Cambium Networks 450 Platform

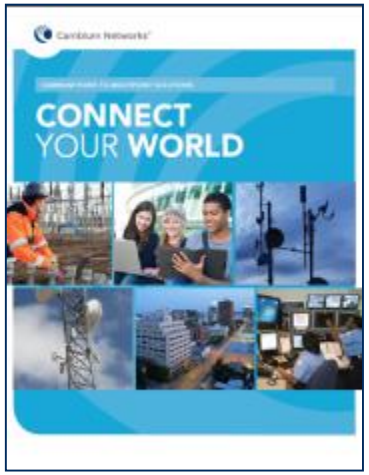
January 2016

Cambium Networks™

Cambium Portfolio

cnMaestro

Product	WLAN	ePMP	450	650	820
Design Focus	Configurable, Cloud Managed, High Performance	Budget Constrained Residential	Unparalleled Scalability for Multipoint networks	Industry Leading Sub-6GHz Performance	Microwave Backhaul
Throughput	250 Mbps / AP	100 Mbps / sector	125 Mbps / sector	450 Mbps	1+ Gbps
Spectrum (GHz)	2.4, 5 GHz	2.4, 5 GHz	900 MHz, 2.4, 3.5, 3.65, 5 GHz	4.9 – 6.0 GHz	6 – 38 GHz



- Extreme Capacity, Unparalleled Scalability
- Low-Cost, Low-Complexity, Low-Maintenance Infrastructure
- Scalable from small to region wide deployments
- Consistent throughput and low latency
- Rapid Deployment
- Supports Video, Data, Voice and Control Applications
- NLOS, nLOS and LOS performance

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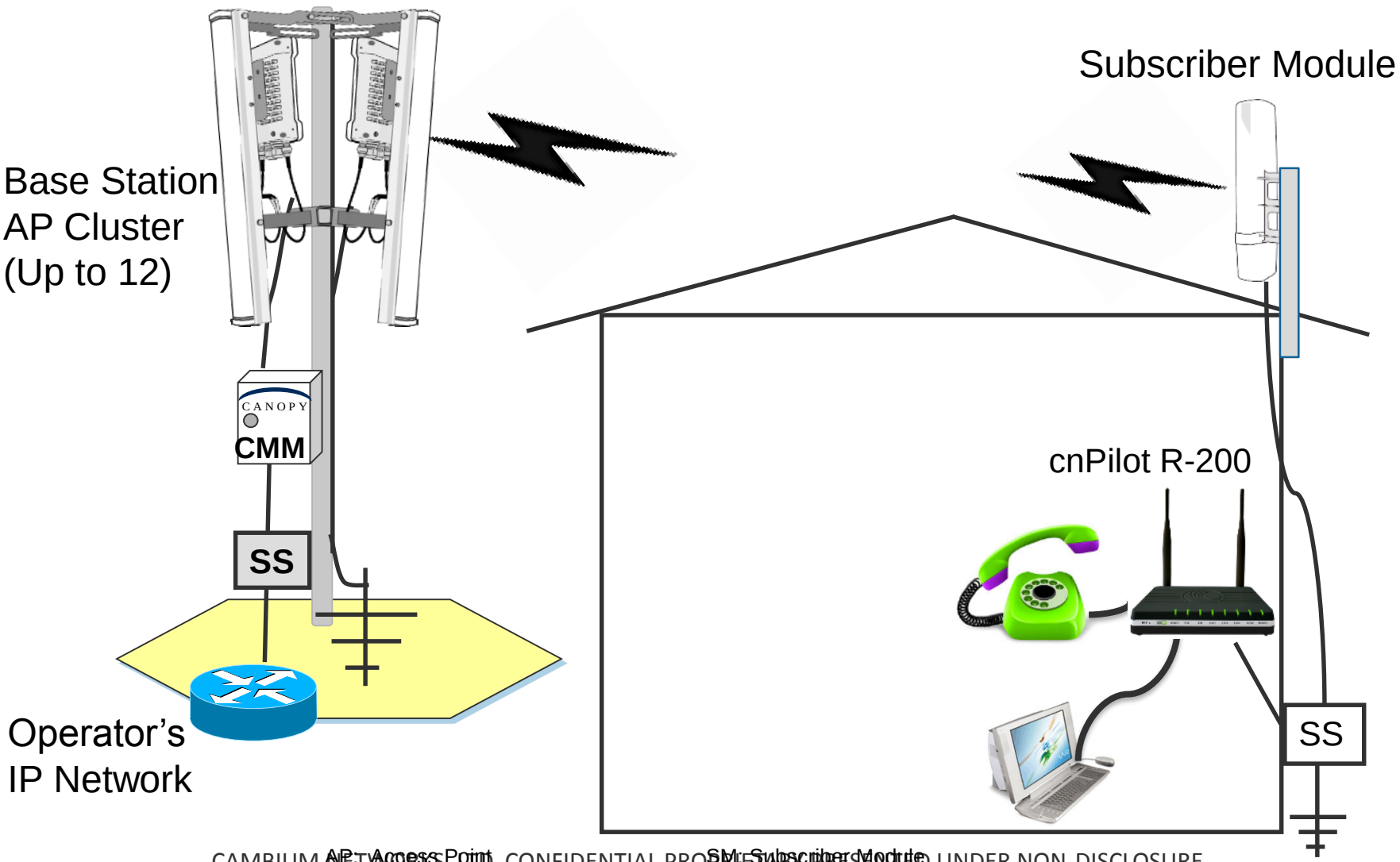
Cambium 450

- 4th Generation (4G) of PMP product family from Cambium
- Dramatically increases overall ***system capacity***
  - ***Over 125 Mbps per Access Point***
  - ***Over 1.5 Gbps of tower bandwidth possible***
  - ***Can support any symmetrical or asymmetrical speed***
- OFDM MIMO provides near Line-of-Sight (nLOS) and LOS
- ***Software defined radio design*** allows for rapid expansion of frequency bands, both licensed and unlicensed
- Utilizes ***GPS synching capability*** to maximize spectral efficiency and very low latency ***supporting VoIP and video***
- Installation and turn up in days, not weeks or months

Overview: PMP 450 Series Architecture

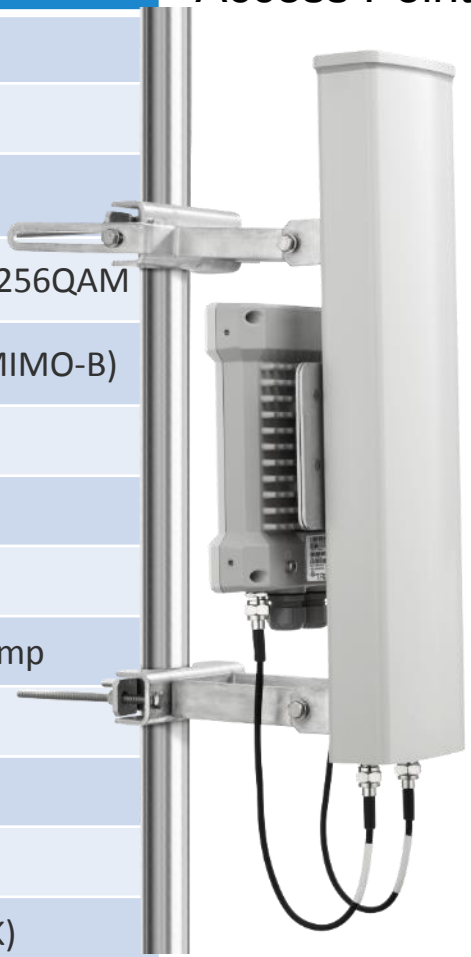


AP: Access Point
SS:– Surge Suppressor
CMM: Cluster Management Module
SM: Subscriber Module
IP: Internet Protocol
C3VoIP – Cambium ATA Router

450 Platform Specifications

Category	Specification
Frequency Bands	900 MHz, 2.4, 3.5, 3.65, 5 GHz
Max Throughput	125 Mbps in 20 MHz channel
Max SM per sector	238
Modulation Modes	2x2 MIMO: QPSK, 16QAM, 64QAM, 256QAM
MIMO Modes	Diversity (MIMO-A), Dual Payload (MIMO-B)
Latency	3-5 ms
Max TX Power	+25 dBm
Channel Bandwidth	5, 7, 10, 20 MHz
Environmental	IP67/66, -40° to +60° C Operating Temp
Power Consumption	10-15 W typical , 15-19 W peak
AP Antenna	17 dBi – (90° sector)
AP Dimensions	11” x 8”
SM Dimensions	8” x 3” (similar in size to Canopy FSK)

Access Point



Subscriber Module

PMP 450: Access Point Dimensions

http://www.cambiumnetworks.com/products/pmp/pmp-450

PMP 450: Subscriber Module Options

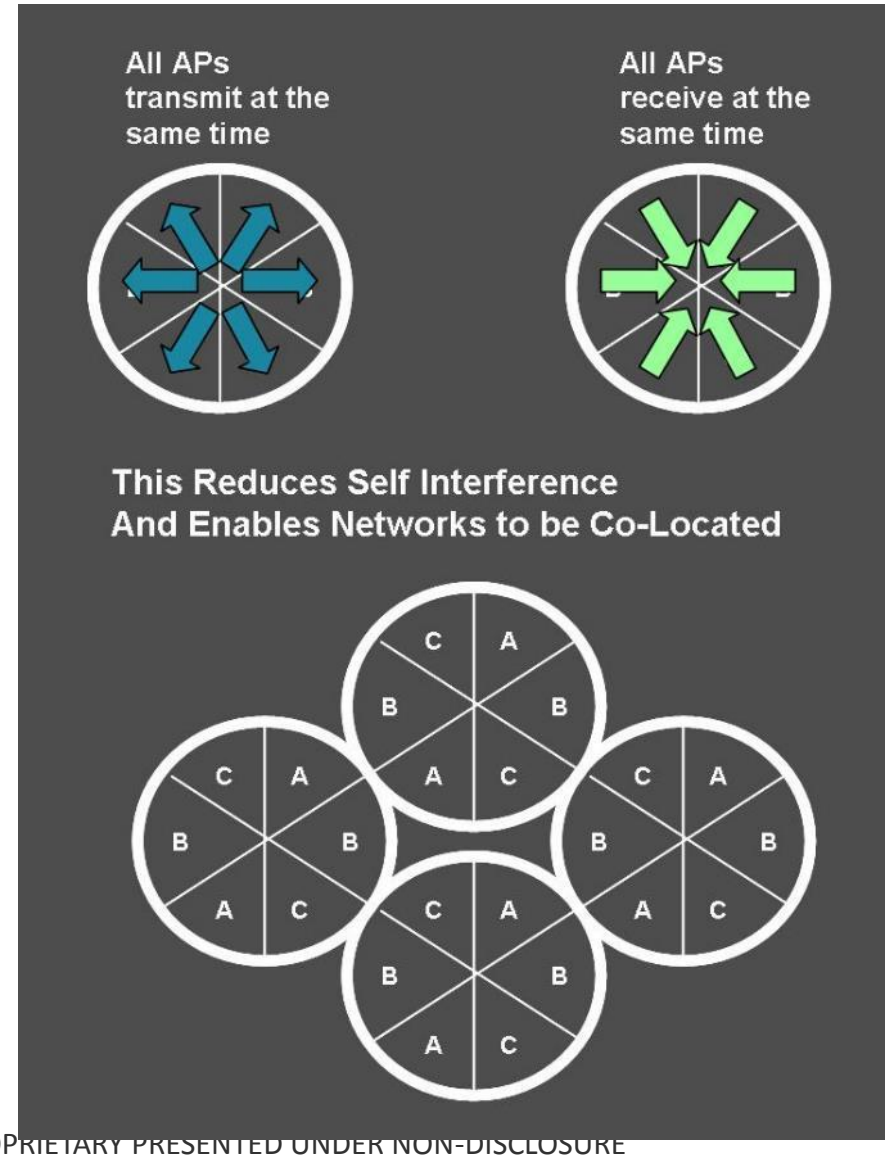
Antenna Options

Integrated Antenna	CLIP (5 GHz only)	Reflector Dish	Connectorized SM
			

PMP 450d	450i Connectorized	450i Integrated High Gain
		

GPS Synchronization

- AP and SM communication is synchronized (all APs and SMs have controlled alternating communication) – reducing self interference
  - All SMs within a network
  - All APs within a cluster
  - All APs on a tower (multiple clusters)
  - All APs on all towers in the network
- Enables channel re-use and easy to deploy multi-sector, multi tower networks (minimal tower separation)
- Use the same number of channels to serve a higher number of users



PMP 450 Advantages

Characteristic	Cambium PMP	Implications
Channel Access	Scheduled TDD – Deterministic and Scalable regardless of load	Without scheduled TDD, users will complain about availability as subscribers are added.
Latency and QoS	Consistent and Deterministic – critical for voice and video and T1 replacements	Without consistent latency, network users will complain about delays and poor performance.
GPS Synchronization	Supported -> Efficient Channel Re-use / Easy Deployment. in Multi-Sector / Multi-Site systems	Unsynchronized systems perform inconsistently and poorly as subscribers are added. Use more channels to serve the same # of users
Throughput and System Capacity (bits/sec/Hz/sq km)	High ability for frequency reuse. Higher aggregate real user throughput and system capacity for given channel width and available spectrum.	Competitive systems require more AP towers to be added to meet demand – but this adds interference.

