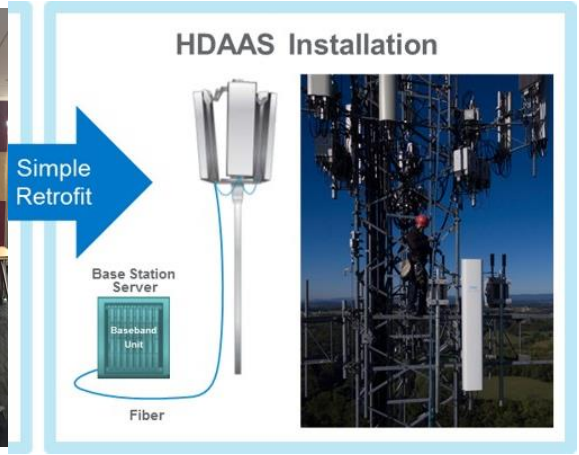
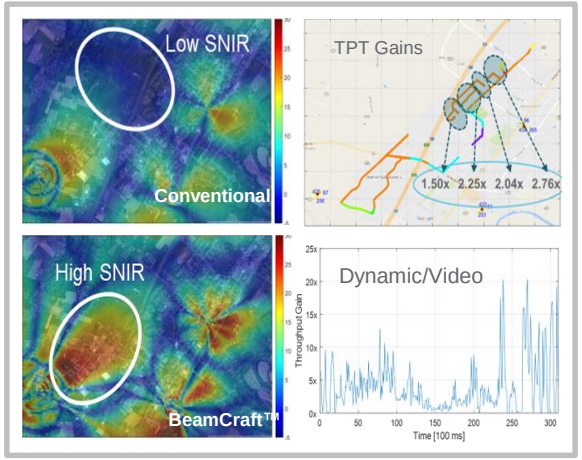
First HDAAS™ Product: BeamCraft™ 500

BeamCraft™ 500

96 elements
48 x 2 polarities
12 rows x 4 cols
63" X 14"





- Unique hybrid beamforming architecture where each digital port exploits full aperture of the array
- LTE-FDD, Band 4 (1700 MHz/2100 MHz) and Band 2 (1900 MHz), 2T2R, 2T4R, 4T4R, split sector
- Max output power =160W (no fans), flexible allocation to any of 1 to 4 beams
- Multiple network field trials showcase the ability to form beams, manage interference and improve capacity
- Software controlled and ready for beam based 5G NR

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Capacity Gain Comparison with 5G New Radio

Use Case: Enhanced Mobile Broadband (eMBB) Macro ISD: 1500

Factor	4G LTE 2x2 MIMO Baseline	5G NR Sub-6 GHz	5G NR > 24 GHz mmWave Fixed Wireless Access
Bandwidth	20 MHz 1x	100 MHz (CA, LAA) 5x	800 MHz 40x
Avg. Spectral Efficiency	1.2 bps/Hz 1x	5 bps/Hz, FD-MIMO * 4x	0.7 bps/Hz ** 0.6x
Densification with Small Cells (Typical)	4 small cells 3x	16 small cells 10x	16 small cells 16x
Area Throughput	72 Mbps 1x	5000 Mbps 69x	8960 Mbps 124x

- Densification is expensive
- Spectral Efficiency (SE) improvement is key to mmWave access
- Need Massive MIMO / multi-beam solutions

* A. Ghosh, "5G New Radio - Technology and Performance," NSF mmWave RCN Workshop https://mediasite.engr.wisc.edu/Mediasite/Play/8328401d68d543289a75a7003f8125941d, July 20, 2017
** F. W. Vook, E. Visotsky, T. A. Thomas and A. Ghosh, "Performance characteristics of 5G mmWave wireless-to-the-home," *2016 50th Asilomar Conference on Signals, Systems and Computers*, Pacific Grove, CA, 2016, pp. 1181-1185.

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mmWave Phased Array Engineering Challenges

S.No.	Challenge	Mitigation
1	PA power efficiency	PA with > 20% efficiency
2	Computational power for CFR and DPD at large bandwidth for each PA	Low power SoC design
3	Data converter power consumption	Low bit data converter designs
4	Heat dissipation	Thermal design and cooling
5	Ref./LO distribution and RF coherence	Novel architecture
6	Component, temperature, mechanical variations	Novel calibration methods and robust array architecture
7	Transition time between beam switching / tracking	Synchronous design to update weights across all elements
8	Conformance Testing and manufacturing	Special equipment, Anechoic chamber, test time $$$$

Blue Danube provides unique solution

More R&D required to solve multi-beam phased array design

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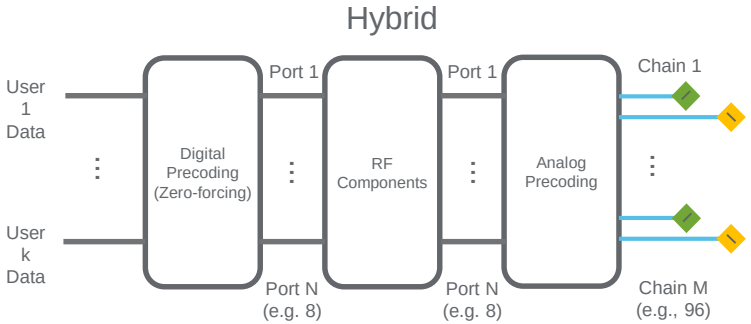
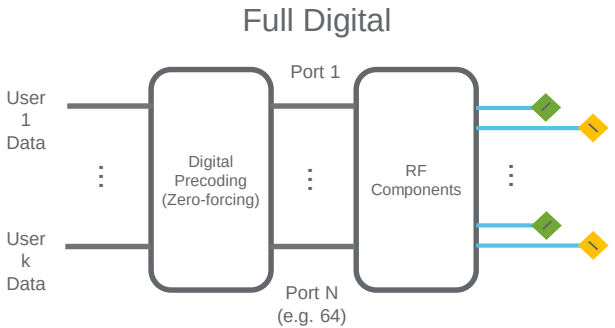
Capacity in Sub-6 GHz

- Massive MIMO and Carrier Aggregation
- Hybrid beamforming technology available today
- Full-digital (16-64 digital ports) prototypes in field trials
  - Cost still needs to be addressed
- Carrier aggregation already supported by mobile modems
- Small cells are available today but expensive backhaul
  - Potential application for mmWave phased array backhaul





Spectrum mining more beneficial at sub-6 GHz

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Thank You

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