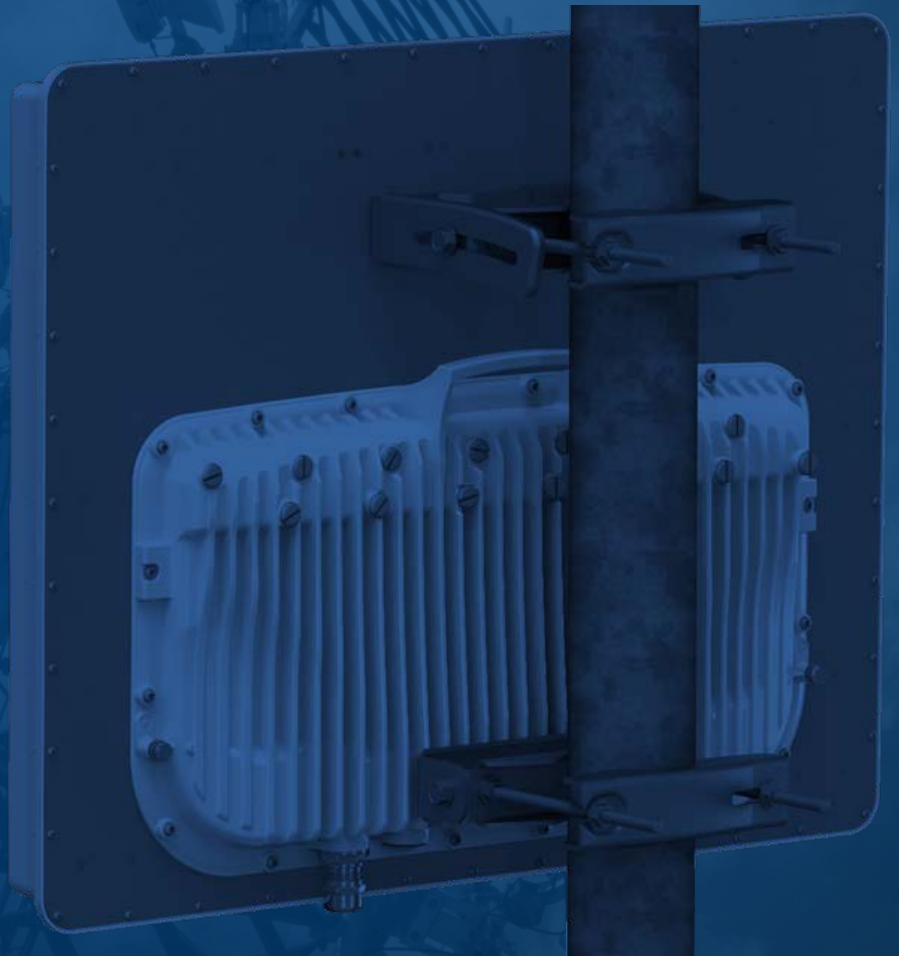


Introducing *cn*Medusa™

June 2016



Who Is Cambium Networks?



Industry leader in Point-to-Multipoint and Point-to-Point IP Wireless Broadband Solutions

**Headquartered in Rolling Meadows, Illinois
with major development centers in the UK and India**

**More than 5 million nodes shipped totaling over \$1B
to thousands of networks in over 150 countries
>700k PMP 450 Subscribers deployed in under 3 years**

