Cambium Networks™

PMP Portfolio Update

Matt Mangriotis
Director of Product Management

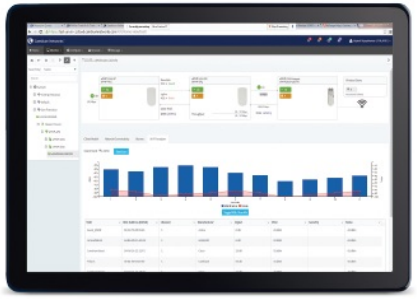
Affordable, Reliable Wireless Connectivity

World-class Wireless Networks

cnPilot™ R190W

E600

E501S



cnMaestro™

Wi-Fi

*e*PMP™ 2000

PMP 450m

PTP 700

Distribution Access & Backhaul

Cambium Networks – 2 meters to 245 kilometers

Cloud Management
cnMaestro
AutoPilot

Backhaul
Point-to-Point
PTP820, PTP670, PTP450/450i, ePTP
900 MHz, 2.4, 4.9, 5, 6-23 GHz

Access
Point-to-Multipoint
PMP450b/d/i/m, ePMP
900 MHz, 2.4, 3, 4.9, 5, GHz

WiFi
Residential/Small Office - R190/200/201
Enterprise - E400/410/600/500/501S
802.11n & 802.11ac

IIoT
Industrial Internet of Things
cnReach
450, 700, 900 MHz

On-Premise Management

PMP 450: Access Point Options

Evolution of Platform →

450 AP

450i AP

450m AP

PMP 450m

- **Leading-Edge Technical Innovation**
  - **More than 3x Capacity vs. 450/450i**
    - *cn*Medusa™ Massive MU-MIMO technology allows simultaneous communication with up to seven SMs
  - **Supreme Spectral Efficiency**
    - Achieve over 550 Mbps in a 20 MHz channel
  - **Protect Your Investment**
    - Continue using existing SMs
  - **Enhanced Link Stability**
    - Uplink Interference mitigation due to beamforming
    - Uplink Rx Sensitivity improvements
    - 10-12 dB better Uplink in total
  - **Advanced Processing Capability**
    - >200k PPS

- **One Simple device to install**
  - Simple Installation and Increased Reliability
  - Integrated 90° sector beam-forming array, **ZERO** RF cables to connect or weatherproof
  - A single Ethernet cable to connect
  - 20” x 25” x 4” (52x65x11 cm)
  - 40 lbs. (18.3 kg)

cnMedusa™

*cn*Medusa - Ground Breaking Innovation

- Truly Massive, going beyond standards of LTE
  - 14 x 14 Massive MU-MIMO

- Beamforming sector array antenna system
  - Integration with radio eliminates points of failure
  - Dramatically lowers product cost
  - Reduces installation costs and installation time

➢ Enables operation in high-noise environments, in narrower channels, to a higher density of customers

R15.1.3 Features

- Released January 19, 2018
- Great new 450m Features:
  - 450m now supports 5, 10, 15, 20, 30 and 40 MHz channels
    - Can demonstrate more than 1.2 Gbps per sector using 40 MHz channels
  - Support for PMP 430 SMs in 450m network
  - Support for 5ms frames for 5 to 20 MHz channels (on 450m)
  - Allows older legacy software to connect to 450m (prior to 14.2.1)
  - Stability and bug fixes also rolled into this release, very stable and well-tested release

R15.1.3 - cnMedusa 40 MHz Channel Bandwidth

15.1.3 – 40MHz Bandwidth Support

PMP/PTP 450/450i/450m THROUGHPUT CALCULATOR	
Mode	PMP
Channel Bandwidth (MHz)	40
Max Range (mi)	1
UL-MUMIMO	0
Mux gain (1 for 450/450i)	7.0
Downlink Data	85%
Contention slots	2
Frame Period (ms)	2.5
Throughput (Mbps)	
DL/UL symbols	148/26
Downlink	1264.4
Uplink	23.3
Total	1287.8

15.3.x – Uplink MU-MIMO

PMP/PTP 450/450i/450m THROUGHPUT CALCULATOR	
Mode	PMP
Channel Bandwidth (MHz)	40
Max Range (mi)	1
UL-MUMIMO	1
Mux gain (1 for 450/450i)	7.0
Downlink Data	85%
Contention slots	2
Frame Period (ms)	2.5
Throughput (Mbps)	
DL/UL symbols	148/26
Downlink	1264.4
Uplink	84.8
Total	1349.2