Select a solution that meets today's needs and supports growth

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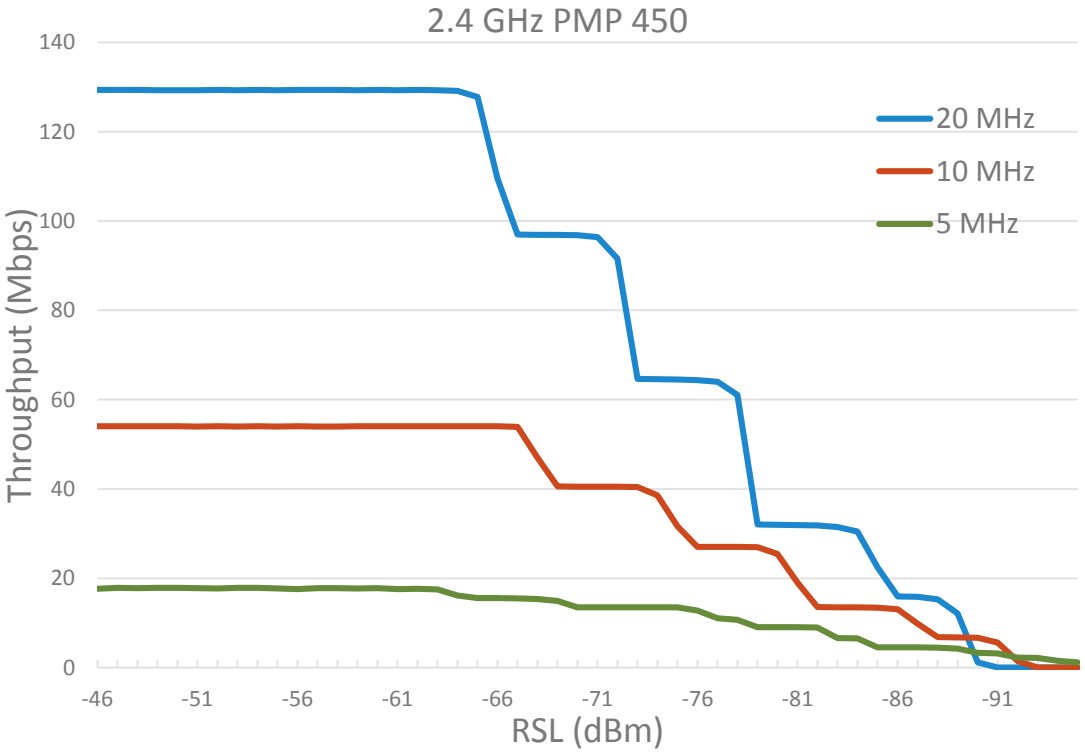
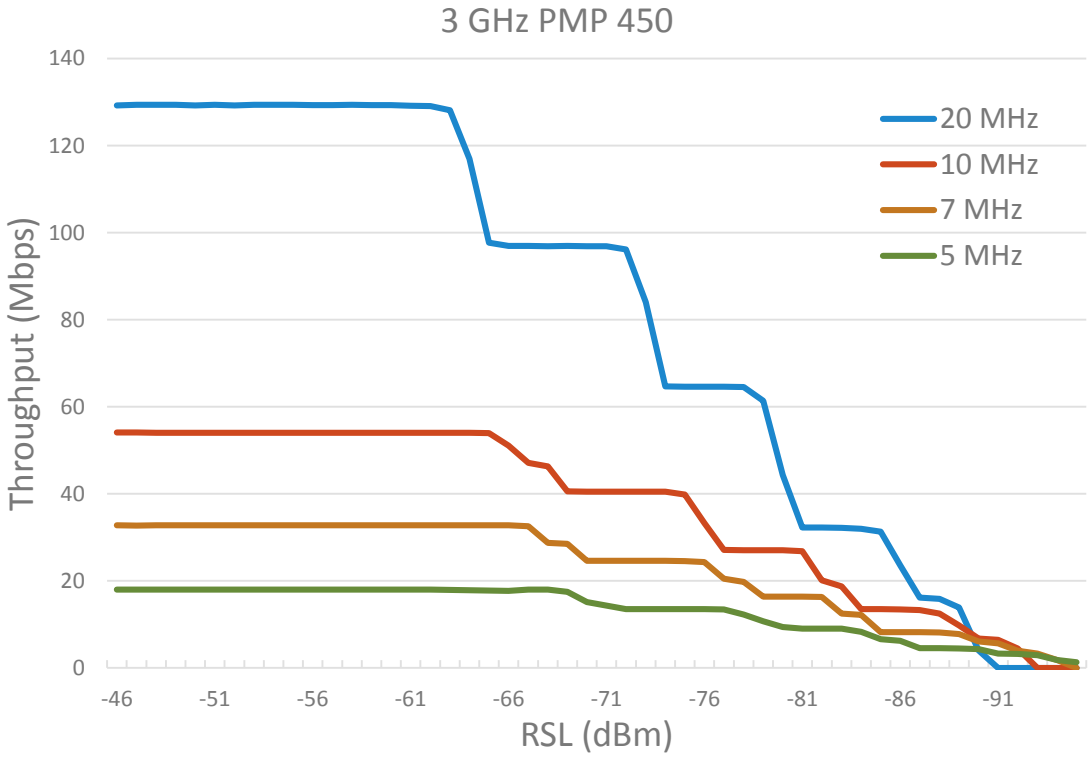
PMP 450 @ 2.4 GHZ
Throughput and Range Performance



Modulation Mode	Sensitivity (dBm)	T-put (Mbps)	CNR (dB)
256QAM (8x)	-66	125	32
64QAM (6X)	-73	90	24
16QAM (4X)	-79	60	17
QPSK (2X)	-86	30	10
QPSK (1X)	-86	15	8

20 MHz Channel -- Maximum LOS range mi (km)			
Frequency Band	Modulation	Integrated (7 dBi)	Offset Reflector (19 dBi)
2.4 GHz	256QAM (8X)	1.7 (2.8)	6.8 (11)
	64QAM (6X)	3.6 (5.8)	14.3 (23)
	16QAM (4X)	7.6 (12)	30 (49)
	QPSK (2X)	16 (25)	40 (64)
	QPSK (1X)	22 (36)	40 (64)

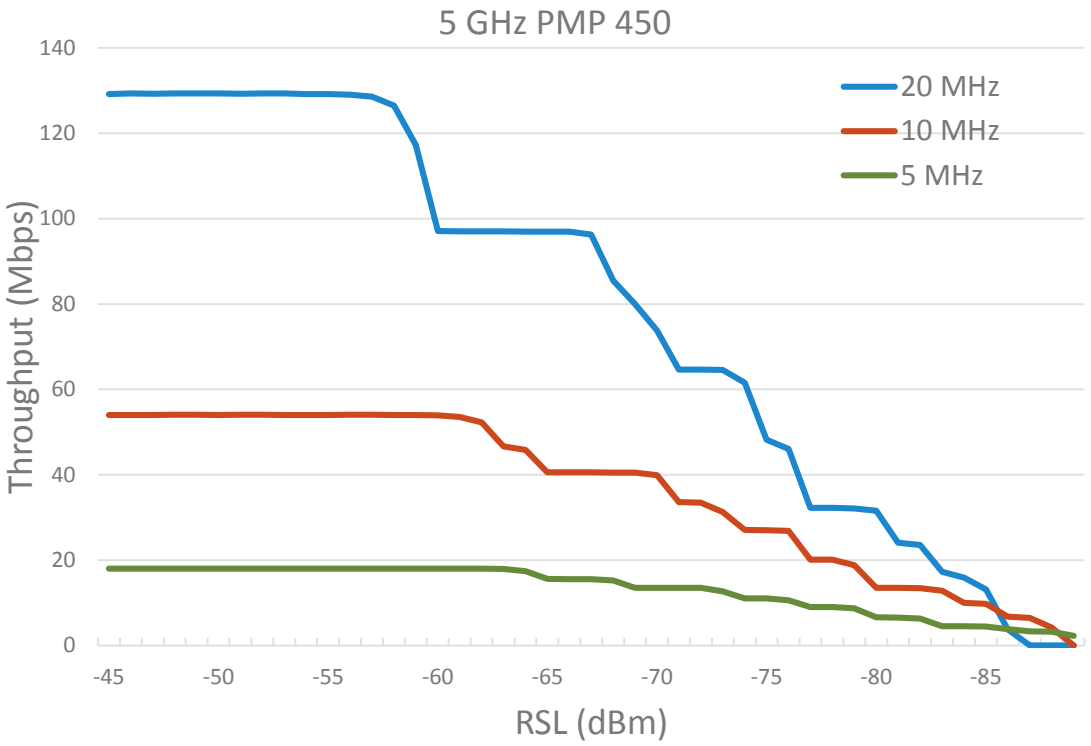
PMP 450 @ 3 GHZ
Throughput and Range Performance



Modulation Mode	Sensitivity (dBm)	T-put (Mbps)	CNR (dB)
256QAM (8x)	-65	125	32
64QAM (6X)	-72	90	24
16QAM (4X)	-78	60	17
QPSK (2X)	-85	30	10
QPSK (1X)	-85	15	8

20 MHz Channel -- Maximum LOS range mi (km)			
Frequency Band	Modulation	Integrated (8 dBi)	Offset Reflector (19 dBi)
3 GHz	256QAM (8X)	0.8 (1.3)	3 (4.6)
	64QAM (6X)	2 (3.3)	7.2 (11.6)
	16QAM (4X)	4.5 (7.3)	16 (26)
	QPSK (2X)	11 (18)	40 (64)
	QPSK (1X)	16 (26)	40 (64)

PMP 450 @ 5 GHZ
Throughput and Range Performance



Modulation Mode	Sensitivity (dBm)	T-put (Mbps)	CNR (dB)
256QAM (8x)	-61	125	32
64QAM (6X)	-72	90	24
16QAM (4X)	-78	60	17
QPSK (2X)	-84	30	10
QPSK (1X)	-84	15	8

20 MHz Channel -- Maximum LOS range mi (km)					
Frequency Band	Modulation	Integrated (9dBi)	CLIP (17dBi)	Offset Reflector (24dBi)	PMP 450d (25dBi)
5.8 GHz	256QAM (8X)	0.3 (0.6)	1 (1.6)	2 (3.1)	2.2 (3.5)
	64QAM (6X)	1.1 (1.8)	3.2 (5)	6.3 (10.2)	7 (11.3)
	16QAM (4X)	2.3 (3.6)	6.3 (10.2)	12.6 (20)	14 (23)
	QPSK (2X)	5 (8)	14 (22.5)	28 (45)	31 (50)
	QPSK (1X)	7 (11.3)	20 (32)	40 (64)	40 (64)

Continual Performance Evolution

More Frequency Bands	2.4 GHz 3.5 GHz 3.65 GHz 4.9-5.9 GHz 900 MHz	Spectrum Agile Architecture
256 QAM, MIMO-A modulations	90 => 125 Mbps Throughput	Enhanced Area-Averaged Capacity, Better link stability
Processing Improvements	Higher PPS	Higher Capacity Enterprise Links Higher Capacity For VoIP-Intensive Applications
Larger MTU Size	1700 Byte MTU	MPLS Tag-Friendly
Feature Rich QoS	Strict Priority Support / Flexible QoS methods and bandwidth mgmt	Controllable, Predictable Performance

Cambium 450 Roadmap

Nov, 2015

2015			2016
2Q	3Q	4Q	1Q

- Completed
- Committed
- In Planning
- Candidate

R14.0 – Aug, 2015
- **PMP 450d – High Gain integrated Parabolic dish**
- **PMP 450i – Wide Band**
- High Gain, Rugged Integrated SM
- SoC Architecture, PPS >35k
- Ifetel/Anatel Launch
- 4.9 & 5.8 GHz for FCC/IC/ETSI

R14.1.1
- **PMP 450i - 900 MHz**
- **High Gain Integrated SM (3 GHz)**

R14.2 - Feb
- 15, 30 MHz Channel support
- 2nd Ethernet port (PMP 450i)

R13.4 – June, 2015
- Frame Utilization Statistics
- Security Banner
- RADIUS VSA for Zero Touch Configuration
- RADIUS CoA Support
- MS-RADIUS Support

R14.1
- PMP 450i Interoperable with 450
- 5.4 and 5.8 ETSI
- 5.1 for FCC
- 5.4 and 5.8 IC
- Cisco ACS Support

R14.1.2 – Open Beta
- 5.2/5.4 for FCC

PMP 450 Release 13.2.1 Highlights

- Packet Processing Improvements
- MIMO-A modulations
- Rate Adapt Algorithm Enhancements
- VLAN priority bit configurable
- VLAN Re-marking
- Forced BER
- IPv6 Filtering and Prioritization
- GLONASS support

Now Available

PMP 450 Release 13.3 Highlights

Now Available

- **5 ms frame length**
  - Enable graceful migration of WiMAX Networks
  - 802.16d and 802.16e
  - PMP 320, Redline, Alvarion, Etc.
  - **Improved throughput at expense of doubling latency**
- **7 MHz channel support**
  - Aligns PMP 450 with 3.5 GHz License Grants
- **Zero Touch Configuration and Import/Export Config file**
  - Accelerate deployments
  - Reduce operating expenses
  - Eliminate human error in configurations
- **Security Features: HTTPS, SNMPv3, FTP/Telnet Disable**
  - Information Assurance demand accelerating
  - Particularly true in industrial communication applications

R13.4

PMP 450 New Features:

- Frame Utilization
- Security Banner
- RADIUS CoA Support
- RADIUS VSA for Zero Touch
- Link Test Enhancements
  - Extrapolated Link Test
  - OIDs for running on SM
  - Time/Date stamp for last time link test run
- Prevent PMP400's from getting upgraded using PMP430 and PTP230 packages
- MS RADIUS support
- Option to disallow PMP 430 SM to register to PMP 450 AP
- Numerous Bug Fixes and Stability Improvements

PMP 100 New Features:

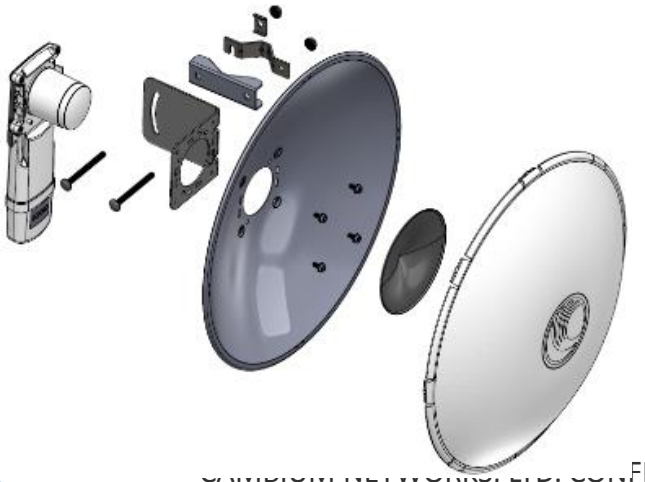
- Sector Spectrum Analyzer
- Read-Only Users (Local and Remote)
- 20 Color Codes
- Export Sessions Status
- HTTPS, SNMPv3, Telnet, FTP
- Zero Touch Configuration
- Import/Export Configuration File
- Numerous Bug Fixes and Stability Improvements

Feature Briefs for all new features are available on the Community Forum site

PMP 450d - Integrated Dish SM

Available Now!

- 25 dBi Integrated dish
- Works with existing power supplies
- Compatible with C3VoIP
- Extremely easy to assemble and deploy
- Reduce total cost of ownership:
  - Single supplier
  - Speed of installation
  - Improved first install rates



Introducing *PMP 450i and PTP 450i*

Available Now!