**Uniquely positioned to deliver breakthrough
Wireless Solutions to network operators globally**

**Over fifteen years of technical innovation and
serving network operators around the world**

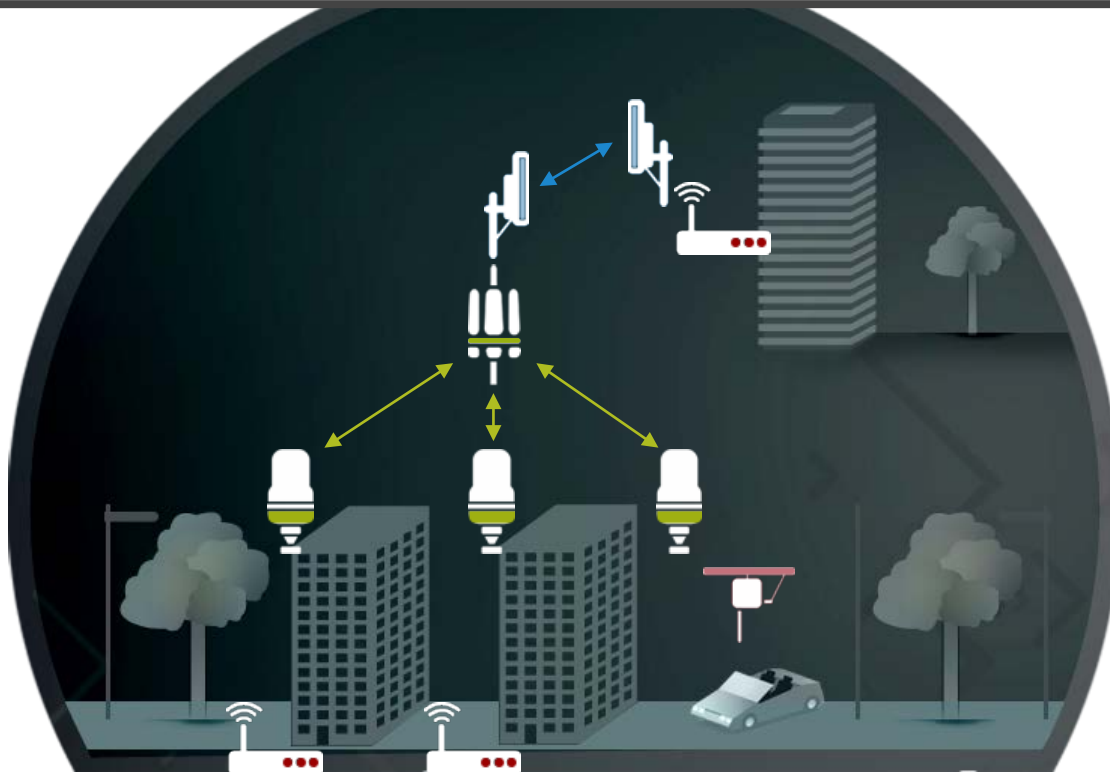
Cambium Value Proposition



- **Connect the unconnected** – people, places, and things
- Best-in-class **resiliency, security and scalability**
- **Affordable** solutions targeted at **developing markets** globally
- **Bridge hard to reach distances** wirelessly from 2 meters to 245 kilometers
- **Cloud-based management** of devices

Cambium Solutions Overview

From 2 meters to 245 km



Point-to-Point



Point-to-Multipoint



Cloud-Managed WiFi

Point-to-Point Backhaul Layer



Secure with proven reliability

High Data Rate 125Mbps – 2+Gbps

Best in class spectral efficiency

Unlicensed, Licensed offerings

Point-to-Multipoint Distribution Layer



Secure, Reliable & Scalable

Up to 375+Mbps throughput

LOS and NLOS Technologies

Unlicensed, Licensed Solutions

Cloud-Managed WiFi Access Layer



Scalable & Enterprise-grade

Indoor & Outdoor

Cloud Management

Complete Network Lifecycle Management – one Manager

cnMaestro™

Planning

Network Management

Inventory Management

WiFi Controller

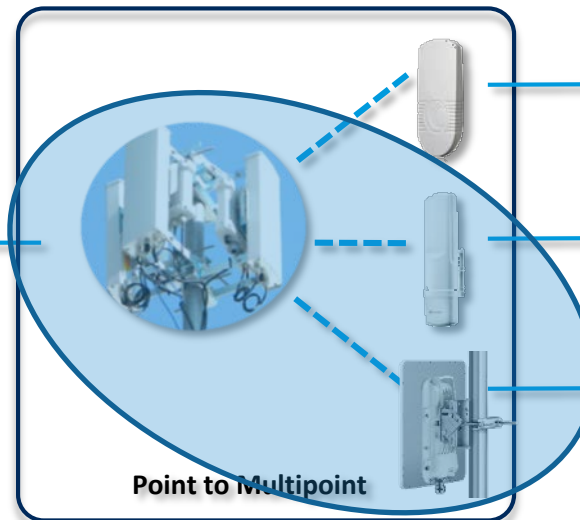
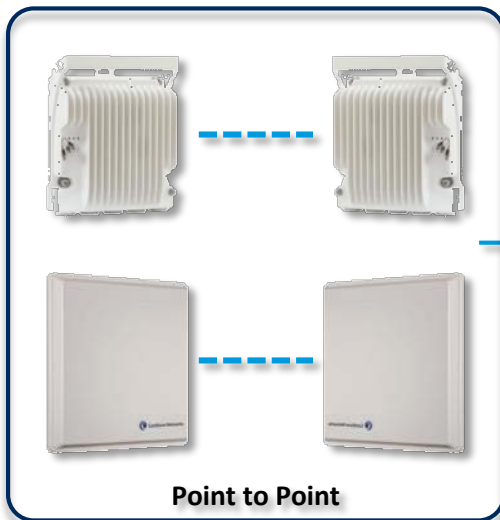
Support & Warranty Services

From 245 km to 2 m

Long Distance: PTP 650, 820

Distribution Access: PMP 450, ePMP

Edge Access: cnPilot



Cambium 450

- Flagship PMP product family from Cambium Networks
- Dramatically increases overall **system capacity**
 - **Over 125 Mbps per Access Point in 20 MHz channel**
 - **Increases to 30 and 40 MHz channels increases capacity >250Mbps**
 - **Over 1.5 Gbps of tower bandwidth possible**
- 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 syncing capability** to maximize spectral efficiency and very low latency **supporting VoIP and video**
- Platform evolution and expansion with 450d, 450i