Current Results Status

Test Duration: 10 Pkt Length: 1714 Test Direction Downlink

Link Test with Multiple VCs

Subscriber Module	VC	Throughput	Efficiency	Fragments		Downlink Rate		Grouping Ratio
				Transmit	Received	SU-MIMO	MU-MIMO	
	Total VCs	**1264.54 Mbps**	**99%**	**24708887**	**24698236**			
SM 120 - [0a-00-3e-b1-50-03] - LUID: 002	18 (Low Priority)	60.52 Mbps	100%	1182120	1182120	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 101 - [0a-00-3e-b1-4e-45] - LUID: 003	19 (Low Priority)	60.52 Mbps	100%	1182102	1182102	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 106 - [0a-00-3e-b1-51-44] - LUID: 004	20 (Low Priority)	60.47 Mbps	99%	1182029	1181144	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 111 - [0a-00-3e-b1-4d-a0] - LUID: 005	21 (Low Priority)	60.52 Mbps	100%	1182120	1182120	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 112 - [0a-00-3e-b1-4e-b9] - LUID: 006	22 (Low Priority)	60.52 Mbps	99%	1183020	1182138	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 100 - [0a-00-3e-b1-51-73] - LUID: 007	23 (Low Priority)	60.52 Mbps	99%	1183020	1182138	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 114 - [0a-00-3e-b1-22-28] - LUID: 008	24 (Low Priority)	60.52 Mbps	99%	1182081	1182080	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 107 - [0a-00-3e-b1-50-95] - LUID: 009	25 (Low Priority)	60.50 Mbps	99%	1181769	1181768	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 119 - [0a-00-3e-b1-50-0d] - LUID: 010	26 (Low Priority)	60.52 Mbps	100%	1182102	1182102	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 110 - [0a-00-3e-b1-4e-b0] - LUID: 011	27 (Low Priority)	60.52 Mbps	100%	1182102	1182102	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 102 - [0a-00-3e-b1-4d-20] - LUID: 012	28 (Low Priority)	60.52 Mbps	100%	1182120	1182120	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 104 - [0a-00-3e-b1-51-6b] - LUID: 013	29 (Low Priority)	60.52 Mbps	100%	1182102	1182102	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 103 - [0a-00-3e-b1-4d-86] - LUID: 014	30 (Low Priority)	60.52 Mbps	99%	1183020	1182138	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 116 - [0a-00-3e-b1-4d-8a] - LUID: 015	31 (Low Priority)	54.43 Mbps	99%	1067705	1063262	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 105 - [0a-00-3e-b1-51-0f] - LUID: 016	32 (Low Priority)	60.52 Mbps	100%	1182120	1182120	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 118 - [0a-00-3e-b1-51-b5] - LUID: 017	33 (Low Priority)	60.52 Mbps	99%	1183020	1182138	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 108 - [0a-00-3e-b1-51-3c] - LUID: 018	34 (Low Priority)	60.52 Mbps	100%	1182120	1182120	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 109 - [0a-00-3e-b1-4e-44] - LUID: 019	35 (Low Priority)	60.52 Mbps	99%	1183020	1182138	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 115 - [0a-00-3e-b1-4f-e9] - LUID: 020	36 (Low Priority)	60.31 Mbps	99%	1178931	1178026	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 117 - [0a-00-3e-b1-4f-9d] - LUID: 021	37 (Low Priority)	60.42 Mbps	99%	1180162	1180156	8X/6X MIMO-B	8X/6X MIMO-B	100%
SM 113 - [0a-00-3e-b1-4d-0f] - LUID: 022	38 (Low Priority)	60.52 Mbps	100%	1182102	1182102	8X/6X MIMO-B	8X/6X MIMO-B	100%

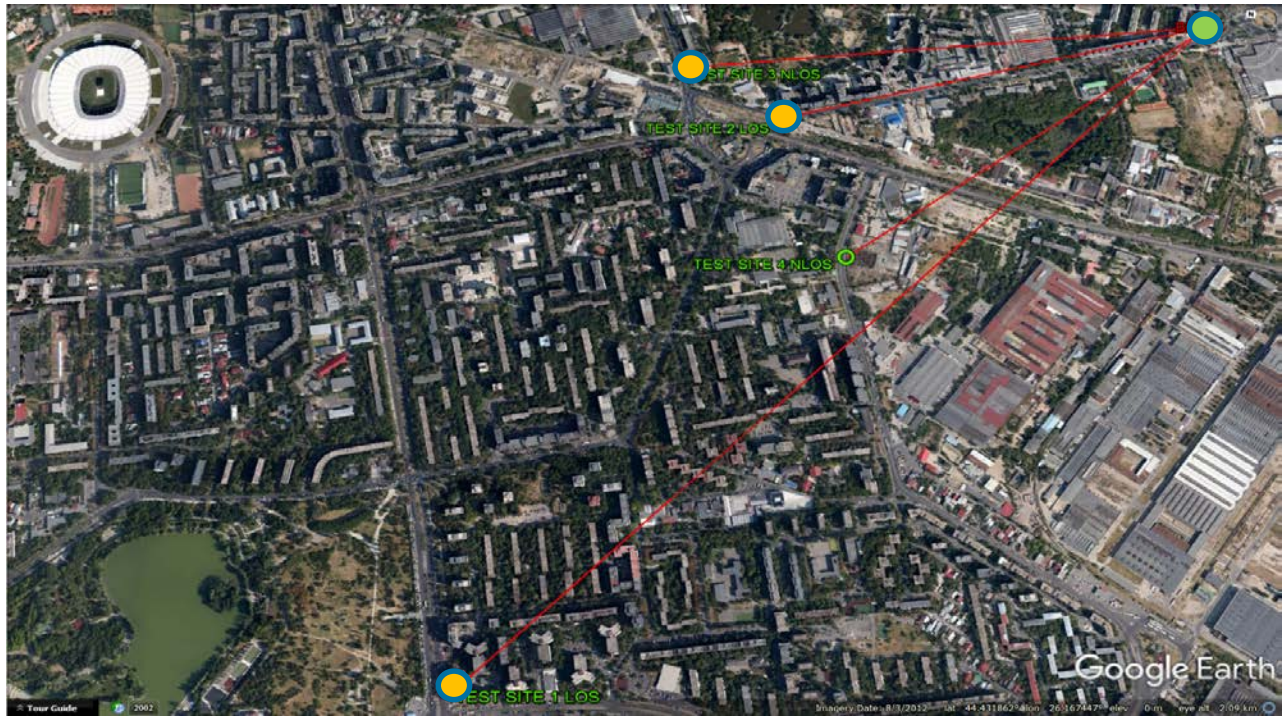
Slot Grouping

Group Size	% Distribution	Average Slot Count
1 (ungrouped)	0.0	0
2	0.0	0
3	0.0	0
4	0.0	0
5	0.0	0
6	0.0	0
7	100.0	147

How many Subscribers do I need to get an improvement

How many SMs do I need to make an improvement?

- 2x SMs which can form groups of 2
- Statically the larger the number of SM's, assuming they cover a large area (in angle from the AP), the larger the chance of 2 or more SM's grouping.



Current Results Status

Test Duration: 10 Pkt Length: 65522 Test Direction Downlink

Link Test with Multiple VCs

Subscriber Module	VC	Throughput	Efficiency	Fragments		Downlink Rate		Grouping Ratio
				Transmit	Received	SU-MIMO	MU-MIMO	
	Total VCs	**225.15 Mbps**	**99%**	**4437898**	**4397479**			
Test BI0281 - [0a-00-3e-bb-72-b4] - LUID: 003	19 (Low Priority)	94.86 Mbps	99%	1853120	1852894	8X/8X MIMO-B	8X/8X MIMO-B	100%
No Site Name - [0a-00-3e-bb-72-68] - LUID: 004	20 (Low Priority)	94.87 Mbps	100%	1853120	1853120	8X/8X MIMO-B	8X/8X MIMO-B	100%
No Site Name - [0a-00-3e-bb-72-5b] - LUID: 005	21 (Low Priority)	35.40 Mbps	94%	731658	691465	8X/2X MIMO-B	8X/4X MIMO-B	100%

2x LOS SMs

1x nLOS SM (trees + lots of high buildings)

*iperf traffic on external PCs validated results

Recent Success with 900 MHz

Cambium Networks™

A New Era for Public Safety in Rural Ohio

"It gets us into communities that need service. It's a good value for us – bang for the buck. Plus, we fulfill one of the goals of our company, and that is to give back to our communities via service to the fire houses."