- **New Radio Design**
  - Ultra Wide-band radio – 4900 to 5925 MHz support
  - Opens up new frequency bands (4.9, 5.1 and 5.2)
  - Includes Dynamic Interference Filtering
  - Improved Radio Characteristics
    - Increased Transmit Power
    - Better Receive Sensitivity
- **New FPGA / SoC architecture**
  - Platform evolution to new generation processor
  - Expect to triple processing power of radio at launch with path to >75k PPS
  - Allows for wider channel support leading to more throughput
- **Ruggedized, IP66/67**
  - Visually similar to PTP 650
  - All metal construction
  - Increased Reliability in harsh environments
  - Optional ATEX/HAZLOC certified models available
- **New Power scheme**
  - 802.3at PoE compatible
  - Aux port with PoE Output
    - Allows direct connection of camera or other equipment

PMP 450i – High Gain Directional SM and BH

- **Integrated Flat Panel Antenna**
  - 23 dBi Gain
  - 12” x 12” panel
  - 11° azimuth and elevation
  - Compact design
  - Easy Alignment and Installation

- **New Tilt Bracket Assembly**
  - Sturdy mounting bracket
  - Reasonably priced
  - Reduce installation time and effort

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PMP 450i – Connectorized Radio

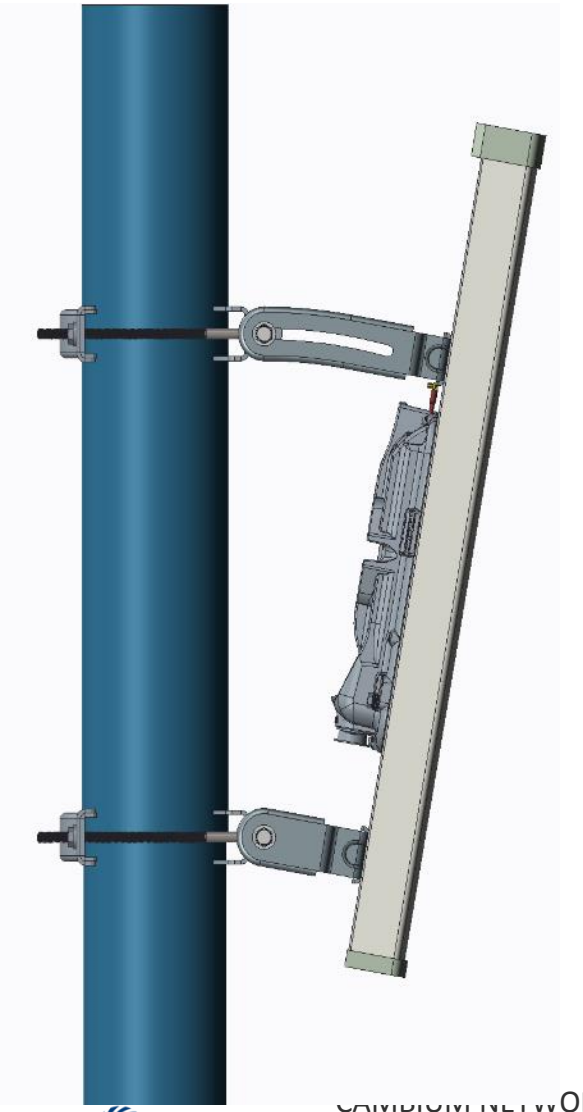
- **Connectorized Radio**
  - Access Point
    - with current PMP 450 Sector Antenna
    - Same mounting points at PMP 450 AP, so can replace that radio on same antenna if necessary
  - Connectorized SM or BH
    - Pair with any dual pol antenna to maximize gain

PMP 450i – Integrated Access Point

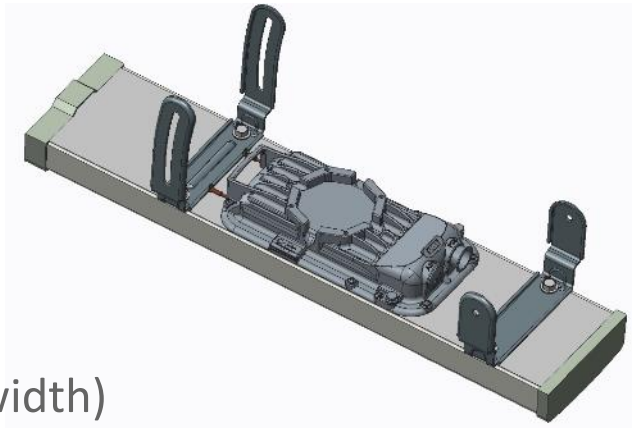
- **Integrated AP**
  - 90° Sector Antenna (3 dB rolloff)
  - 16 dBi Gain
  - Only 5.5 lbs
  - Easy to install, compact design
  - Front-to-back isolation not suitable for frequency re-use

Cambium 5GHz Sector Antenna

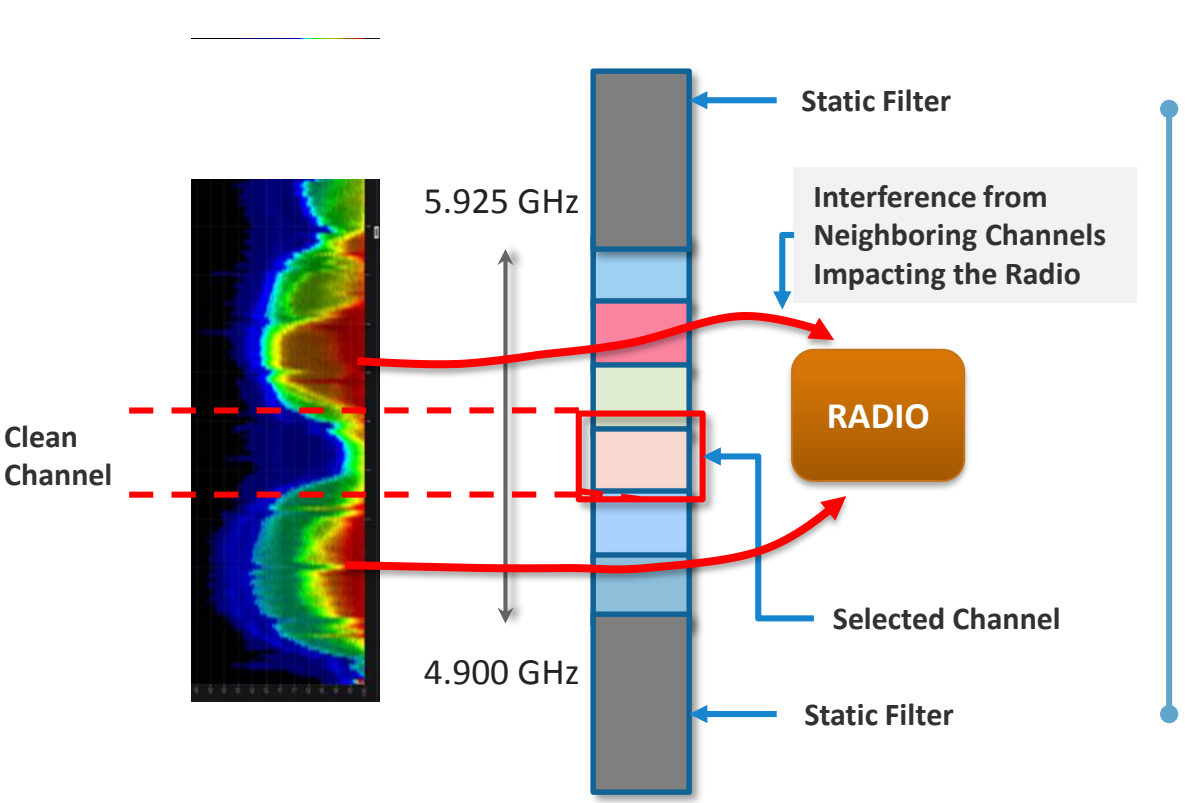
Available
May, 2016

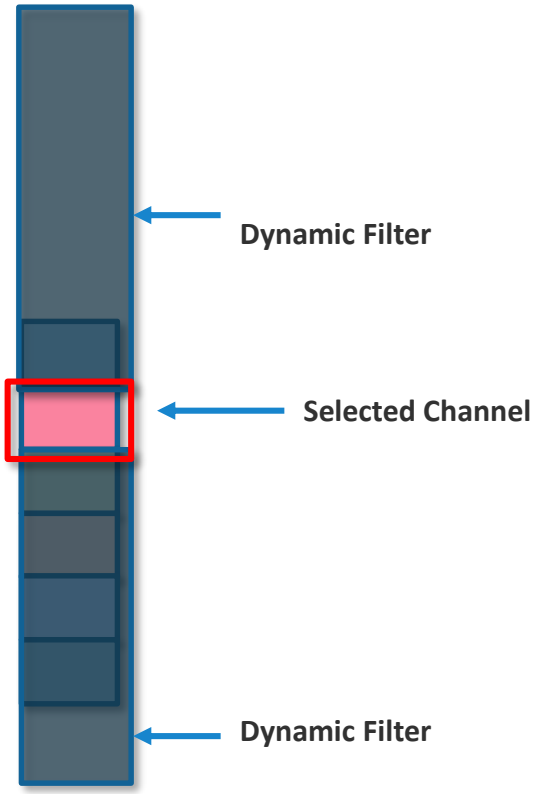


- Performance Differentiation
  - Will replace Integrated Access Point
  - Integrated 2x2 Dual-Pol Sector
  - **Optimized for ABAB channel re-use**
  - Null-fill
  - Improved gain response across frequency and azimuth
  - Easy to install
- Key Specifications
  - 17 dBi gain
  - 4.9 to 6.1 GHz
  - 90 degree (3 dB beam width)
  - 120 degree (6 dB beam width)
  - Front/Back Ratio: > 32 dB



Dynamic Interference Filtering





Spectrum

Traditional Fixed Filter

Makes Radio Susceptible to Neighboring Channel Interference

Cambium's Dynamic Filtering

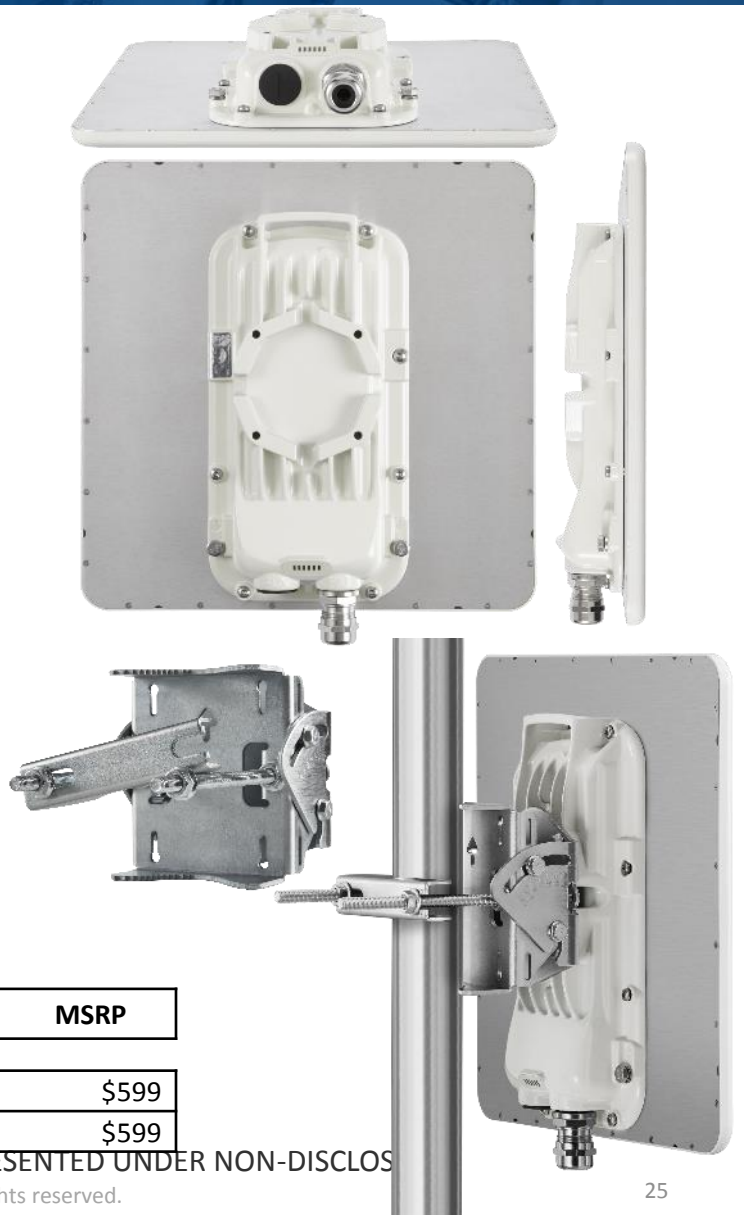
Wraps around selected channel, Filtering out Interference from Neighboring Channels

High Gain Directional SM – 3 GHz

- **Providing a High Gain alternative form factor for 3 GHz**

- **Integrated Flat Panel Antenna**
  - 19 dBi Gain
  - 12” x 12” panel
  - 11° azimuth and elevation
  - Compact design
  - Easy Alignment and Installation

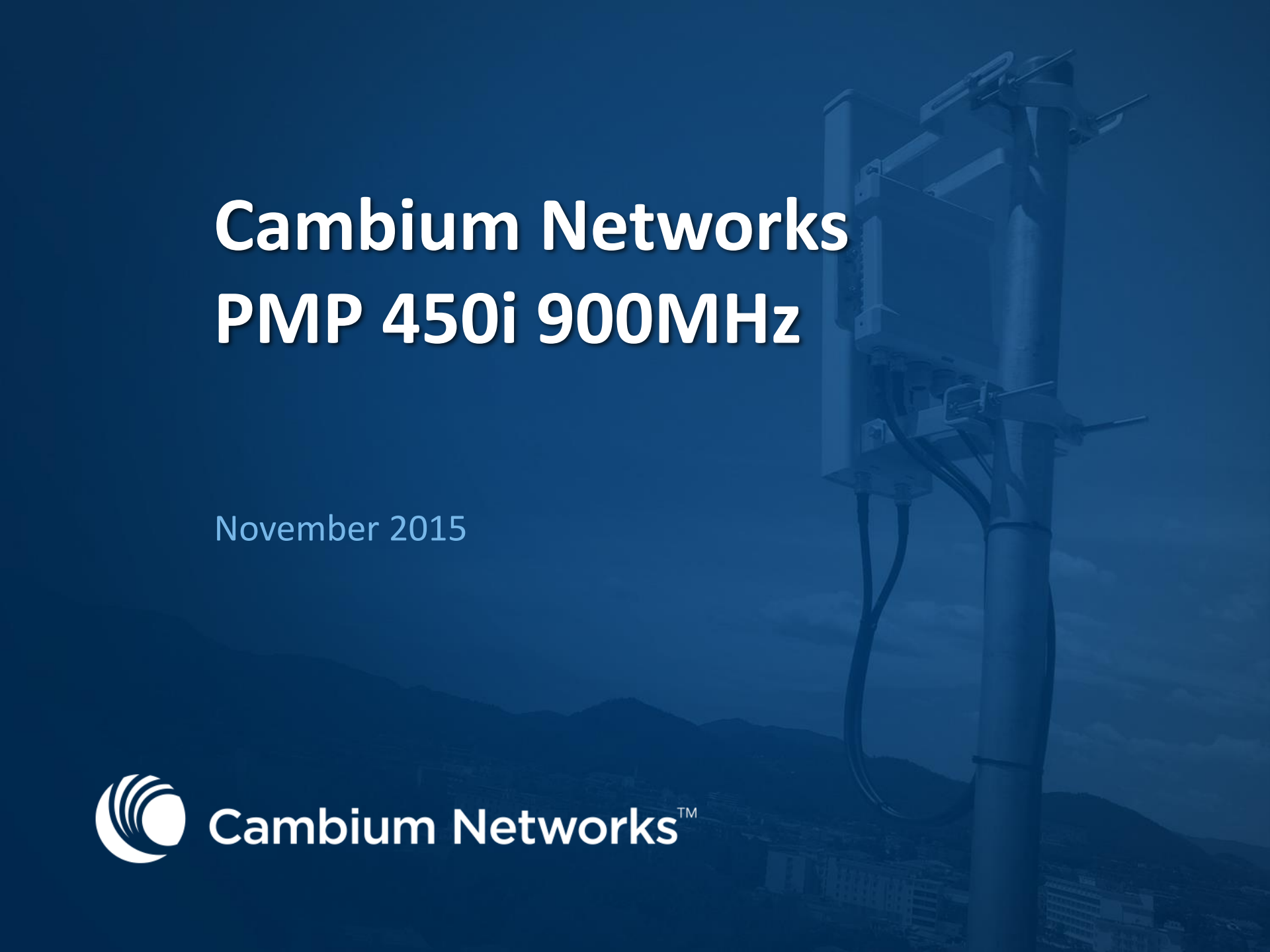
- **Same PMP 450 SM, new Antenna and mechanics**