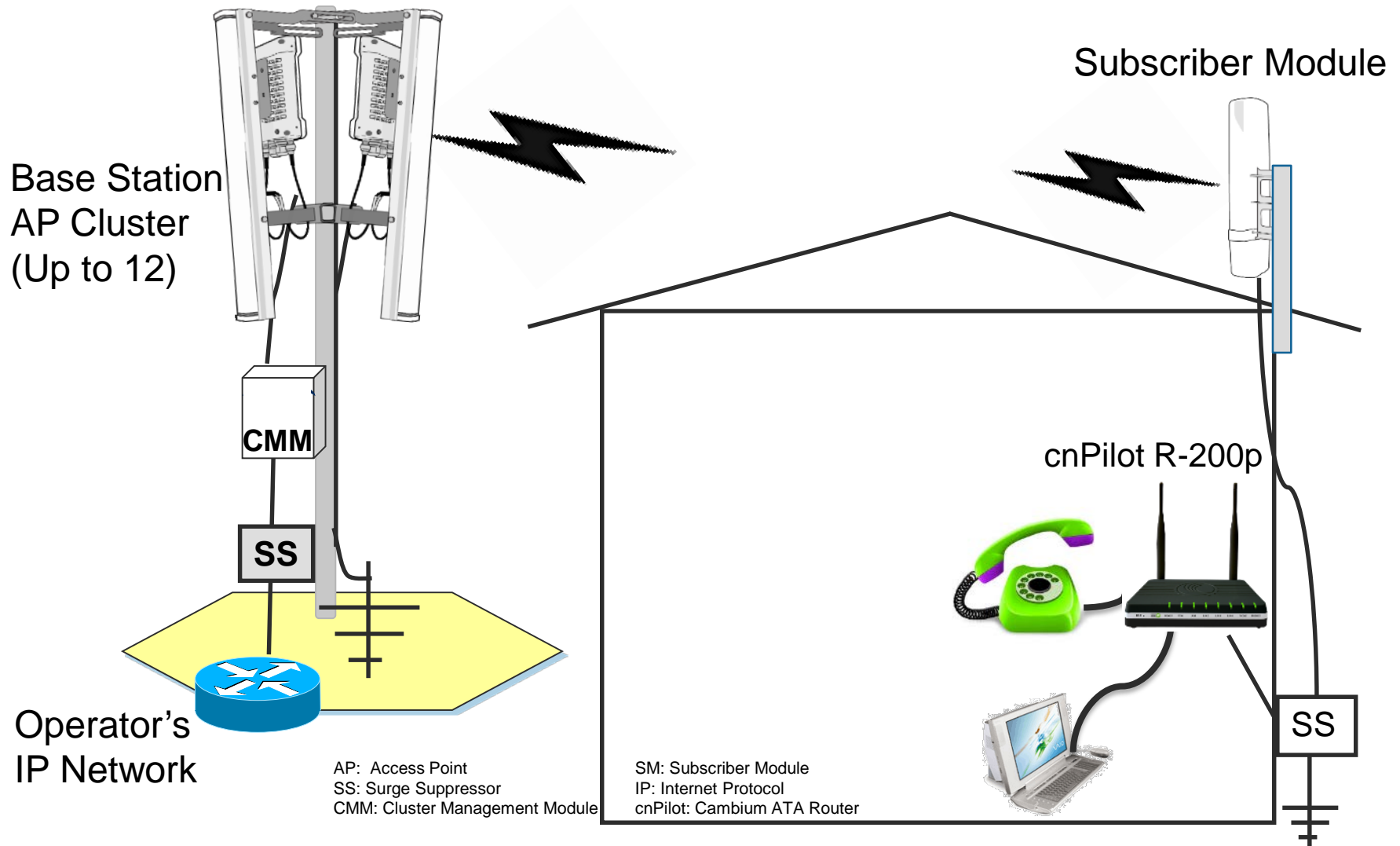


Continual Performance Evolution

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, Optimized performance	Introduction of 450i – Advanced Radio Hardware
Larger MTU Size	1700 Byte MTU	MPLS Tag-Friendly
Feature Rich QoS	Strict Priority Support / Flexible QoS methods and bandwidth mgmt	Controllable, Predictable Performance