-Dave Hanum, Owner, New Era

Overview

In the Appalachian reaches of rural Ohio, high performance Wi-Fi has only just arrived. Dial-up Internet access extended into limited areas, but many lacked even cell phone coverage. New Era Broadband of Pomeroy, OH decided to tackle the challenge of supplying reliable, high-speed Wi-Fi for the benefit of the hard-to-reach communities in need.

New Era was particularly concerned with connecting the area's fire houses. Local firefighters were struggling to prevent their certifications from lapsing due to lack of access to required online training programs. Loss of those certifications, inability to file emergency reports online, and even rely on communications infrastructure necessary for rapid response vital for public safety was too great a risk for these communities.

Challenges

New Era had to find a solution that would overcome the central obstacles of rugged terrain and very limited resources. They had to leverage any available infrastructure, such as partnering with the counties' emergency medical services to mount equipment on existing radio towers or get support to erect new ones.

Why New Era Chose Cambium Networks:

- From dial-up to High Speed for rural fire houses and surrounding homes, affordably.
- A 500-fold increase in bandwidth, from 40 kbps to 20 Mbps.
  Reliability and speed for vital response time in public safety.
- Supports essential applications: online training videos (streaming), regular internet usage, reporting software for the fire houses, VPN, and more.

CS NEW ERA 02222018

New Era Broadband

- Connecting Fire Houses in rural Ohio using PMP 450 900 MHz.
- Terrain makes it unsuitable for other technologies, and isolates from interference.
- Achieving results over 5x what any other product was able to deliver, and enhancing public safety communications.

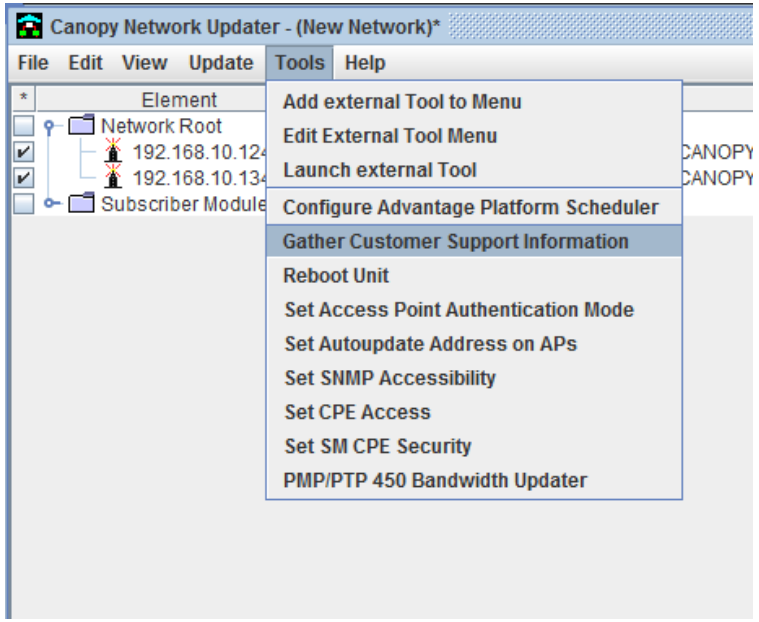
Health Check Services

- Purpose: Audit of the customer network
  - Detect misconfiguration
  - Review configuration for any optimization in:
    - Throughput,
    - Latency Reduction
    - Network Resiliency
- Focus:
  - System
  - Radio
  - Ethernet
  - Security