Part Number	Description	MSRP
C035045C014A	3.3 – 3.6 GHz PMP 450 High Gain Directional Integrated Subscriber	$599
C036045C014A	3.55 – 3.8 GHz PMP 450 High Gain Directional Integrated Subscriber	$599

Cambium Networks PMP 450i 900MHz

November 2015



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450i 900 MHz: Key System Features

Features	Customer Benefit / Competitive Advantage
Redesigned 900 MHz Radio (902-928 MHz)	Increased performance, based on 450i platform
Improved Range and Coverage	**Make NLOS links.** Using 900 MHz, propagation is fantastic. Upgrade your tough NLOS deployments to higher throughputs.
Rugged Enclosure for AP	Specified using **Industrial-rated components**. Designed to meet IP66 and IP67 ratings for harsh environments.
Clean installation for SM	Attach the SM directly to the slim but powerful (12 dBi) Yagi antenna.
Updated SoC (FPGA) chipset on the AP	**Triple the processing power compared to PMP 450, an order of magnitude more than PMP 100**. Allows for future platform enhancements.
Multifunction AUX port on the AP	A second Ethernet port with multiple functions allow for greater flexibility of deployment: add a camera or other PoE device directly, provide GPS timing in/out, and an audible alignment tone.
Updated Power Scheme	Industry standard 802.3at PoE compatible on the AP. **Continue to use the existing 30 VDC power for the SMs.**

PMP 450i 900 MHz Overview

- **900 MHz ISM band Operation**
  - 902-928 MHz
  - 5, 7, 10 or 20 MHz channels supported
- **2x2 MIMO design**
  - Allows higher capacity
- **Power Scheme - New for AP, Same for SM**
  - AP will be 802.3at PoE compatible (56 VDC)
  - SM will be 30 VDC, and can **re-use existing PSU**
- **Next Generation Architecture**
  - **Utilizing PMP 450i architecture**
  - Maximize Spectral efficiency
    - Using GPS timing and colocation with PMP 100 900 MHz
- **Product Design Goal**
  - Under similar RF conditions, similar channel size, **3x - 4x PMP 100**
  - 4 Mbps capacity to **12-16 Mbps capacity**
  - In clean spectrum, **PMP 450 900 MHz can provide 100+ Mbps per sector**

PMP 450i 900 MHz Migration Strategy

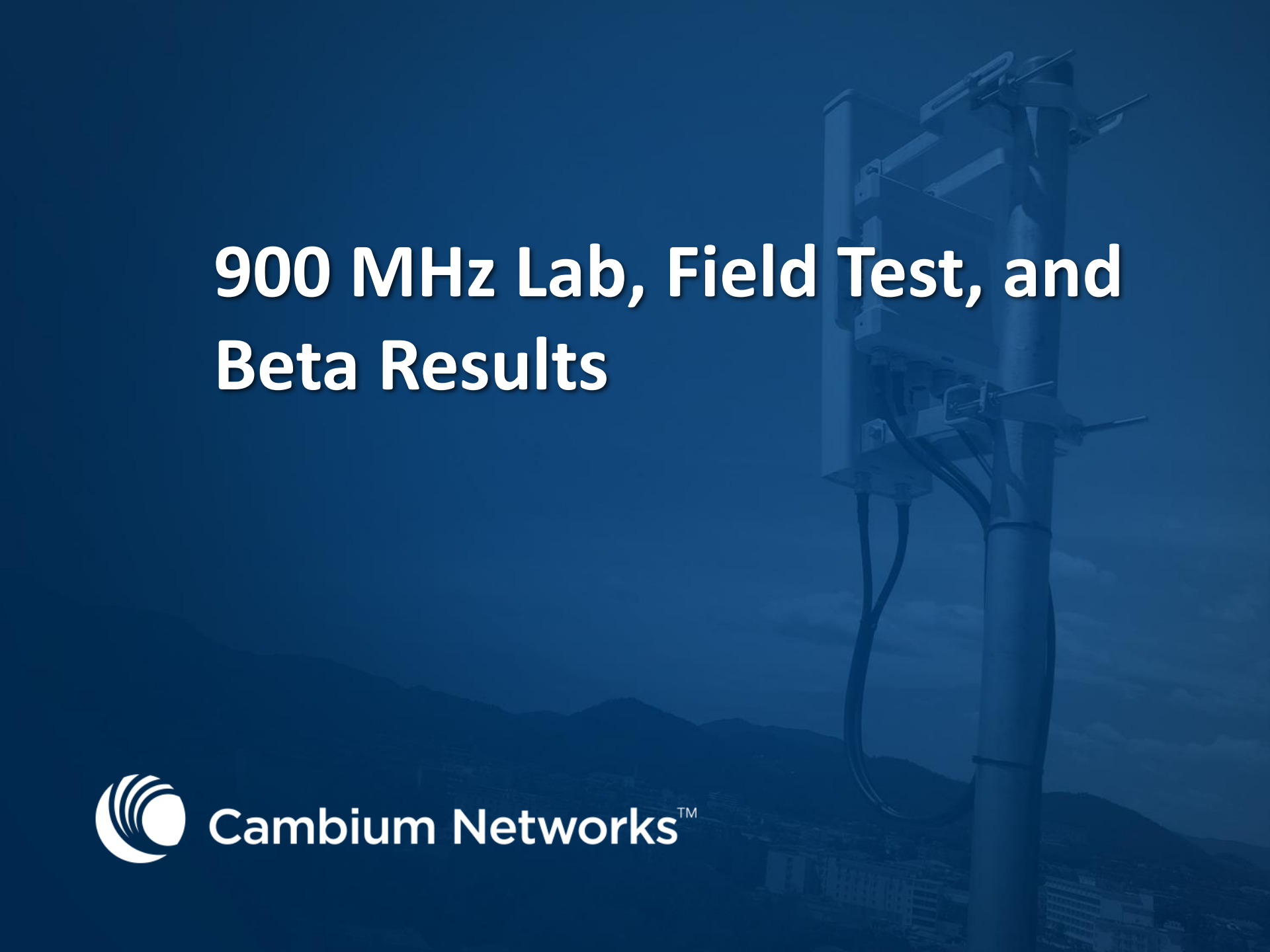
- Phased approach , can be migration or a permanent solution
  - Provides strategy to migrate one site at a time, versus a total rip and replace
  - It is recommended to replace the entire site, versus one sector at the site
- Selecting the correct system parameters is key to minimize interference
  - Several parameters must be considered (e.g. duty cycle, range, contention slots, etc.)
  - Use the co-location/migration tool in order to determine optimal co-existence parameters
- Synchronization between PMP 100 and PMP 450i 900 MHz is critical
  - Both PMP 100 and PMP 450i are TDD systems
    - A TDD cycle, or frame, is the minimum amount of time used to communicate in both directions
  - Different systems have different frame lengths and timing
    - Choosing the same parameters on both systems does not guarantee coexistence
  - Use the tool and strategy guide available at:

https://support.cambiumnetworks.com/files/pmp450i/

Cambium 900MHz Antennas

- Performance Differentiation
  - Dual slant polarization system to isolate from Vertical or Horizontal deployments
  - High Front to Back ratios to allow Frequency Re-use and high Spectral Efficiency
- SM Yagi Antenna
  - Dual slant
  - 40° beam width
  - 41” in length
  - Cables to connect the SM
- AP Sector Antenna
  - 902-928 MHz
  - 65 degree (3 dB beam width)
  - Can be used for 60 or 90 degree sector
  - Front/Back Ratio: > 32 dB
  - 35” x 11” x 5”
  - AP radio mounts to back of antenna

900 MHz Lab, Field Test, and Beta Results



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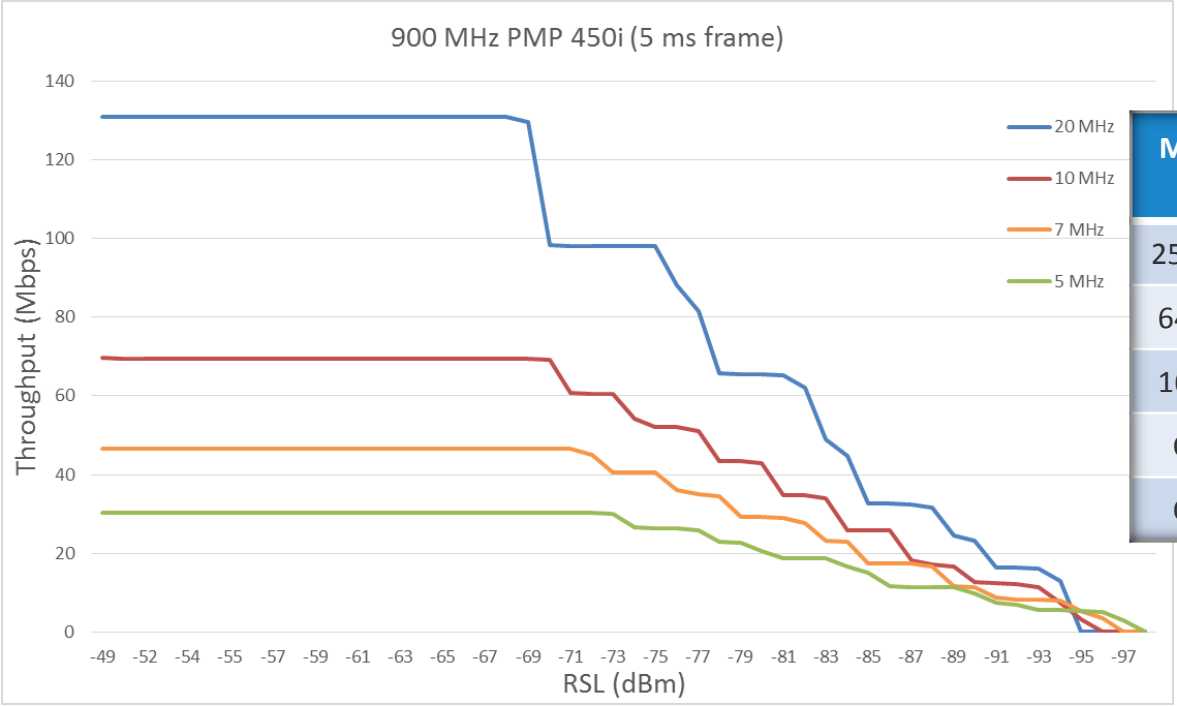
900 MHz Lab Results

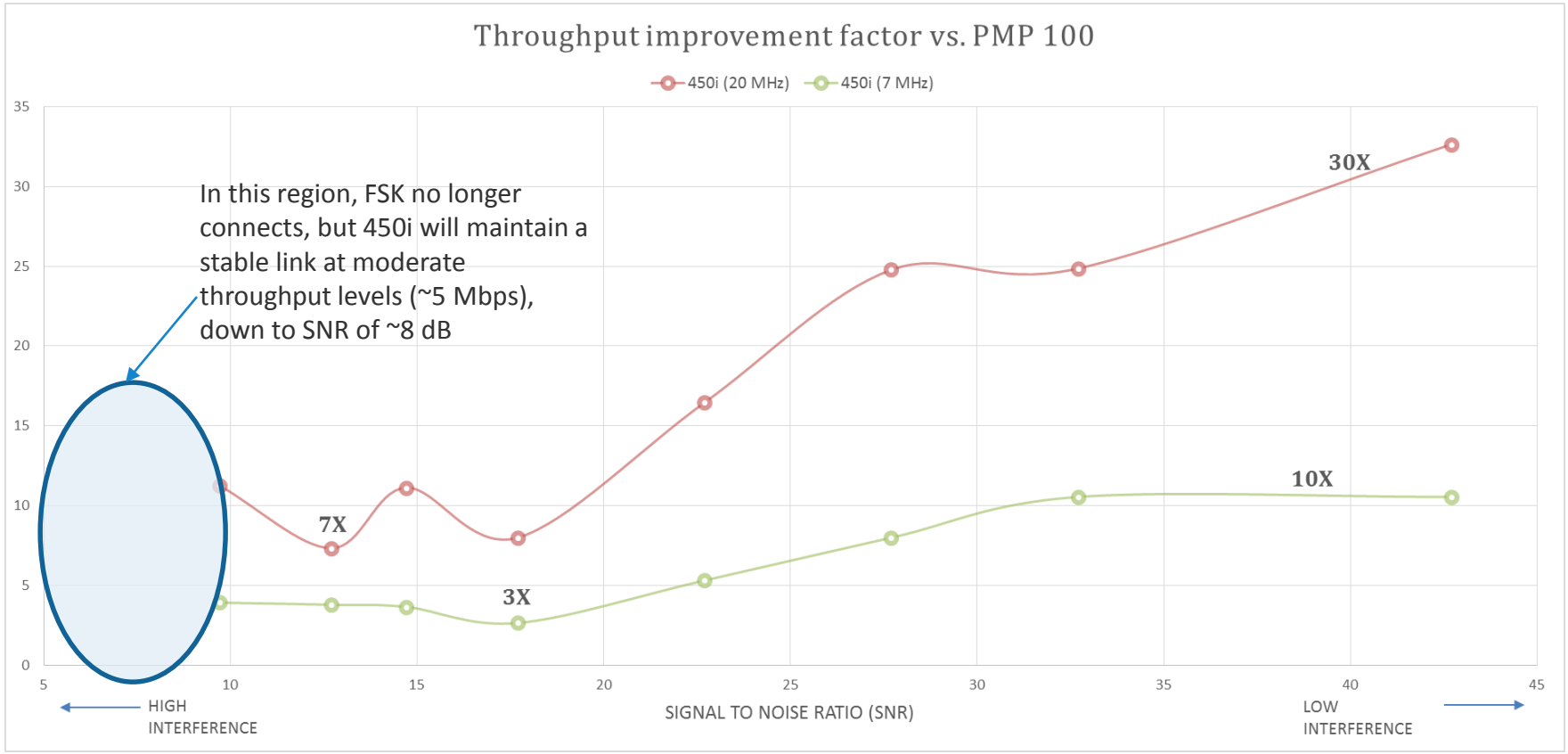


7 MHz Channels

Modulation Mode	Sensitivity (dBm)	T-put (Mbps)	CNR (dB)
256QAM (8x)	-73	45	32
64QAM (6X)	-79	35	24
16QAM (4X)	-85	24	17
QPSK (2X)	-92	12	10
QPSK (1X)	-95	6	8