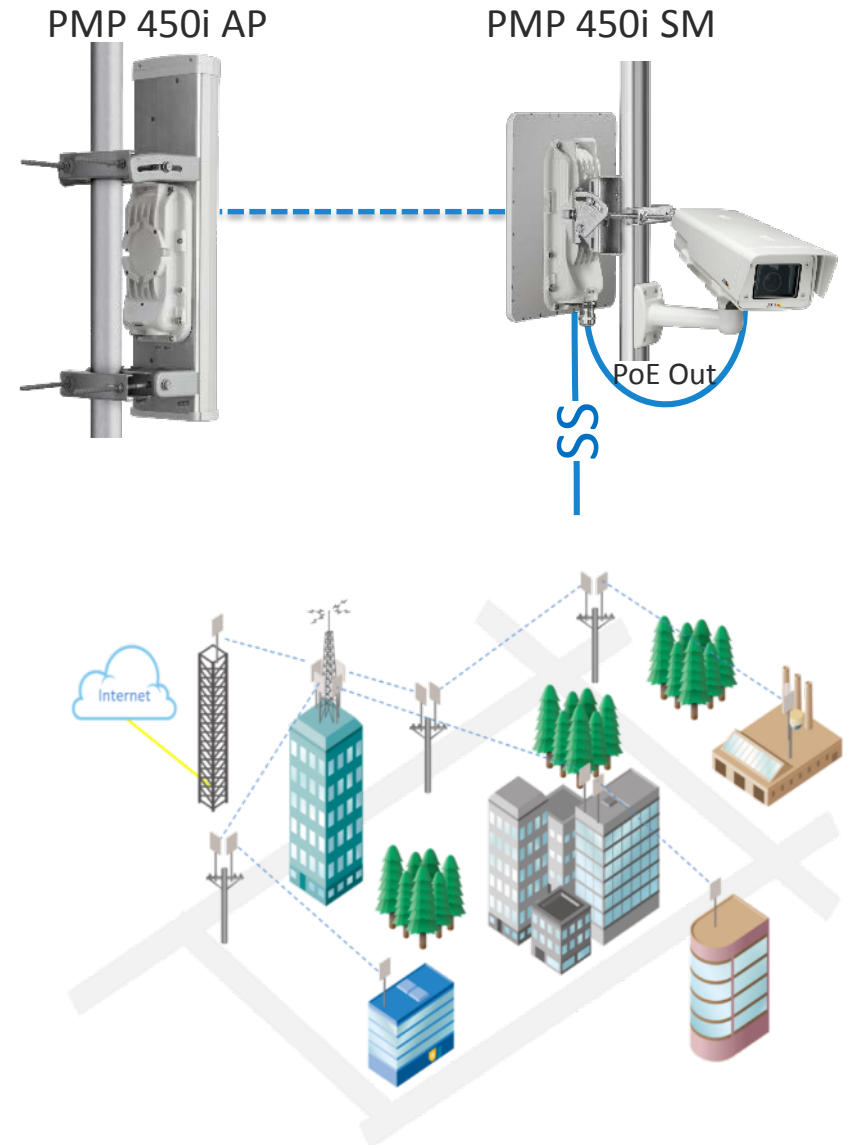


Architecture: PMP 450 Residential Applications

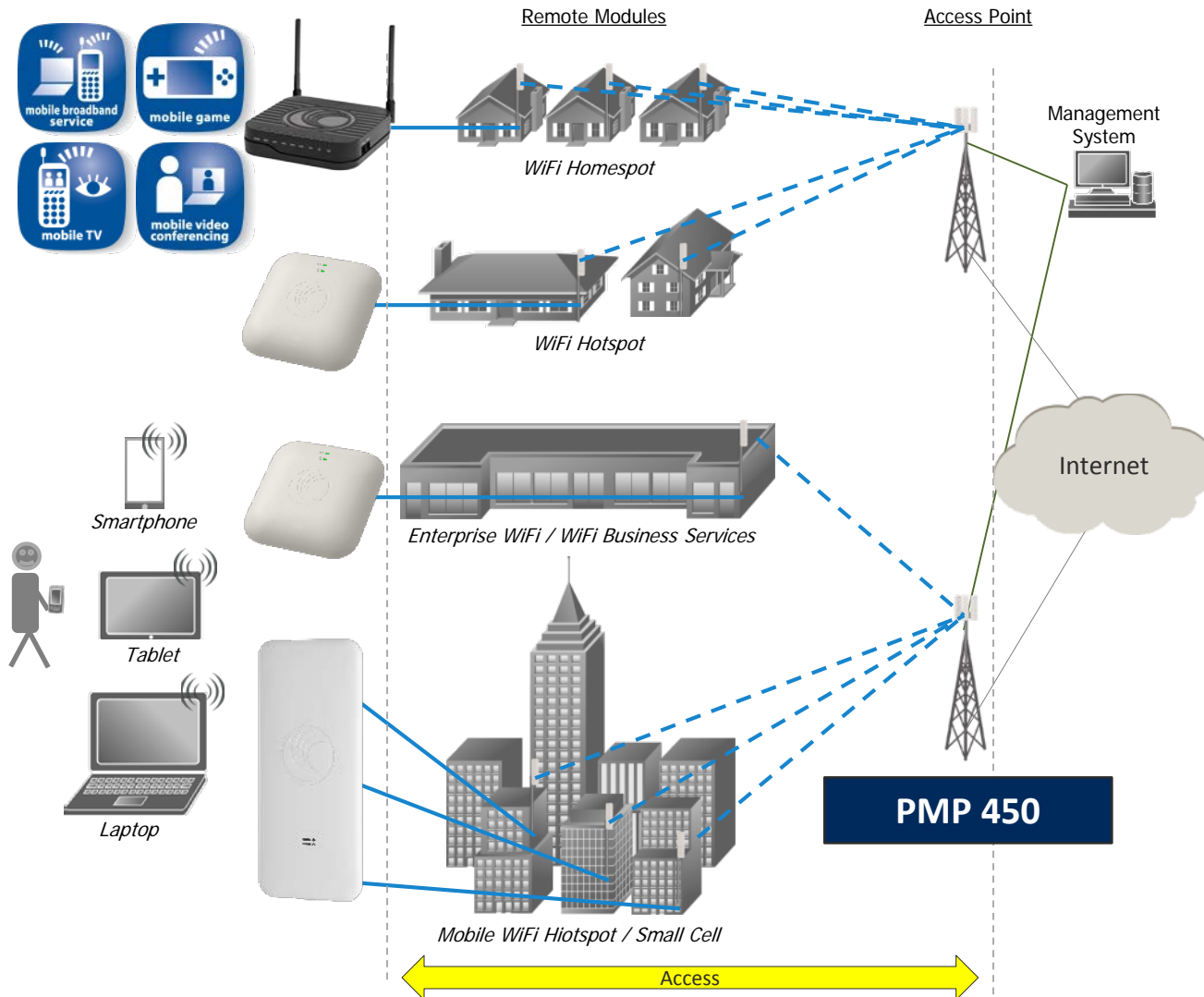


Applications: PMP Video Surveillance

- **Complete wireless solution** that can be mission critical reliability:
 - provide both backhaul and last mile solutions
 - **LOS, nLOS and NLOS** capability with outstanding performance, no one can compete
- Outstanding **Security** Protection
 - Secure Management protocols
 - AES 128-bit encryption
 - Roles-based security transaction auditing
- Industry **Leading Radio Performance** to meet video streaming requirements:
 - High radio performance, including AMOD, MIMO, Tx power and Rx Sensitivity, Cyclic Prefix, Low latency and jitter, etc.
- Ruggedized **Small Product Footprints**, easily pass municipal outdoor esthetics ordinances