- Currently Supports:
  - PMP100/PMP430/PMP450
- Future Support:
  - ePMP

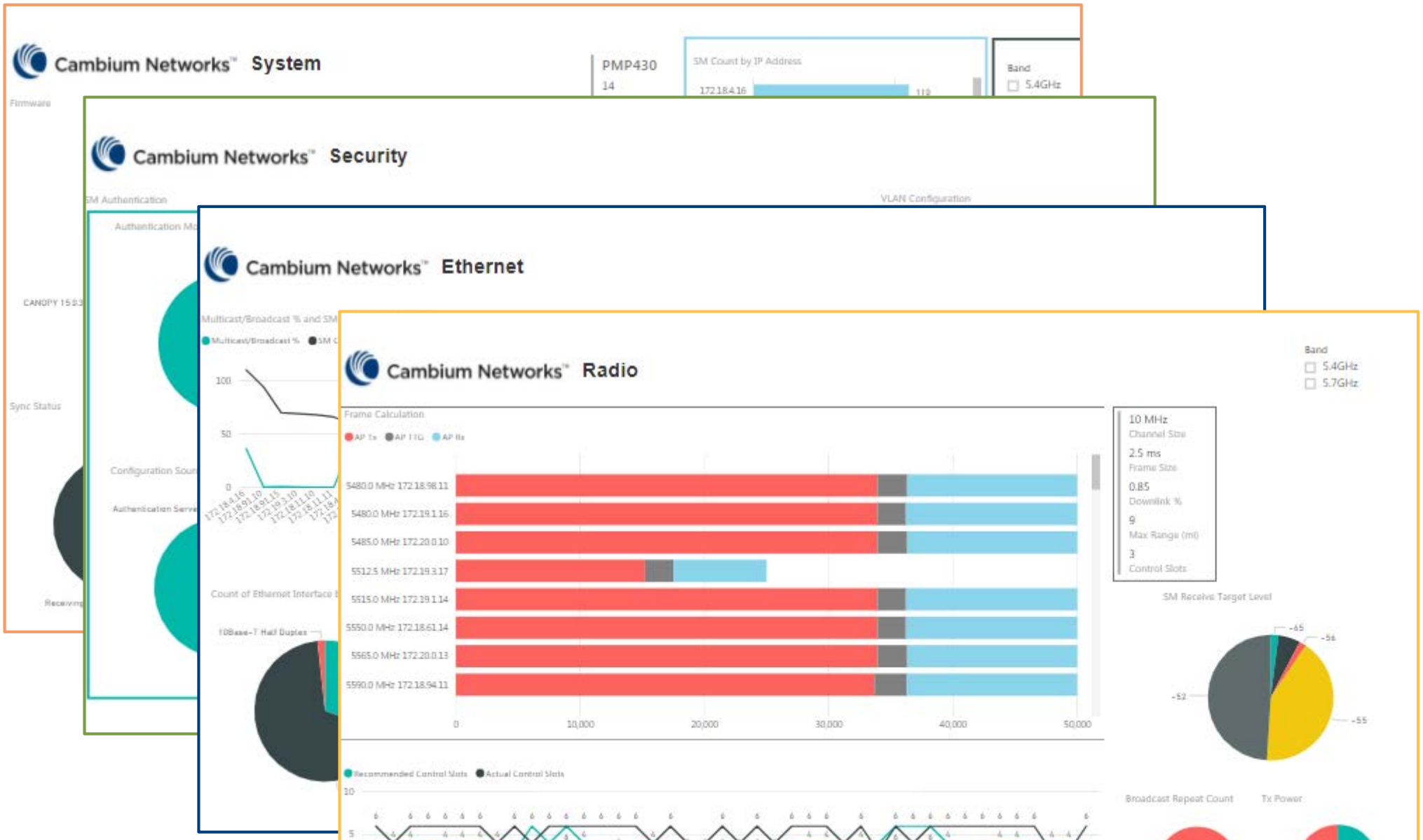
Data Collection

- For a Network Snapshot
  - CNUT Customer Support capture



- For Trending Feedback
  - cnMaestro support (*Q2 2018)

Interactive Report



What’s Next?

Cambium Networks™

Cambium 450 Roadmap 2018

March, 2018

2017	2018			
4Q	1Q	2Q	3Q	4Q

R15.1.3 - Jan
- cnArcher
- 30, 40 MHz Channels (450m)
- SFP – 2.5 Gbps BiDi (450m)
- Legacy s/w support (450m)
- 5ms Frame Length (450m)
- Support for 430 SM (450m)

R15.2 – Apr
- Weighted Fair Queuing
- SM Prioritization
- 4-Level QoS
- 256-bit AES
- Limit Max Modulation

R15.4 – Oct
- **3 GHz 450m**
- IPv6 Management (dual stack)
- UL MU-MIMO Phase 2 (450m)

R15.1.5 - Mar
- **450b (5 GHz) (High-gain)**
- Stability Fixes
  - VC / Idle Session Reuse
  - SM AP Scanning Missing Beacons
  - RADIUS registration
  - PPPoE Session Issues
  - 430 SM Registration

R15.3 – June
- Adaptive CIR
- Auto Contention Slots
- Layer 3 PVID Mapping
- DL Flood Test for 450/450i
- CBRS SAS Support (3 GHz FCC)*
- AUX Port (450m)
- UL MU-MIMO Phase 1 (450m)

Completed
Committed
In Planning
Candidate

*Pending Implementation of rules by FCC

PMP 450b

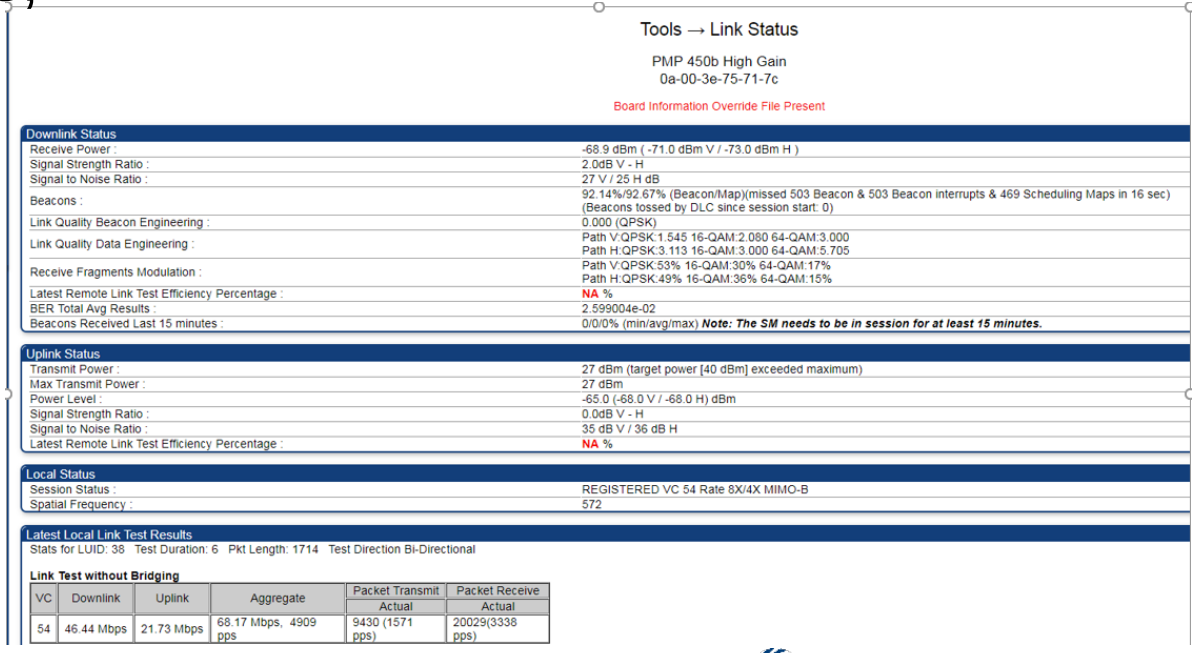
- **Two Form Factors:**
  - Integrated mid-gain antenna (17 dBi) similar to Force 180
  - High Gain integrated antenna (24dBi), similar to Force 200
- **New FPGA / SoC architecture**
  - Next-gen processor, **Enhanced Packet Processing**
  - Better support for wider channels → more throughput
  - **Wideband support (4.9 – 5.925 GHz)**
- **I/O changes**
  - Single **Gigabit** Ethernet port
  - Audio jack for alignment tone
- **Re-use of 30 VDC Power scheme**
  - Same power supply as current 450 SM
  - Polarity Agnostic – Can use “Canopy” or “UBNT” 30 VDC PSU
- **Prices (MSRP):**
  - $299 for mid-gain version
  - $349 for Integrated dish version (sold in 4-packs)

Available in Sept, 2017

Available in March, 2018

Beta Feedback

- We received feedback from several beta customers
- Updated and more detailed reports are expected.
- Great results reported, with performances as expected per specifications.
- Customers using it with 40 MHz channels,
  - 200+ Mbps of throughput @ 2-3 miles range.