12 dBi Yagi Antenna -- Maximum LOS range mi (km)			
Frequency Band	Modulation	20 MHz Channel	7 MHz Channel
900 MHz	256QAM (8X)	7 (11)	11 (20)
	64QAM (6X)	14 (23)	24 (39)
	16QAM (4X)	29 (46)	48 (78)
	QPSK (2X)	58 (93)	108 (174)
	QPSK (1X)	80 (131)	120 (193)

Field Testing vs. PMP 100 900 MHz



- Testing has shown vast improvement over FSK
- In worst case interference, using the same channel size (7 MHz), the PMP 450i 900 MHz product provides 3 times throughput
- As the interference level decreases, the gains are better with the 450i

Strategic Roadmap 2016

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Cambium 450 Roadmap 2016

Jan, 2016

2016				2017
1Q	2Q	3Q	4Q	1Q

R14.3 - May
- 40 MHz Channels
- IGMP Snooping
- Multicast to Unicast conversion
- MEF Certification
- ATEX/HAZLOC Certification
- cnMaestro Agent

R15.1 - October
- **450i – 3 GHz**
- Adaptive CIR
- Optimized FFT (256 for 5 MHz)
- Extra FEC for link robustness
- QoS Enhancements (4-level)
- Video Surveillance Optimizer
- Video Frame Control
- SM Installation app

- Completed
- Committed
- In Planning
- Candidate

R15 - August
- **Massive MIMO AP**
- Multiple RF Chains
- Beam Steering
- 5.150 – 5.925 MHz support
- Re-use of 450 SMs

R15.2 - December
- **Wideband SM**
- Sync – IEEE 1588v2
- OAM (Y.1731, 802.3ag, 802.3ah)
- Massive MIMO Enhancements
- IPv6 Management
- 256 bit AES

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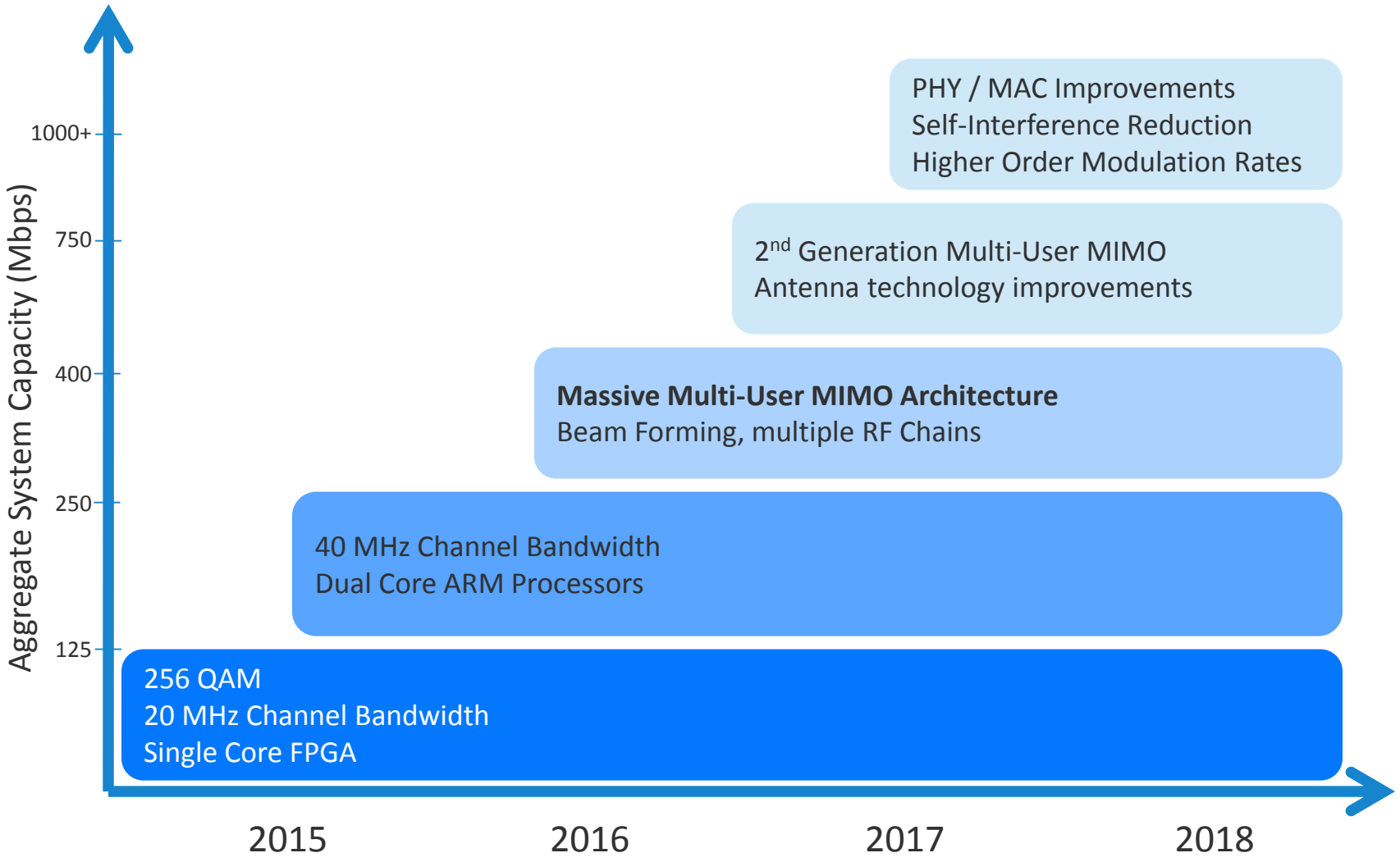
Data Rate Technology Advancement Horizon



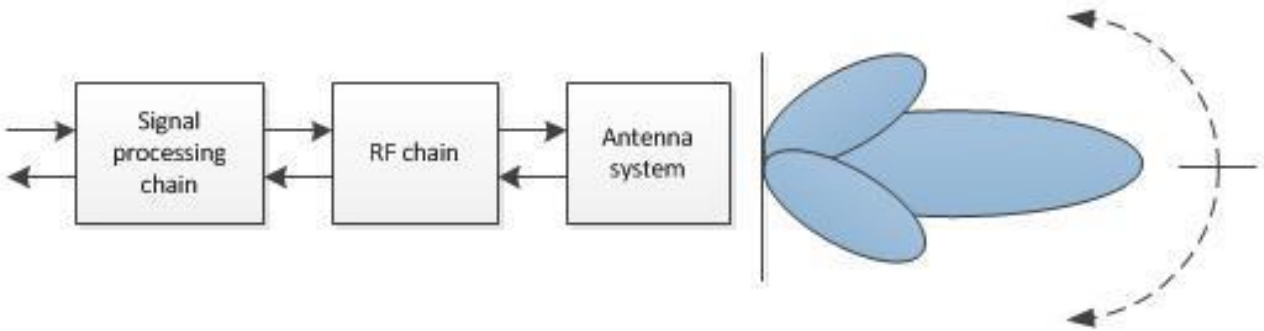
Massive MU-MIMO: Defined

- Typical multiplexing techniques to increase the density of data in a frame:
  - FDMA (Frequency Division Multiple Access)
  - TDMA (Time Division Multiple Access)
  - CDMA (Code Division Multiple Access)

- MU-MIMO adds spatial multiplexing (SDMA)
  - Mutual interference between users is minimized due to the spatial locations of the accessed users.

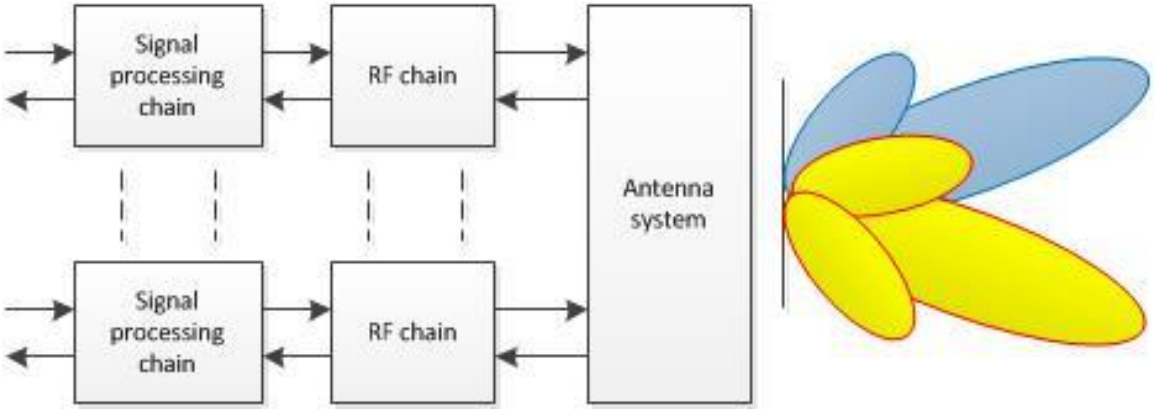
- Spatial multiplexing ensures mutual interference between users is low enough to provide reliable communication

Beam Steering and MU-MIMO



Beam steering

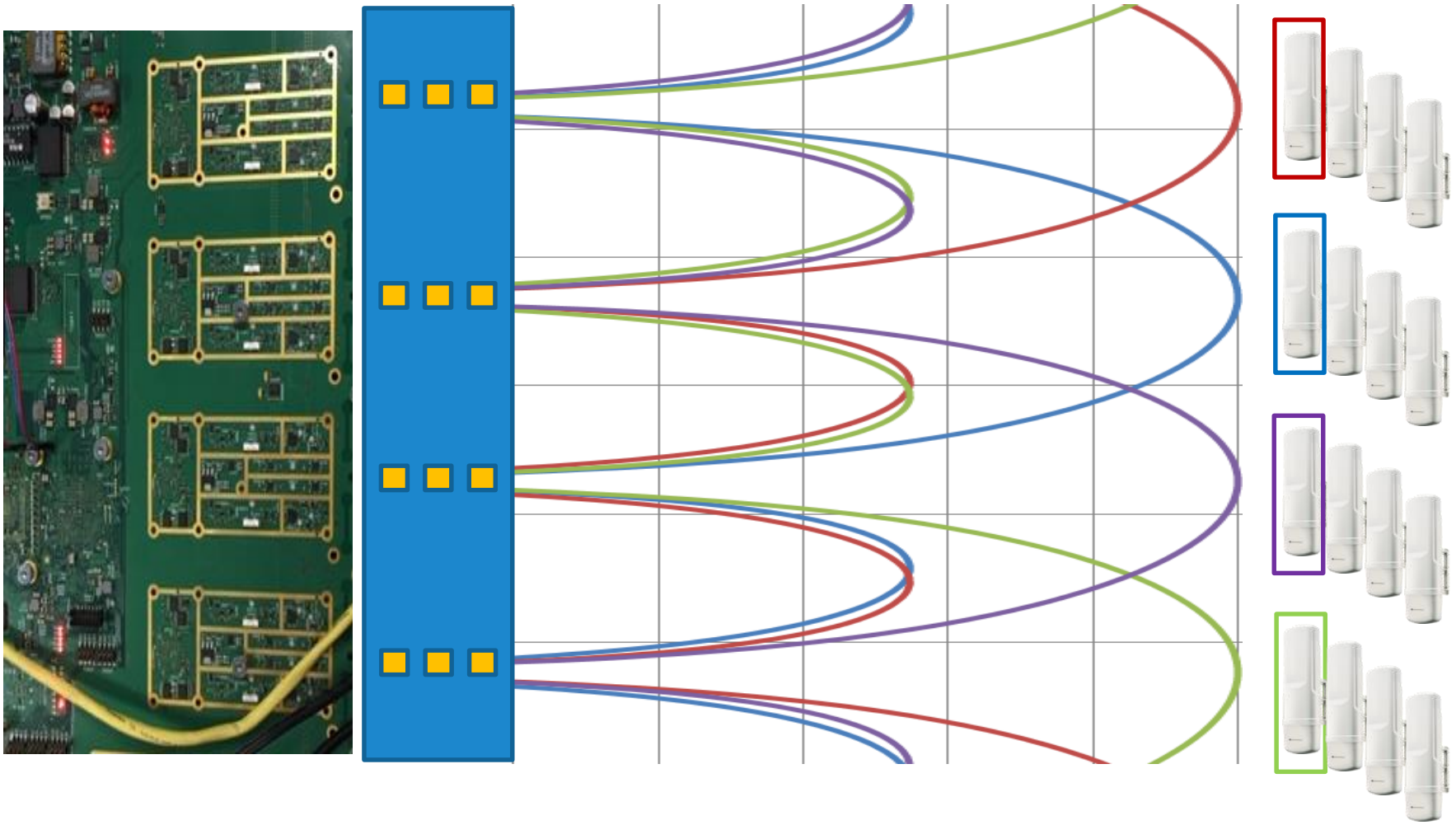
- Allows pointing a single beam at a time to the wanted user.
- In a TDD system, the beam direction can change for each user/time slot
- Main benefit is to increase the antenna gain toward the wanted user AND/OR decrease the antenna gain toward the unwanted interferers
- Requires a steerable antenna in front of a "conventional" radio system



Multi-User beamforming (MU-MIMO)

- Extension of the beam steering concept
- Allows pointing multiple beams to multiple wanted users simultaneously.
- Main benefit is a capacity increase the capability to communicate with multiple users at the same time on the same frequency.
- Requires a multi-beam antenna AND a multiple chain receiver

How Does MUMIMO Work?



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What is Cambium MU-MIMO?