Applications: Carrier Wi-Fi Services



- Extend subscription services for mobile and nomadic subscribers
- Enable WiFi offload to alleviate macro-cell congestion
- Enable location-based services for social media and networking
- Enable WiFi analytics to improve customer experience management and marketing analytics
- “Single pane of glass” and cloud management

PMP 450 Globally Deployed

- Deployed in systems worldwide
- **Extreme Scalability**
 - Largest single network using only PMP 450 just deployed 100,000th subscriber
- North America is the strongest region, followed by EMEA
- Important strategic wins with large Service Providers in emerging markets, both in CALA (Peru and Mexico) and India
- **Flexible Solutions**
 - Customer sizes vary widely from a few hundred subscribers to hundreds of thousands
 - Several frequencies available to provide solutions for many situations (many tools in the toolbox) including 900 MHz, 2.4 GHz, 3GHz and 5GHz
 - Residential and Enterprise Access; Industrial Internet of Things; CCTV Transport; WiFi Transport

Network Operator Challenges

- Spectrum Availability
 - Available 5 GHz spectrum
 - Relatively narrow 3 GHz assignments
- Noise Floor and Interference
- Network Operator Business Case against ARPU
 - Capital Investment
 - Operating Expense
- Ramp in average capacity demand per served address

Go **MASSIVE**

cambiumnetworks.com/gomassive

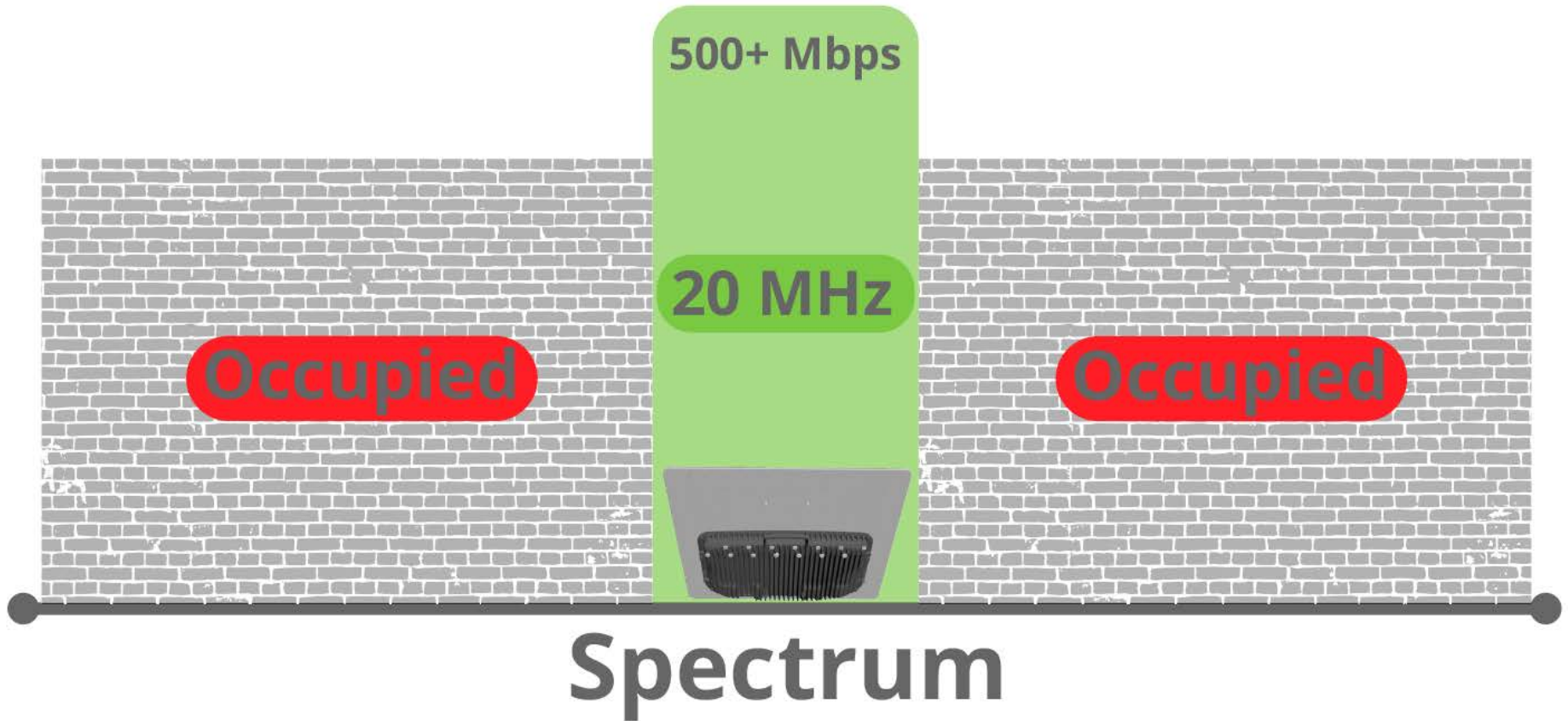


Cambium Networks™

Why Go Massive Now?



Why not Just Increase Channel Size?



Can you Afford Total Network Replacement?