Tools → Link Status

PMP 450b High Gain
0a-00-3e-75-71-7c

Board Information Override File Present

Downlink Status

Receive Power :	-68.9 dBm (-71.0 dBm V / -73.0 dBm H)
Signal Strength Ratio :	2.0dB V - H
Signal to Noise Ratio :	27 V / 25 H dB
Beacons :	92.14%/92.67% (Beacon/Map)(missed 503 Beacon & 503 Beacon interrupts & 469 Scheduling Maps in 16 sec) (Beacons tossed by DLC since session start: 0)
Link Quality Beacon Engineering :	0.000 (QPSK)
Link Quality Data Engineering :	Path V:QPSK:1.545 16-QAM:2.080 64-QAM:3.000 Path H:QPSK:3.113 16-QAM:3.000 64-QAM:5.705
Receive Fragments Modulation :	Path V:QPSK:53% 16-QAM:30% 64-QAM:17% Path H:QPSK:49% 16-QAM:36% 64-QAM:15%
Latest Remote Link Test Efficiency Percentage :	NA %
BER Total Avg Results :	2.599004e-02
Beacons Received Last 15 minutes :	0/0/0% (min/avg/max) ***Note: The SM needs to be in session for at least 15 minutes.***

Uplink Status

Transmit Power :	27 dBm (target power [40 dBm] exceeded maximum)
Max Transmit Power :	27 dBm
Power Level :	-65.0 (-68.0 V / -68.0 H) dBm
Signal Strength Ratio :	0.0dB V - H
Signal to Noise Ratio :	35 dB V / 36 dB H
Latest Remote Link Test Efficiency Percentage :	NA %

Local Status

Session Status :	REGISTERED VC 54 Rate 8X/4X MIMO-B
Spatial Frequency :	572

Latest Local Link Test Results

Stats for LUID: 38 Test Duration: 6 Pkt Length: 1714 Test Direction Bi-Directional

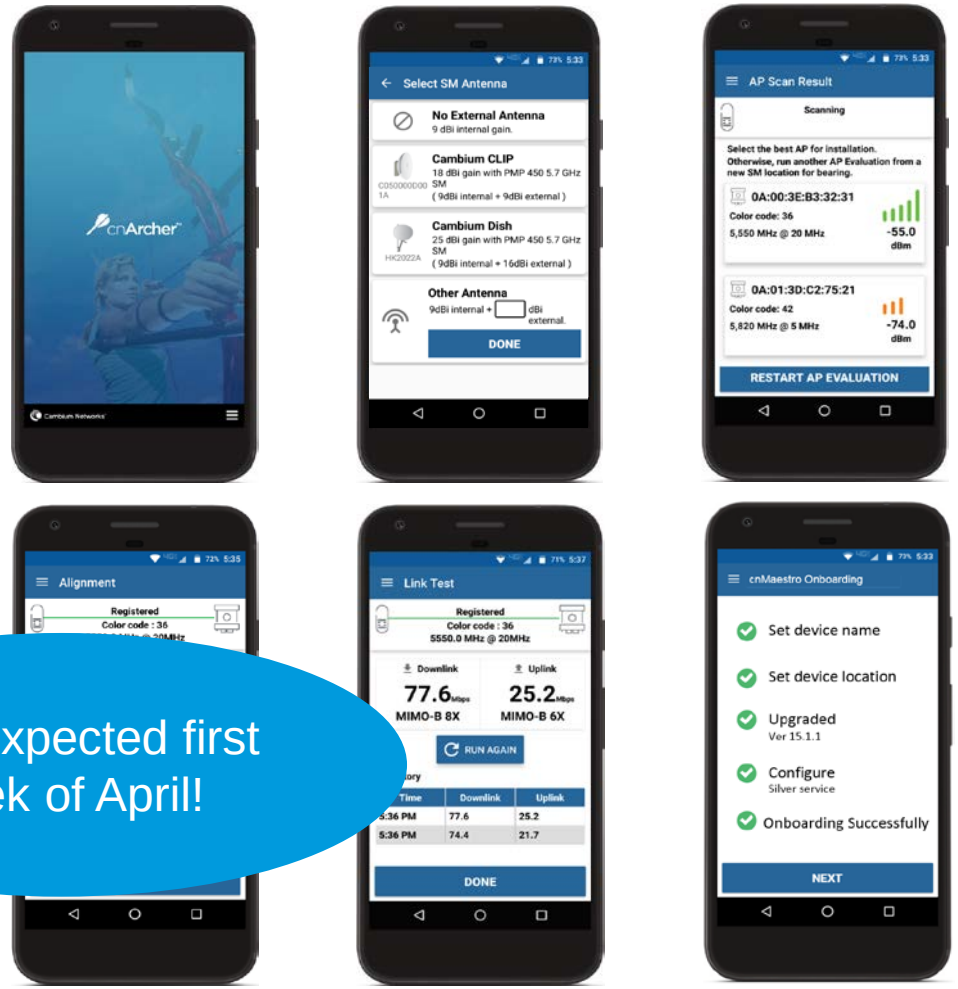
Link Test without Bridging

VC	Downlink	Uplink	Aggregate	Packet Transmit Actual	Packet Receive Actual
54	46.44 Mbps	21.73 Mbps	68.17 Mbps, 4909 pps	9430 (1571 pps)	20029(3338 pps)

cnArcher

Released Dec. 2017

- Mobile Device App for SM Installers
- Simplifies SM installation Process
  - No bulky Laptop Required during Installs
  - Repeatable & Reliable SM Install Process
- Offers full DEMO mode! (No SM Needed)
- Requires Android 6.X or Greater
- Release v1.0.2 Supports Canopy PMP SMs
- Next Major Release by Q2/2018
  - ePMP SM support
  - iOS version
- Work Order with QR Code coming soon!