- **Cambium MU-MIMO Sector:**
  - Single AP Device + Integrated Sector Array Antenna
    - no RF cables to connect
  - Re-use existing frequency plan, no change to RF network
  - Dynamically adjusts to isolate sub-sectors

Technology generation	Max Mbps/20 MHz per sector
FSK : PMP100	14
OFDM : PMP430	48
PMP MIMO : PMP450	100
MU-MIMO : PMP450 SM	**200 to > 500**

- **Mu-MIMO AP Perfomance Benefits:**
  - >3X Sector capacity increase
  - Higher subscriber density per AP
  - Higher data rate, higher ARPU per SM
  - Higher interference tolerance
  - Enterprise customer focus

- **Mu-MIMO AP Operational Benefits**
  - **Re-use existing PMP 450 subcriber modules**
    - **SM backward compatible with SW upgrade**
  - Reduced number of sites
    - Reduced site CAPEX
    - Reduced overall OPEX

Cambium 450 Platform Summary

- Industry leading PMP solution for critical networks
- Proven field reliability
  - Built upon our quality legacy (preceding product fielded for >10 years)
  - >40 Year calculated MTBF (based on field returns and reliability testing)
- Extreme Scalability
  - Access Points can support many subscribers
  - Many Access Points can be deployed at each site for maximal throughput
- OFDM MIMO → MU-MIMO
  - 2x2 MIMO provides high bandwidth for LOS access, and a path to MU-MIMO
  - Single payload modulations provide link enhancement for nLOS and NLOS
  - **Future-proof your platform investment, utilize PMP 450 SM in the Multi-User MIMO system**
- GPS synchronization
  - Maximize spectral efficiency, frequency re-use across network
  - Minimize self-interference, maintain low and consistent latency
- **Robust Roadmap for future platform enhancements**
  - **Serving customer needs for years to come**

Thank You

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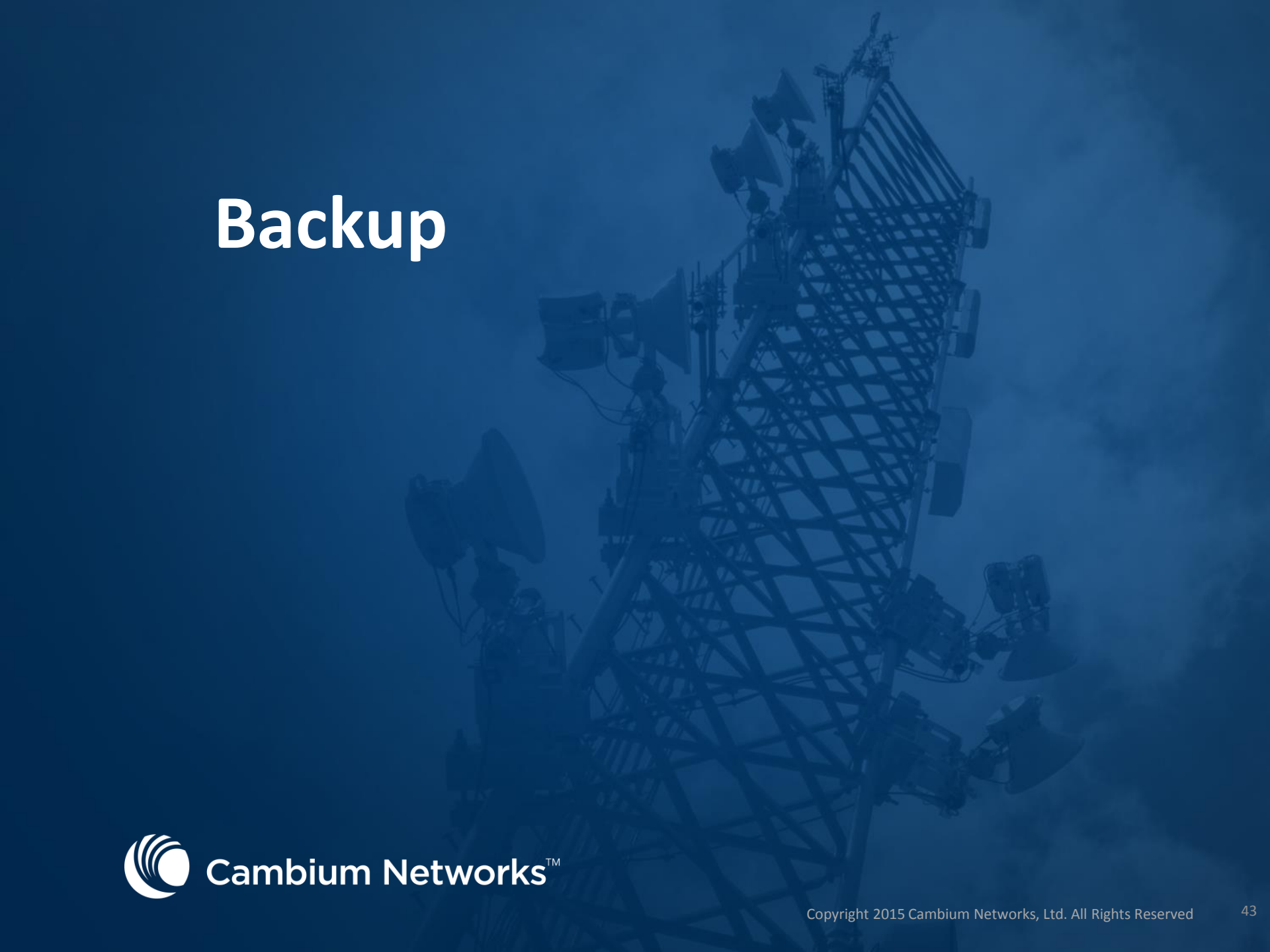
Backup



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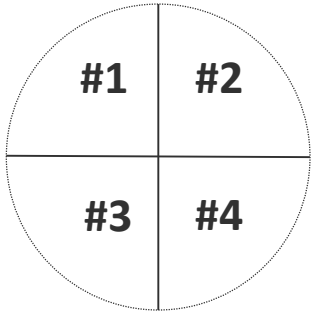
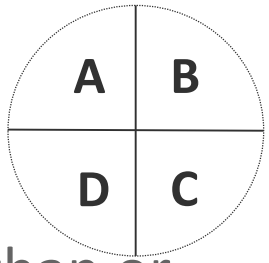
The Importance of Spectral Efficiency

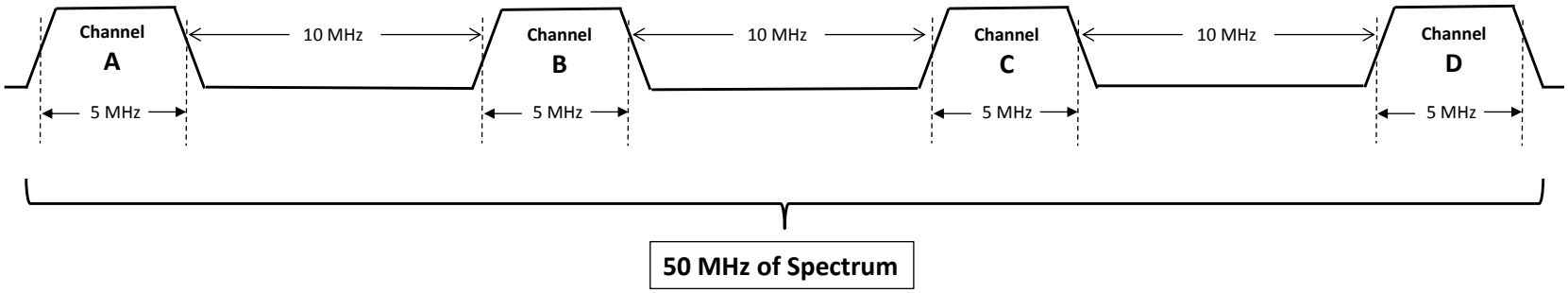
- Spectral Efficiency:
  - A measure of how efficiently a wireless solution utilizes RF spectrum
    - Defined as Throughput Achieved (bps) per Spectrum Utilized (Hz) – bps / Hz
- Clear Spectrum is a scarce resource
- A solution that makes efficient use of this scarce resource provides a superior Return on Investment to the Network Operator
- Example for Illustration: Four Sector AP Site with 6 km coverage radius deployed in 50 MHz of available spectrum:



Unsynchronized Deployment in 50 MHz



- No channel reuse with the cell
- Guard Bands between channels used must be greater than or equal to 2X then channel Bandwidth



- Avg Capacity of 5 MHz channel with 6 km range = 22 Mbps
- Spectral Efficiency of Unsynchronized Deployment:

4 x 22 Mbps = 88 Mbps / 50 Mhz = 1.8 bps/Hz

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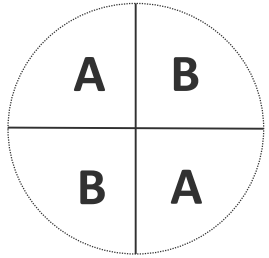
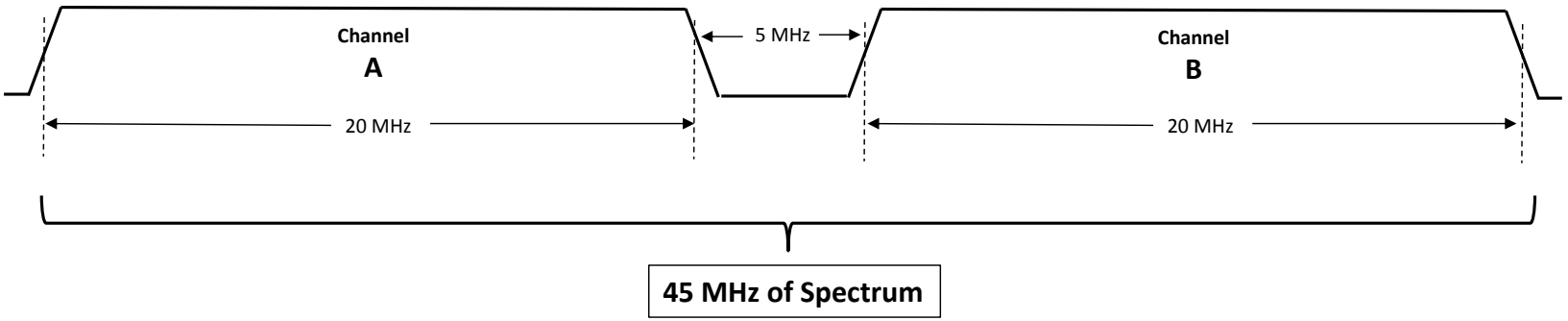
ePMP GPS Sync Deployment in 50MHz

- 2 channel reuse supported within the cell
- 5 MHz Guard Bands between channels



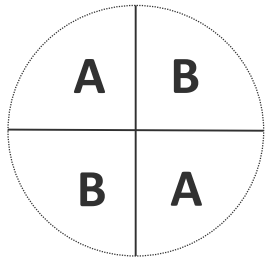


- Avg Capacity of 20 MHz channel with 6 km range = 65 Mbps
- Spectral Efficiency of Synchronized Deployment:

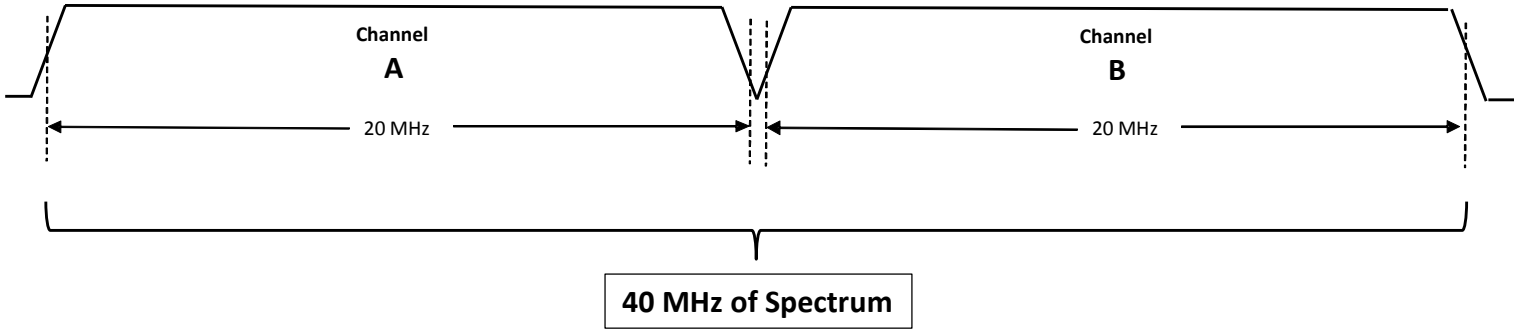
4 x 65 Mbps = 260 Mbps / 45 Mhz = 5.8 bps/Hz

> 3X Spectral Efficiency for ePMP GPS Sync Solution

PMP 450 Deployment in 40MHz



- 2 channel reuse supported within the cell
- **No Guard Bands** required between channels



- Avg Capacity of 20 MHz channel at 6 km range = 95 Mbps
- Spectral Efficiency of Synchronized Deployment:

4 x 95 Mbps = 380 Mbps / 40 Mhz = 9.5 bps/Hz

65% higher Spectral Efficiency for PMP 450 over ePMP, 5x higher than an unsynchronized solution

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PMP450 Frame

- PMP450 uses a TDD frame structure with frame lengths of 2.5 ms and 5 ms
  - 2.5 ms frame optimized for latency
  - 5 ms frame optimized for throughput
- Flexible DL/UL ratio, configurable in 1% increments
  - Allows operator to select time based on the direction of the most amount of traffic
  - Fine granularity simplifies co-location with other deployments
- Downlink and uplink transmission are scheduled: the system performance scales efficiently with the number of users
  - One AP supports up to 238 SMs
  - All frame time is used for data/control transmission, except for TTG (transmit to receive gap) and RTG (receive to transmit gap)
  - No contention mechanism for accessing resources for data/control transmission
- Advantage over other technologies
  - WiFi-based systems such as Airmax can see dramatic increases in latency with the number of SMs in the network
  - Fixed allocation systems like Radwin may provide lower latency but cannot scale

PMP450 Scheduler: features

- Implemented in hardware: fast! It can schedule data for current frame, both in the DL and UL directions
- Two QoS levels: High Priority and Low Priority traffic for each SM
  - High priority traffic (if enabled) is scheduled before low priority traffic
- Committed Information Rate (CIR): if configured, scheduler will give priority to SMs that have not met their CIR
- Maximum Information Rate (MIR): if configured, scheduler will cap throughput of SMs that have met their MIR
- Burst capability: SM can temporarily exceed its MIR, to support download of large files → better user experience

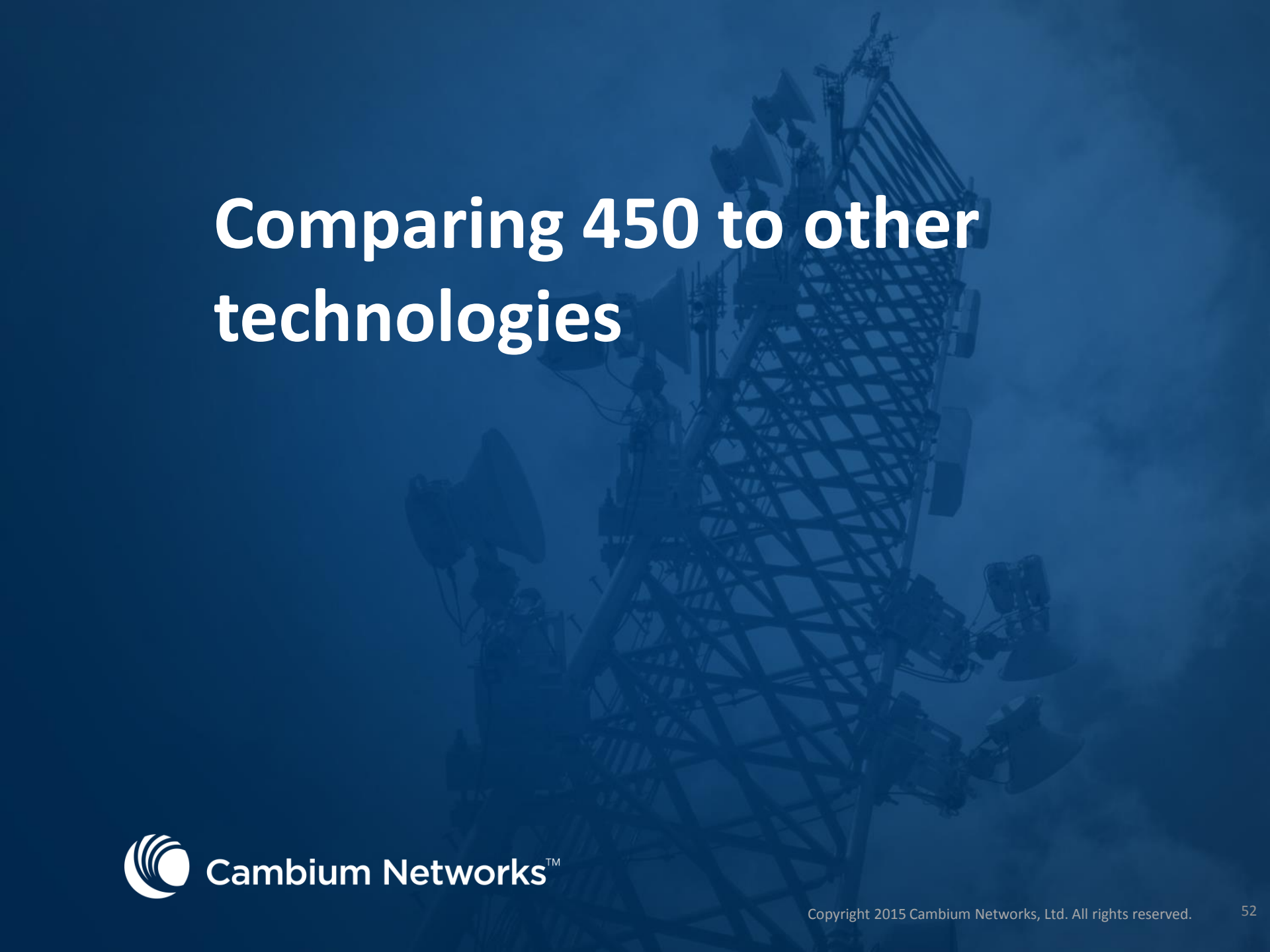
PMP450 Scheduler: more features

- Ethernet packets fragmented in small packets
  - Each fragment is acknowledged independently
  - Only corrupted fragments need to be retransmitted → low retransmission overhead
- Guaranteed packet delivery: scheduler re-schedules a corrupted fragments until it is received correctly → system bit error rate (BER) virtually zero
  - Avoiding higher layers to recover corrupted data keeps system latency low
- Automatic rate adapt: scheduler selects modulation that maximizes throughput, given current channel conditions
  - DL and UL modulation selection are independent
  - Selected modulation adapts to changing channel conditions
  - Frame by frame updates

PMP 450 can support up to 238 SMs per Sector!