Introducing *cn*Medusa™

- **Increase Capacity for Tomorrow's Media Rich Applications**
 - Over 400 Mbps today, roadmap beyond 1 Gbps per sector
- **Do More with the Same Spectrum**
 - Over 400 Mbps in a 20 MHz channel
 - 20 bps/Hz, over 40 bps/Hz with frequency re-use
- **Protect your Investment**
 - Use existing Subscriber deployments in the enhanced network

cnMedusa - Ground Breaking Innovation

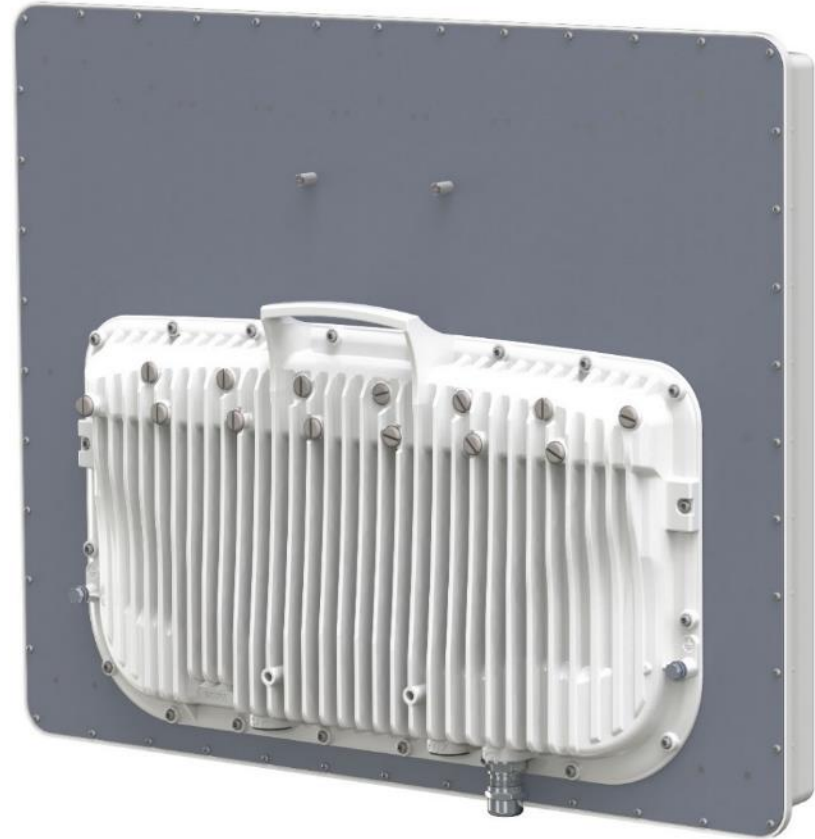
- Truly Massive, going beyond standards of LTE
 - 14 x 14 Massive MU-MIMO
- Beamforming sector array antenna system
 - Integration with radio eliminates points of failure
 - Dramatically lowers product cost
 - Reduces installation costs and installation time
- Enables operation in high-noise environments, in narrower channels, to a higher density of customers

*cn*Medusa - Just the Beginning

- ***cn*Medusa** is more than just a product
 - It represents the technology that enables “5G-like” capacities and provides the platform for innovation
 - Combining innovation in radio design, antenna technology and extreme RF engineering allows Cambium to unleash this first-of-its-kind performance engine
- **PMP 450m** is the first product powered by *cn*Medusa... but it won't be the last
 - Created to leverage the power of the 450 platform
 - Yet allow capacities to reach levels beyond expectations

PMP 450m

- **More than 3x Capacity vs. 450/450i**
 - *cnMedusa*[™] Massive MU-MIMO technology allows simultaneous communication with multiple SMs in a sector
- **One Simple device to install**
 - Integrated 90° sector beam-forming array
 - Radio integrated, only a single cable necessary
 - 20" x 25" x 4" (52x65x11 cm)
 - 31 lbs. (14.1 kg)
- **Supreme Spectral Efficiency**
 - Achieve over 400 Mbps in a 20 MHz channel



Cambium 450m: Key System Features

Features	Customer Benefit / Competitive Advantage
cnMedusa™ Massive MU-MIMO	Combining Beam Forming and multiple RF chains yields more than 3X throughput , simply by changing the AP Hardware (in a typical deployment)
Integrated 90° Sector Antenna Array	Leading Edge antenna innovation brings Smart Beamforming to the 450 platform, ZERO RF cables to connect or weatherproof
Multiple RF Chains	14 x 14 MIMO system allows simultaneous communication to up to seven SMs
Utilize existing SMs	Realize capacity upgrade without any truck rolls to Subscriber sites
No need for Frequency Re-plan	Using the same 20 MHz channel, capacity enhancements are attained without any network changes , but substantial increase in spectral efficiency
Multiple I/O Options	AUX port (second Ethernet port) with multiple functions allow for greater flexibility of deployment. A SFP port also available for optical connection.
Wideband Radio 5150 – 5925 MHz	One SKU to allow operation in all 5 GHz unlicensed bands

What makes up Massive MU-MIMO?

- Massive MU-MIMO encompasses several technologies:
 - MIMO
 - MU-MIMO
 - Beamforming
 - Massive MIMO
- All of these, and their own supporting technologies working together, add up to a Massive MU-MIMO solution.

What is MIMO?