Beta expected first week of April!

Download and Install cnArcher from "Google Play" Now!

cnArcher – About the Application

Why should I Use it?

- ✓ Eliminates need for warehouse pre-configuration
- ✓ Eliminates need for bulky laptop during Install
- ✓ Eliminates need for local power supply
  - When used with a battery dongle
- ✓ Minimizes UI screens Installers must learn
- ✓ Eliminates need for phone call to Network Operations Center
  - Can locally set SLA (e.g. Gold, Silver, Bronze) configuration

cnArcher – About the Application

What does it do?

- Upgrades SM Software
  - SM upgraded directly from mobile device to desired version
- Pre-Configure SMs
  - Reduces channel scan list to speed up AP evaluations
- Simplifies AP Evaluation
  - Provides graphical results
  - Click to select AP and configure SM’s color code
- SM Alignment
  - Graphical alignment screen
  - Help optimize for best signal strength
  - Monitor dual receive chain signal imbalance
- Validates Installation
  - Run link test
  - View throughputs & modulations
- Automatically Configures SM Location
  - Mobile device's latitude/longitude configured on every SM
- Configures SM to Enable User Traffic
  - Device name
  - IP address (DHCP/static)
  - Management VLAN
  - Data VLAN

Connectivity Between cnArcher and SM

- A portable WiFi AP (in bridge mode) is required for cnArcher to communicate to the SM's LAN interface
- Cambium has tested with LinkTechs / Geva
  - 15W - Passive PoE 24V -15W Battery WiFi AP
  - Provides additional benefit of powering SM (Battery PoE) and validating installation prior to running cables
  - http://www.linktechs.net (Department → PowerLink)
  - http://www.gevaelettronica.it

R15.2 Features

- Beta Released March 15, 2018
- Many new features:
  - –Weighted Fair Queuing
    - Alternative sharing of prioritized bandwidth (as opposed to strict priority queueing)
  - –SM Prioritization
    - Ability to allow specific SM in given sector to be served ahead of others (at same priority level)
  - –4-Level QoS
    - Additional granularity in traffic service flows (i.e. voice, video, general data, multicast traffic)
  - –256-bit AES
    - Higher level of over-the-air encryption
  - –Limit Max Modulation
    - Can allow for additional stability, if operator chooses

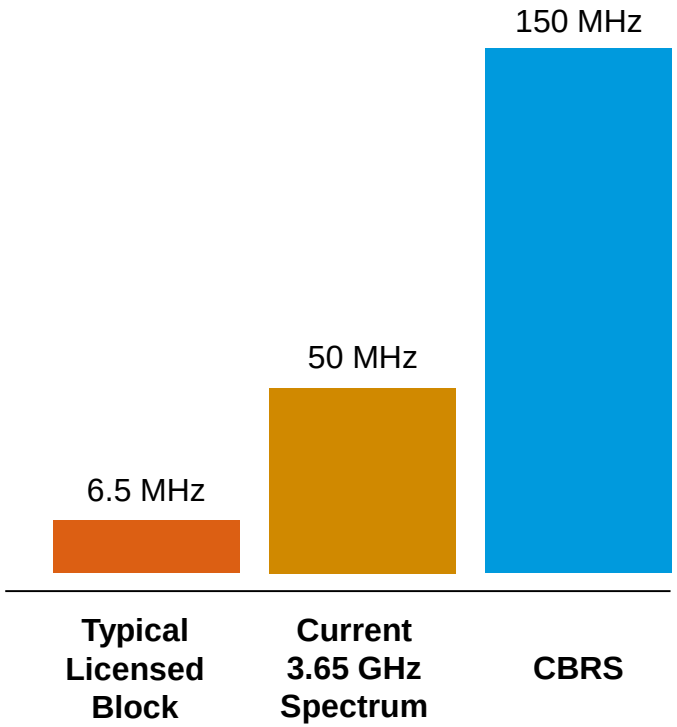
Cambium Networks™

3 GHz 450m

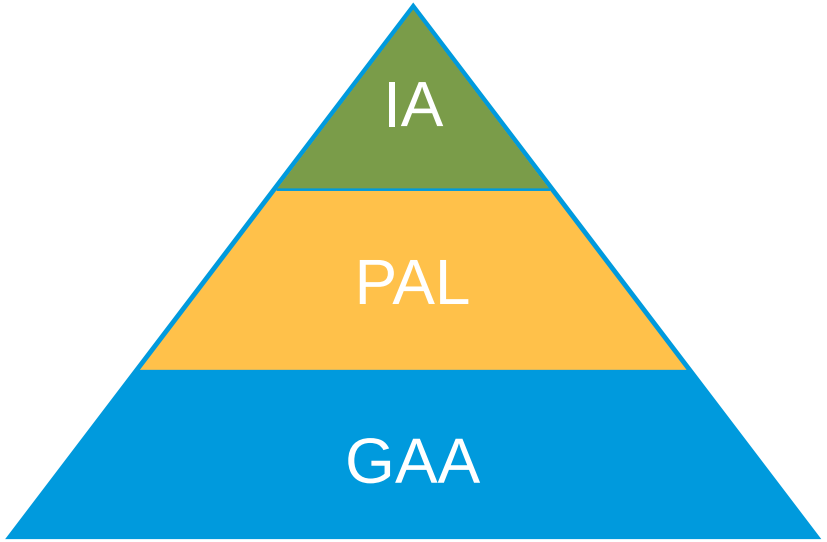
Matt Mangriotis
Director of Product Management