Panoramic view of our large RF isolation chamber with >200 SM connected to single AP

Comparing 450 to other technologies



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450 Proprietary technology differentiators

PHY layer based on 512-FFT OFDM • Immunity to multipath • 144 pilot tones for channel response equalization • 2.5ms fixed frame length • TDD cycle up to 85% in 1% steps • Rate adapt modulation up to 256QAM • 5 MHz, 7 MHz channel bandwidth	**MAC Layer based on Canopy scheduler** • Connection oriented L2 protocol granting delivery of 64bytes fragments • Up to 238 Virtual Circuits for unicast data transport in each direction • Dedicated multicast VC • Ack messages scheduled in the same TDD cycle • ARQ feedback implemented in HW • QoS with 2.5Gbits of burst capacity
HW design • Higher Tx power in 5.4 FCC • High quality sector antenna with >35dB front-to-back ratio • Frequency reuse 2 with no guard band • Direct mount antenna • IP67 protection grade • Redundancy on GPS sources • Audible tone alignment tool • >40 years MTBF	**Software feature set** • Traffic classification with DPI • Private air interface to **proxy** management session • AP evaluation algorithm • Color code prioritization • VLAN mapping on source MAC-address basis • RADIUS based access management • Framed IP • QinQ • CIR

**Blue color indicates items that cPMP cannot do as currently architected

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Why PMP 450 vs. ePMP ?

- **Better Hardware**
  - Carrier Class Component Selection
  - Carrier Grade
  - Increased MTBF (> 40 Years)
  - Industrial temperature range -40 to +60 °C
- **Better RF Architecture**
  - Spectral Efficiency
    - No guard band required between adjacent channels
    - Total cost of deployment is less, can maximize use of available frequencies
  - Frequency availability and flexibility
    - 2.4, 3 GHz and 5 GHz, with more coming (4.9, 900 MHz, 2.5 GHz?)
- **FPGA-based Scheduler**
  - Throughput and latency benefits in the face of interference
    - Fragmentation (Canopy Scheduler, FPGA)
    - RF chipset differences (Catalina filters better, resulting in no guard bands)
    - Resistance to Multipath issues
  - Robust software features allowing scalable networks
    - CIR, RADIUS support, Multicast handling
    - Layer 2/3 Routing and configuration features (VLAN remarking/priority, QinQ, PPPoE client, etc.)
  - Uplink/Downlink granularity
    - More suitable for high uplink conditions (i.e. video surveillance)
- **Future Proof Platform**
  - FPGA-based architecture
  - supports features and performance that cannot be duplicated on a standards-based chip set
- **Security Suite of Features**
  - HTTPS, SNMPv3, Telnet/FTP/TFTP disable, Security Banner

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Spectral Efficiency

- In a single sector:
  - ePMP = 100 Mbps / 20 MHz = 5 bps/Hz
  - 450 = 125 Mbps / 20 MHz = 6.25 bps/Hz

- However, on a fully loaded site:
  - ePMP can deploy ABAB (frequency pattern), but a 5 MHz guard band channel is required between ‘A’ and ‘B’
    - So, 100 Mbps * 4 APs / 45 MHz = **9 bps/Hz** (total T-Put = 400 Mbps)
  - 450 can deploy with frequency plan of ABAB or ABCABC (with **no guard band required** between adjacent sectors)
    - So, 125 Mbps * 4 APs / 40 MHz = **12.5 bps/Hz** (total T-Put = 500 Mbps)
    - Or, 125 Mbps * 6 APs / 60 MHz = **12.5 bps/Hz** (total T-Put = 750 Mbps)

Performance in the face of Interference

- Fragmentation
  - If a packet fails CRC when being transmitted, ePMP must retransmit the whole packet in most cases
  - PMP 450 breaks packets into 64 byte fragments, and will only retransmit those that don't make it, resulting in more efficient
- Latency
  - Latency will always be higher in ePMP due to the fact that bandwidth requests cannot be "mapped" until the following frame (so at least 5ms additional latency best case)
  - PMP 450 can do this for the current frame
  - Due to contention-based protocol in ePMP, latency will increase more dramatically with loading (and number of subscribers)

Future Proof Platform

- FPGA-based solution can adapt over time
  - It is not constrained to the chosen ASIC chipset that the "standards" bring
- Standards (such as 802.16e or 802.11n) offer a lot of features inbuilt to the chip, hence a lower cost
- FPGA architecture trades off higher cost for flexibility
- Evidence of this is in the features and characteristics of the 450 platform, many of which cannot be duplicated on a standards-based product
  - Frequency spins
  - Highly sophisticated RF architecture
  - Unparalleled performance in unique scheduler mechanisms

Figures of Merit

Figure of Merit	PMP 450	ePMP
Frequencies Available	2.4, 3.5, 3.65, 5.47-5.875	2.4, 5.1-5.9
Spectral Efficiency (single sector)	6.25	5
Spectral Efficiency (Network)	12.5	8
Sub carriers (resistance to multipath)	512	64
Highest Modulation	256 QAM	64 QAM
Latency (GPS sync mode)	3-5 ms	17-20 ms
Component Selection	Industrial (Carrier) Grade	Commercial Grade
Temperature Range	-40 to +60 °C	-30 to +60 °C
MTBF	>40 Years	>30 Years
Duty Cycle (UL/DL ratio)	Up to 85% by 1% increments	3 fixed levels
Maximum subscribers per AP	238	120

Positioning PMP450 and LTE

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Cambium Position

- Not one tool/band for all jobs
- Lower cost base infrastructure with 450 will win
- PMP 450 will stay ahead of LTE roadmap (Massive MIMO)
- N/nLOS results in degradation for all customers
- PMP 450 optimized for fixed in all RF environments
- LTE complexity prohibitive to fixed WISP deployments

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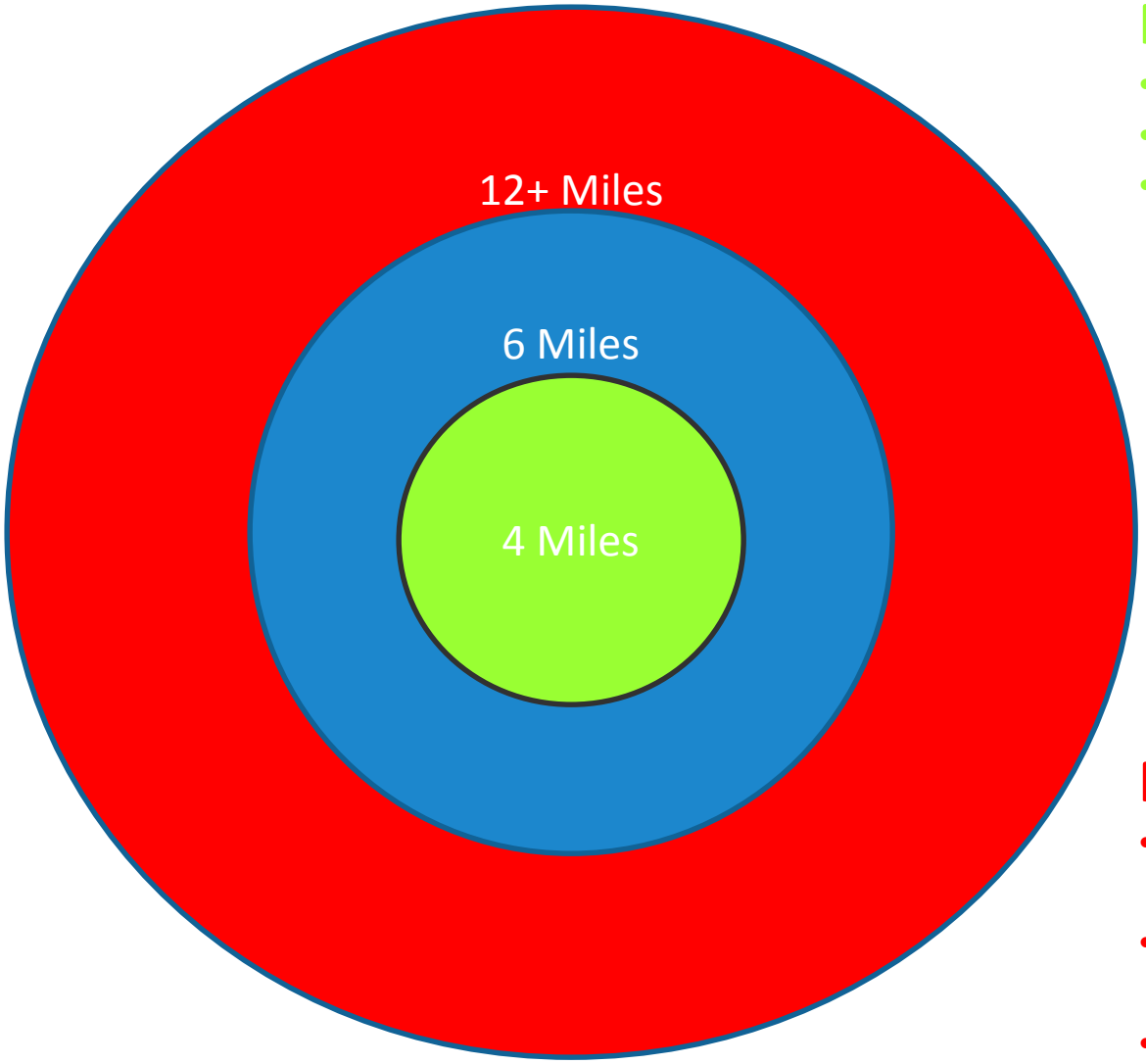
Cambium Solution for Fixed Access



PMP 450 5.x

- 450 MHz of spectrum available
- Capacity of over 100 Mbps per AP
- Maintain a high level of capacity to customers (offering 10-20 Mbps down 3-5 Mbps up)

PMP 450 3.x

- 3.5/3.65 ideal for mid-range
- Clean spectrum with better propagation
- Precious spectrum ideal for delivering high service levels

PMP 450i 900 MHz

- Enhanced filtering for high noise environments
- Great propagation for reaching outliers
- Serve outliers without degrading customers close in

So, what do Customers care about ?

1. ROI Horizon
   a) CapEx
   b) OpEx
2. Performance/Functionality
3. Multisourcing
4. Standardization transition
5. Support
6. Network compatibility (with existing network technology)
7. Other factors ??

LTE - Discussion

STRENGTHS of LTE

- Standardization
  - WiMax to LTE
  - Potentially enables multi-vendor CPE sourcing*
- Higher Tx Power = Longer distances = Fewer towers! (Canada)
- Competitive CPE prices
- Promises…..

WEAKNESS of LTE

- Short term field history. Unproven
- Higher Base station CapEx compared to PMP 450
- Higher latency: PMP 450 (TBD - 10 ms)*
- Lower sector/site throughput
- Rev. 9 LTE = 64 QAM
- Complex solution designed and optimized for mobility

* NGI testing

Compare and Contrast

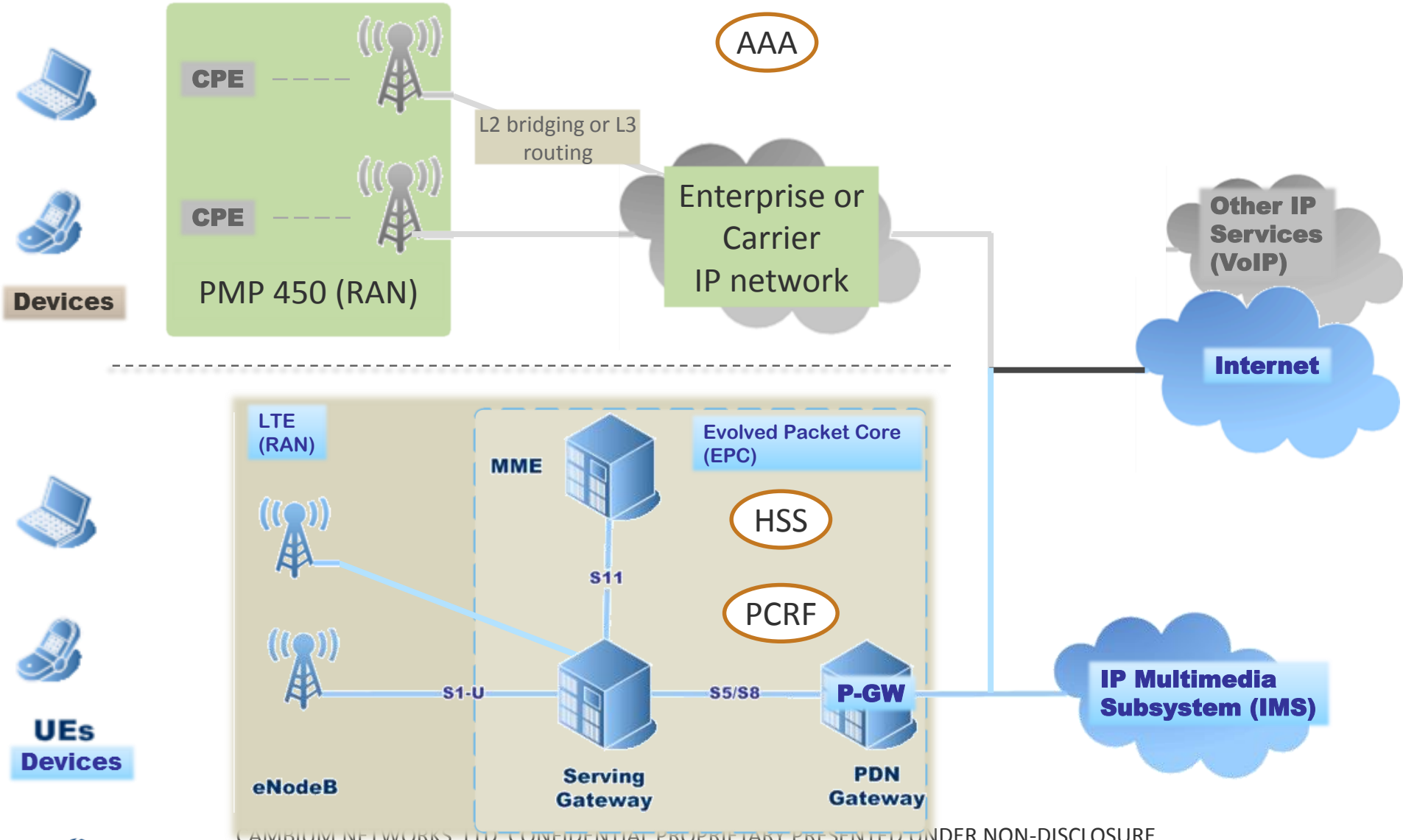
LTE

- Complex architecture
- Mobility Focused
- Optimized for device (UE) battery life
- Specialized training and hiring needs
- TDD LTE is relatively new. Vendors in early stage in the field (trials)
- Designed for “clean” spectrum
- LTE evolution takes Time
  - Standards based therefore Feature evolution takes time
  - “Productization” & IoT takes even more time
- High CapEx, Longer ROI period