- Multiple Input Multiple Output (MIMO) is a range of technologies to:
 - Multiply wireless link capacity without using more spectrum
- Achieved by:
 - Allowing the system to transmit and/or receive more than one data signal simultaneously
- In a single polarization system, data is transmitted and received on a single polarity of the radio wave (i.e. a Vertical polarization antenna)
- In a dual polarization system, horizontal and vertical (or dual slant) polarities are used to transmit and receive data.
 - This can double the capacity, by sending two sets of data
 - Or, the same data can be sent twice, improving reliability
- A separate antenna element is used for each polarization

Multiple Antenna MIMO Techniques

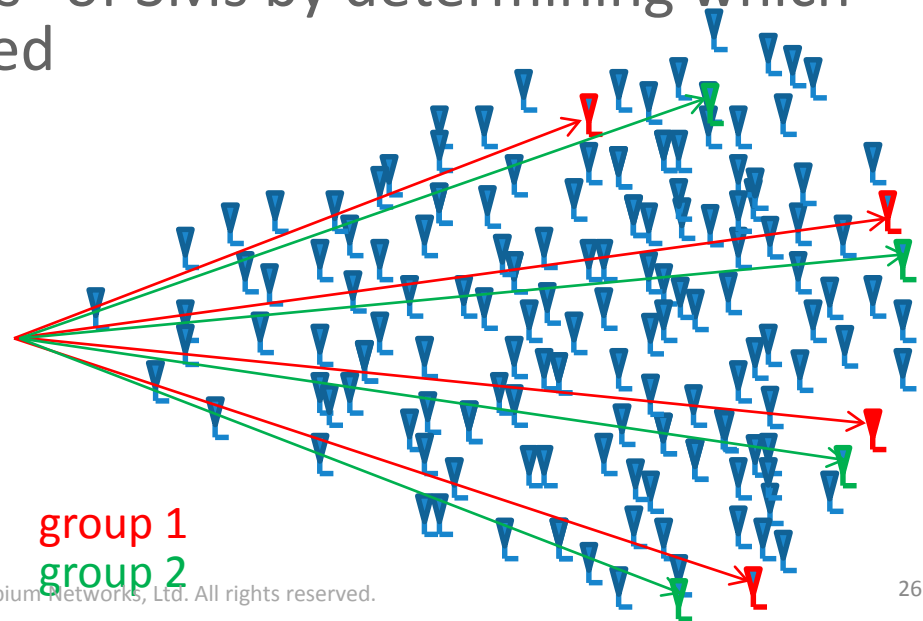
- Multiple antennas, each dually polarized, can be used to multiply capacity again without requiring more spectrum
- When more antennas are added, the complexity of signal processing required to extract data from the transmissions increases
- Systems can use arrays of antennas to multiply the gains from MIMO
 - These are described as A:B (or A x B)
 - This refers to an array of antennas with A number of Tx antenna elements with B number of Rx antenna elements
- Beyond 8x8, this is considered **Massive MIMO**

What is MU-MIMO?

- MIMO techniques are primarily designed to increase capacity between **two** wireless nodes
- Multi-User MIMO (MU-MIMO) uses the antenna array to communicate to **multiple** wireless nodes simultaneously
 - The AP communicates to multiple subscribers simultaneously rather than each in serial
 - This is done via **Spatial Multiplexing**

Spatial Multiplexing

- Spatial Multiplexing is the process of using multiple radio beams to communicate to multiple subscribers, where the beams are separated by space
 - By separating the beams from each other in space, interference is avoided
 - This works most efficiently if the subscribers are separated by wide angles
- *cnMedusa* creates “groups” of SMs by determining which can be spatially multiplexed
 - Minimum separation of group members is ~6.5 degrees
 - Grouping algorithm runs every TDD frame



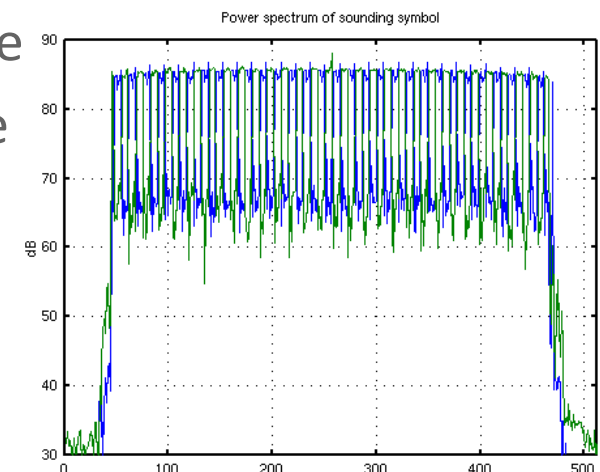
Channel State Information (Sounding)

MU-MIMO requires up to date CSI (Channel State Information) at the Access Point.

cnMedusa periodically collects CSI from all SMs to evaluate channel conditions, then decides which group of SMs can simultaneously access the channel.

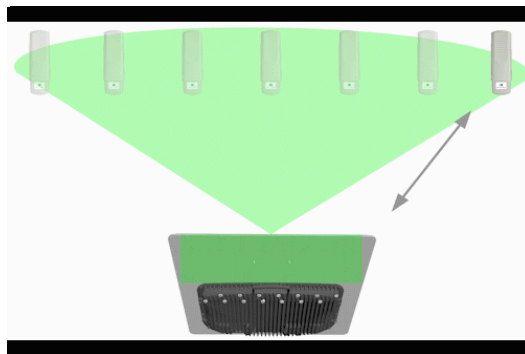
The channel information transmitted by the SM to the AP is used to:

- Determine if the SM is eligible for beamforming or MU-MIMO
- Calculate the PHY weights for beamforming communication
- Establishing groups of SMs in MU-MIMO mode
- Calculate the PHY weights in MU-MIMO mode