CBRS and New 3 GHz Spectrum

Opportunity



Tiered Flexible Use



Incumbents

- DoD Radars (coastal areas)
- Satellite Earth Stations

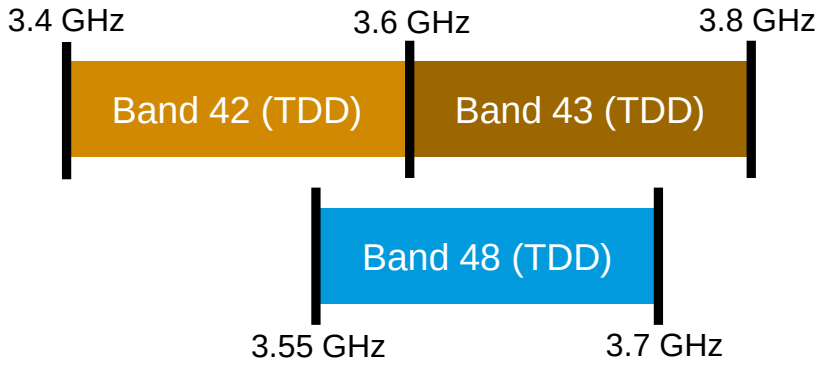
Priority Access Licenses (PAL)

- Up to 70 MHz of spectrum licensed by auction

General Authorized Access (GAA)

- At least 80 MHz nationwide

Establishing a New Common Band



CBRS and New 3 GHz Spectrum

- Ensure 450 platform readiness by working with several SAS providers

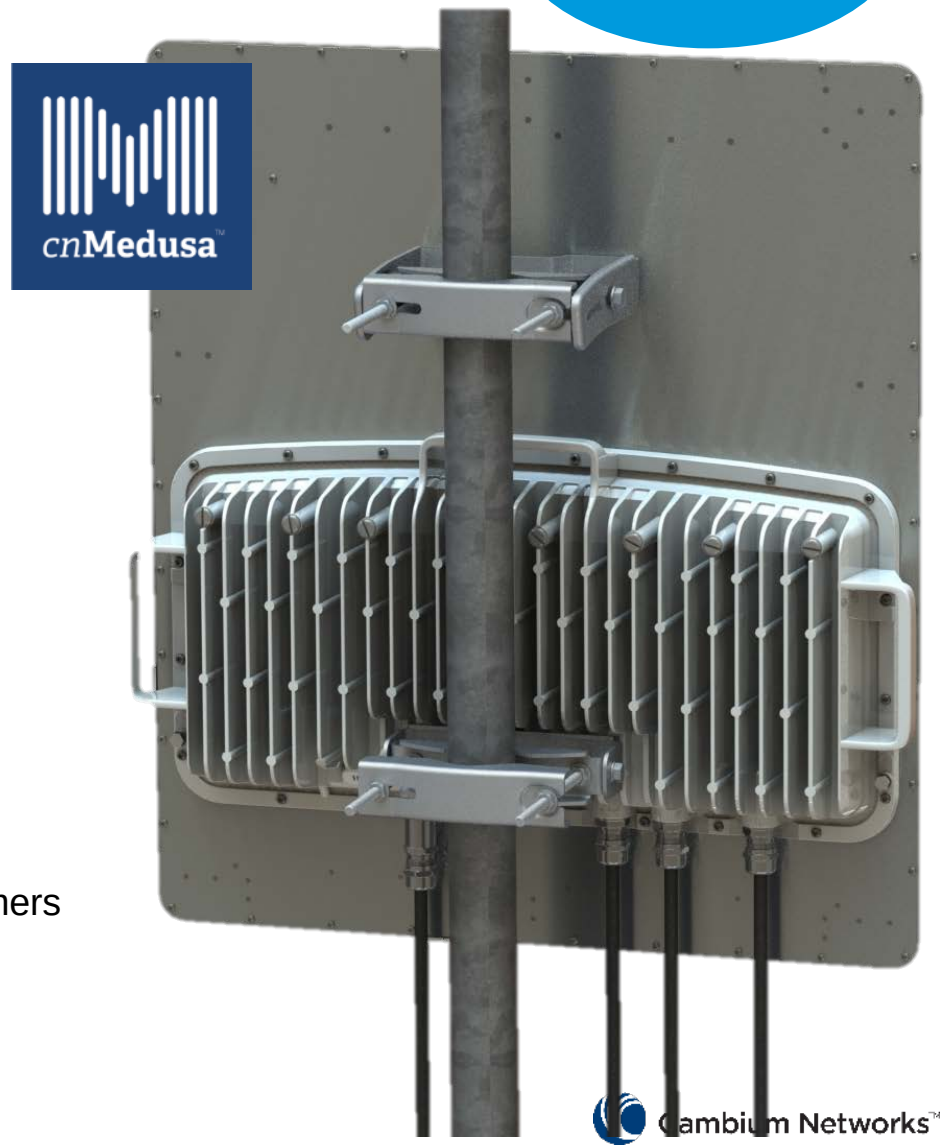
- Hardware support for the frequency with all models
- cnMaestro will bridge the communication from Radio to SAS
  - See the demo at the booth

- Increased spectral availability can be taken advantage of by…

3 GHz - PMP 450m

Q3 2018

- **Leading-Edge Technical Innovation**
  - **8x8 MU-MIMO**
  - **47 dbm (50 dbm design goal)**
  - **2-3XCapacity vs. 450/450i**
    - cnMedusa Massive Multi-User MIMO
  - **Supreme Spectral Efficiency**
    - Achieve >750 Mbps in a 40 MHz channel
  - **Enhanced Link Stability**
    - Uplink Interference mitigation due to beamforming
    - Uplink Rx Sensitivity improvements (5-6 dB better)
  - **Advanced Processing Capability**
    - >100k PPS
  - **One Simple device to install**
    - Integrated 90° sector beam-forming array
    - ZERO RF cables to connect or weatherproof
    - ≈ 611 x 692 x 175 mm
    - ≈ 18kg
- **Investment Protection**
  - Provides capacity and spectral efficiency increases for existing 450 customers
  - Extend the useful life of existing networks and support SM density growth`



3 GHz PMP 450 vs. LTE Whitepaper


Cambium Networks

A COMPARISON

PMP 450 and LTE in 3 GHz

INTRODUCTION

The LTE (Long Term Evolution) standard provides for great performance and has (at some point on the roadmap) many features that make it well-suited for any use case. The 3rd Generation Partnership Project (3GPP) originally came together as an industry group to create mobile standards that would move mobile (cellular) infrastructure forward. This group has continued to evolve the standard, and is backed by the largest telecommunications groups in the world. The LTE standard has been developed by this group and has had billions of hours and dollars poured into it to create the standard protocol for mobile telecommunications. As it stands, the release definitions are frozen through Release 13, with Release 14 soon to come. Chipset manufacturers are doing their best to keep up with the release schedule, and incorporating features defined in these releases in their latest offerings.