PMP450 Technology

- Very Simple, adaptable architecture
- Low training requirement
- Field Proven technology:
  3+ years, 450,000 modules, 55 countries
- Purpose built: Unlicensed, Fixed WBB
- Like LTE uses OFDM – UL & DL
- Cutting edge available today (such as 256 QAM ≡ Higher throughput); LTE Rel 9 is 64 QAM
- Relatively lower CapEx. Quicker return on investment
- Robust roadmap – Massive MIMO on existing PMP 450 platform

The LTE architecture in contrast



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The LTE architecture

- UE = **U**ser **E**quipment ≡ Devices
- FDD (dominant USA) and TDD (Rest Of World)
- The EPC is “Logical” entity. Common (FDD & TDD). SGW and PGW are typically collocated. Fixed and Mobile LTE can share the EPC
- Market developments:
  - Cost reduced EPCs being offered (EPC in a box) E.g.: Quortus and others

The Standards body – 3GPP (GSM, UMTS, LTE)

Standards	When introduced	Key features
Prior releases	1999 – 2007	UMTS (3G) and HxPA
Release 8	2008 Q4	LTE Introduced
Release 9	2009 Q4	WiMAX and LTE/UMTS Interoperability
Release 10	2011 Q1	LTE-A: Carrier aggregation (CA), 8x8 MIMO, …
Release 11	2012 Q3	Enhancements, New Freq Bands,
Release 12	2014 Q3	More CA enhancements LTE Device-to-Device (D2D)
Release 13	2016 (Planned)	LAA LTE (proposed). More IoT enhancements

TDD LTE BANDS

Band No.	Frequency band	Band width
42	3400 MHz - 3600 MHz	200 MHz
43	3600 MHz - 3800 MHz	200 MHz

From 3GPP release to incorporation into manufactured devices takes time and depends greatly on customer adoption.

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License Assisted LTE (LAA LTE) aka Unlicensed LTE

- Unlicensed spectrum will ***assist*** licensed spectrum
  - Requires Operator to have Licensed bands
  - Control signaling
- 3GPP NOT standardizing *stand-alone* at this time
- Focused on 5 GHz primarily
- Early stages
  - NTT DoCoMo and Verizon testing
  - QUALCOMM promoting LAA LTE
  - Claims coexistence with Wi-Fi
  - status: CableLabs skeptical on LTE playing nice with Wi-Fi
- Could impact 3.65 GHz down the line

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Our Area of interest: TDD, 3.4 – 3.8 GHz LTE

- Wide bandwidth LTE band: 42 + 43 = 400 MHz!
- 3GHz LTE Still in infancy (relative to other LTE bands)
  - Fixed wireless, Small cell backhaul (Softbank)
  - No significant Devices (UEs); one Asus laptop
- 3GHz LTE interest group formed (UK B/PCCW)
- 3GPP release 9 is common, Release 10 is out (but still with bugs).
- Similar in-building penetration vis-à-vis 2.6 GHz
  - *More than 20 operators with plans for commercial 3.5GHz*
  - *Who: (a) WiMax (Bahrain) (b) Backhaul –Bahama (c) MBB (Japan; in process)*

Comparing the PMP 450 to LTE

	PMP 450 Technology	TDD LTE
Product Maturity	Field proven: >55 countries, >300k units deployed over 2.5 years	3 GHz LTE not yet widely deployed
Air Interface Technology	Secure air interface, proprietary and cannot be decoded without proprietary equipment	Secure, OFDMA in DL and UL SC-FDMA
RF Environment	Purpose built for noisy spectrum	Designed for clean spectrum
Network Complexity	Non hierarchical, Simple, Flat, Easy-to-deploy architecture and maintain Training requirements are simpler and common across platform	Complex network - RAN and EPC Designed for mobility (roaming), and battery life preservation Specialized Training requirement
Latency	2.5 ms frame and scheduler results in low latency of 3 – 5 ms. Consistently low due to mature scheduling mechanisms	Latency of 5-10 ms. 50 ms one time setup latency, reports of longer latency (>30 ms)
EIRP	Radio purpose built to work within EIRP limits → Lower power consumption and savings to end customers	Components designed for high power licensed band transmission → suboptimal cost per byte transmitted

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Comparing the PMP 450 to LTE (cont'd.)

	PMP 450 Technology	TDD LTE
Feature Responsiveness	Control of entire network equipment (i.e. not tied to standards) means: • Features that cross AP-SM boundary • No eco-system dependency • Faster adoption of new functionality	Standardization is good. BUT – • RAN features take time to standardize • Interop requirements increase as features are added • Adds to cost and complexity
Deployment architecture	L2 bridge or L3 ⇒ Easy backend Integration	Tunneled mobility architecture is unnecessary and adds complexity and overhead for a fixed wireless network
ROI Time Horizon	Shorter payback period due to Lower CapEx & OpEx	Longer payback period due to equipment expense, recurring license fees, complex gateways and core equipment requirements
Traffic architecture	Traffic can break out close to the edge at the Tower. Flexible architecture	LTE requires all traffic to be tunneled to a backend PGW

PMP CASE STUDIES

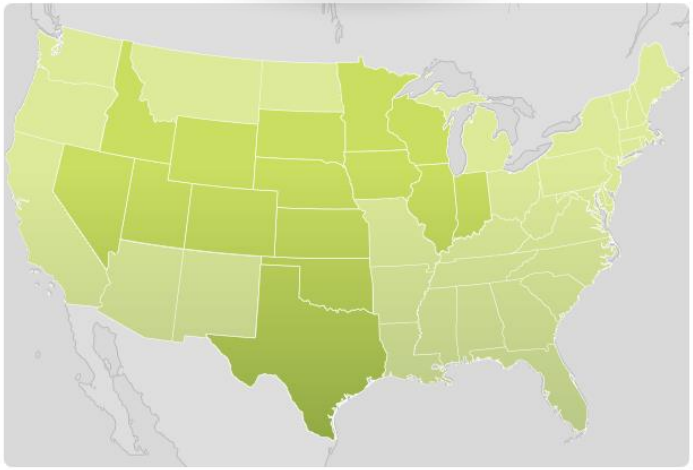
NGI - Italy

- Over 1,500 PMP450 installed in our network in last 18 months
- Over 55k SMs deployed (with 60k scheduled for next year)
- Over 150 PMP450 with >150 SMs
- **Performance** up to 60Mbps aggregate on real world (cell radius 20km)
- **Low latency and jitter**
- **Very good user experience**
- **Reliable**
- Fully integrated in our network management system

eolo

Rise Broadband - USA

- Family of companies
- Over 175k subscribers
- Many different geographical markets
  - Across 15 states
- Grow by acquisition and value Cambium networks higher than others (due to ease of integration with their current network)
- Key differentiators for Rise Broadband:
  - **Confidence in platform (Experience, Reliability and Quality)**
  - **Spectral efficiency** and ability to service dense areas (**Scalability**)



Silo Wireless

Challenge	• Increasing demand for broadband services exceeded the capacity of the existing wireless broadband network. • Silo needed to continue to satisfy existing customers while adding new subscribers.
Solution	• Migrate backhaul infrastructure to licensed spectrum • Deploy PMP 450 access networks to business and residential customers in dense locations • Deploy ePMP access networks to customers in low density areas
Results	• Consistent network architecture enables rapid growth • Increased customer satisfaction from business and residential customers • Plans for offering new services to existing customers and expanding to add new customers

SILO WIRELESS

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SMART, Philippines

Challenge	• SMART telecommunications a wireless and wireline service provider. • They wanted to reach new revenue opportunities and rapidly expand their network to offer voice connectivity to locations where dial up connectivity did not yet exist.
Cambium Networks Solution	• They chose cost effective unlicensed solution for mass deployment. • They deployed Cambium wireless broadband point to point and point to multipoint solutions.
Cambium Solution Value	• World's largest unlicensed wireless broadband deployment. Reaching new revenue opportunities and breaking open new revenue streams quickly • 25 cities installed in less than one year • Serving hundreds of thousands of subscribers since 2005

Telemar

Application	• Business and residential customers in rural Vicenza Italy were waiting for broadband connectivity • Telemar saw the opportunity and connected them with wireless broadband
Challenge	• Strong demand for broadband services required a solution that was scalable to support rapid growth
Solution	• After testing multiple solutions, Telemar deployed the PMP 450 wireless access solution because of scalability • One network supports more than 1,000 government, business and residential customers, and growth is continuing

Telemar
internet quality provider

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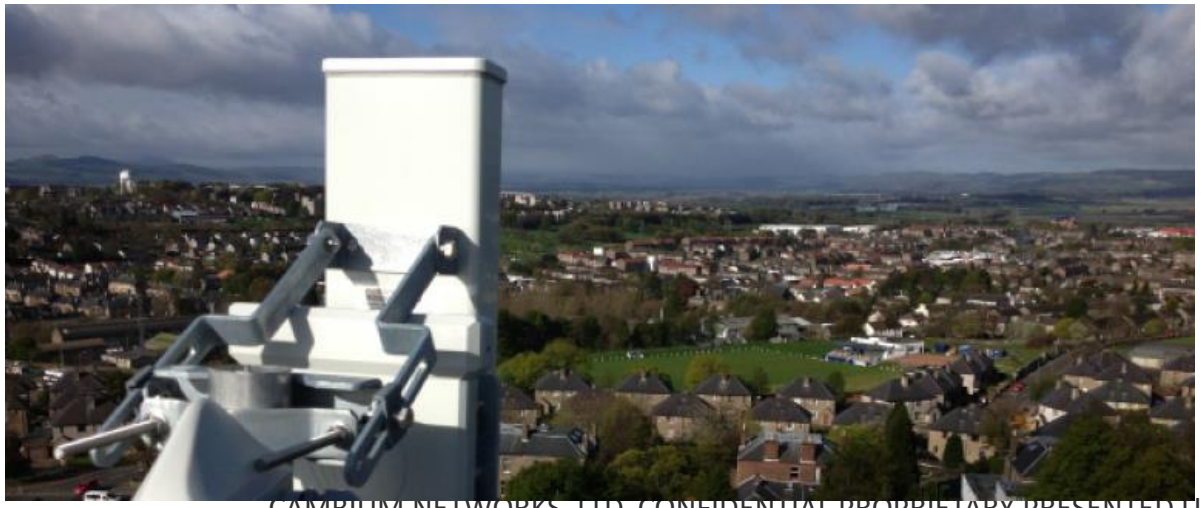
City of Palm Beach, Florida

Application	• Video surveillance for public safety
Challenge	• Need one system for video surveillance and Automatic License Plate Recognition (ALPR). • High reliability • Solution must use unlicensed bands • Solution must be installed so as not to be obtrusive
Solution	• PTP backhaul infrastructure • PMP wireless access network • Integrated to cameras and ALPR systems covering the entire town and bridges • Installed in weeks, with zero downtime

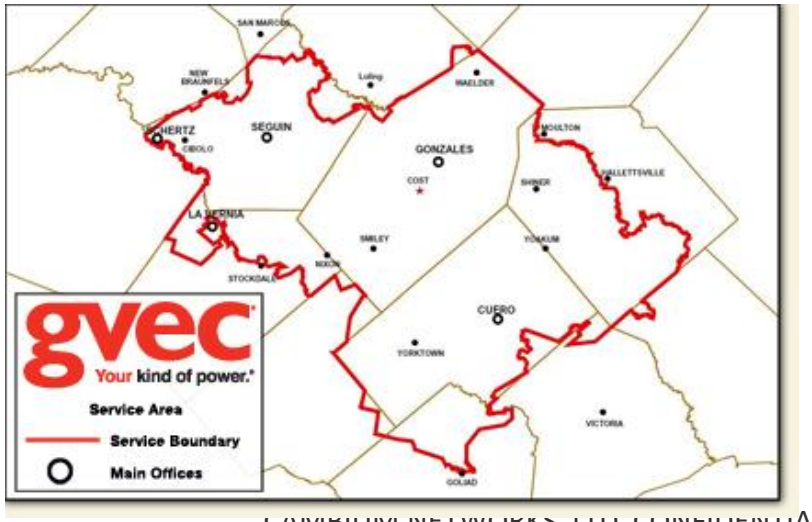
Dundee, Scotland

Application	• Located in rural Scotland, Dundee was awarded the ICF Founders award to transform life in broadband.
Challenge	• Deliver broadband infrastructure to revitalize business and residential connectivity • Connect 150,000 citizens in a 21 square mile area
Solution	• PTP wireless backhaul to the area • PMP wireless access network to provide wide area coverage • Increased bandwidth to businesses 3X at lower cost • Provided residential access to many for the first time • Reliable performance, with extensions planned



GVEC

Application	• Guadelupe Valley Electric Cooperative (GVEC) is a utility that covers 3,500 square miles in south Texas • Has 245 miles of transmission lines with 41 power transmitters • Provide Video, voice and data communications services to current power customers
Challenge	• Serve a customer base with communications service • Needs to be reliable to satisfy customer needs • Needs to be low total cost to fit GVEC business model
Solution	• PTP licensed and unlicensed backhaul infrastructure • PMP unlicensed access network



gvec
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