However, just because a product utilizes the LTE standard does not inherently mean it has any of these features, or the optimal level of performance. The system implementation; that is, the application of chipset to functional system, makes all the difference. As is nearly always the case, there are tradeoffs to be made between system cost and performance. Striking the proper balance for the targeted market segment is key to creating a product that will be successfully implemented.

CUSTOMER EXPERIENCE

Globally, the 3 GHz band has been a licensed frequency band that was defined for the WiMAX standard. It is not typically available to Service Providers without having purchased or leased this frequency. However, some efforts have been made to make it more readily available in certain parts of the world. Specifically, in the United States and Canada, 50 MHz of this spectrum (3650-3700 MHz) had been available under a "lightly licensed" condition. An operator needed to obtain a nationwide, non-exclusive license at very low cost from the regulatory body, then register any equipment that would be operating in that band. This propelled the use of this band forward tremendously over the last several years.

Cambium Networks introduced the 450 platform operating in the 3 GHz band in 2014. Since then, it has been deployed in hundreds of networks globally. This represents a substantial number of operators that are helping to bridge the digital divide, and connect rural customers. Upcoming changes to this band in the United States (via the Citizens Band Radio Service (CBRS) initiative) will allow additional frequency

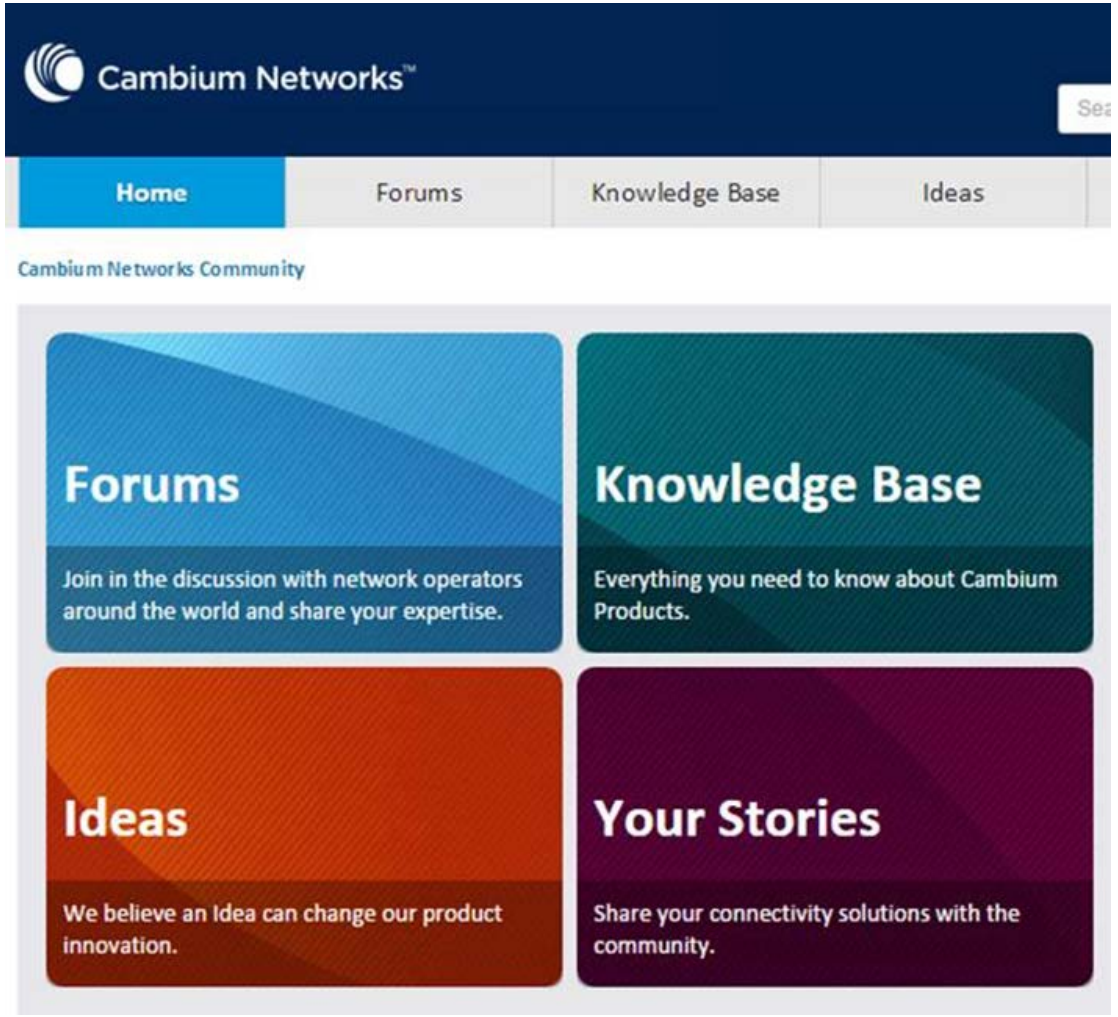
Paper available at:
https://www.cambiumnetworks.com/resource/comparison-pmp-450-lte-3-ghz/

In many ways, 450 outperforms any existing LTE solution

BEST ● ◓ ○ ◒ ● WORST	EXISTING LTE SOLUTIONS	CAMBIUM PMP
Customer Experience	◒	●
Range and Coverage	●	○
Interference Mitigation	○	●
Total Sector Capacity	○	●
Subscriber Bandwidth	◒	●
Infrastructure Costs	●	●
Mobility Support	●	●
Total Cost of Ownership	●	●

Cambium Community

- Learn from network operators around the world
- Community Forum
  - Products
  - Network Planning
  - Languages
  - Business Issues
- Knowledge Base with technical detail documents
- Submit development ideas
- Real world connectivity stories



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