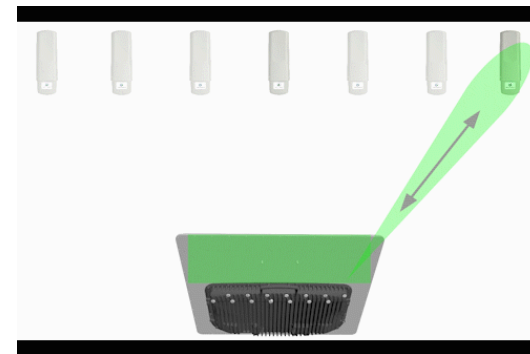
450m Integrated Antenna Array

- In conventional systems, a static sector antenna provides a wide beam, typically covering 90 to 120 degrees
- Beamforming uses an antenna array to dynamically create a narrow beam aimed at the subscriber of interest
 - In advanced systems these beams are moved between subscribers as the subscribers need



Sector Mode

Antenna Gain: 14.5 dBi
Array Gain: 0 dB
Conductive Power: 10 dBm + 8.5 dB +3 dB



Beamforming Mode

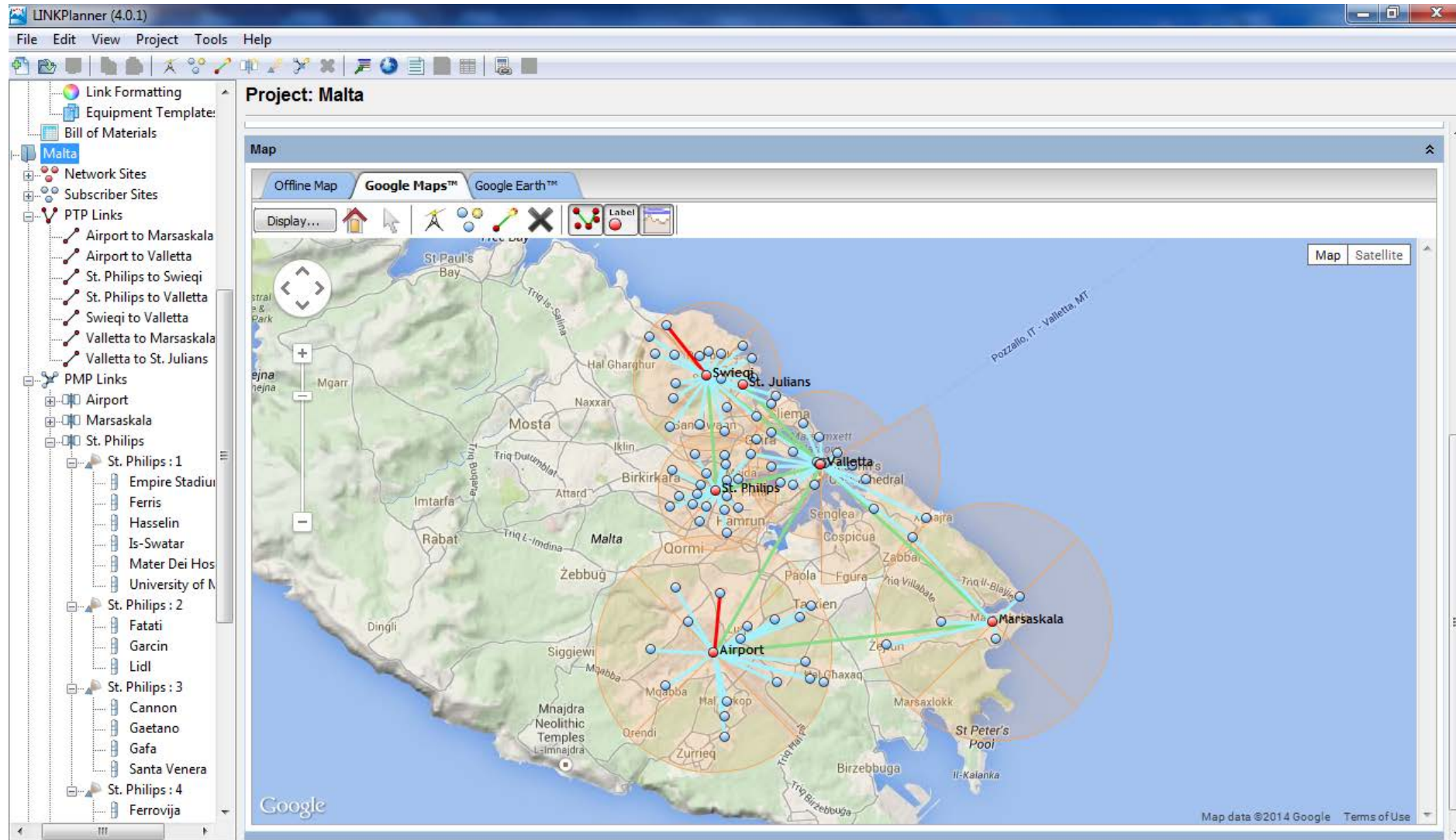
Antenna Gain: 14.5 dBi
Array Gain: 8.5 dB
Conductive Power: 1.5 dBm + 8.5 dB +3 dB

MU-MIMO Operation

1. The access point identifies which subscribers are connected
2. Sounding collected from each SM
3. The antenna array forms a narrow beam covering the subscriber of interest and uses it to transmit and/or receive data
4. This process can occur simultaneously for multiple SMs

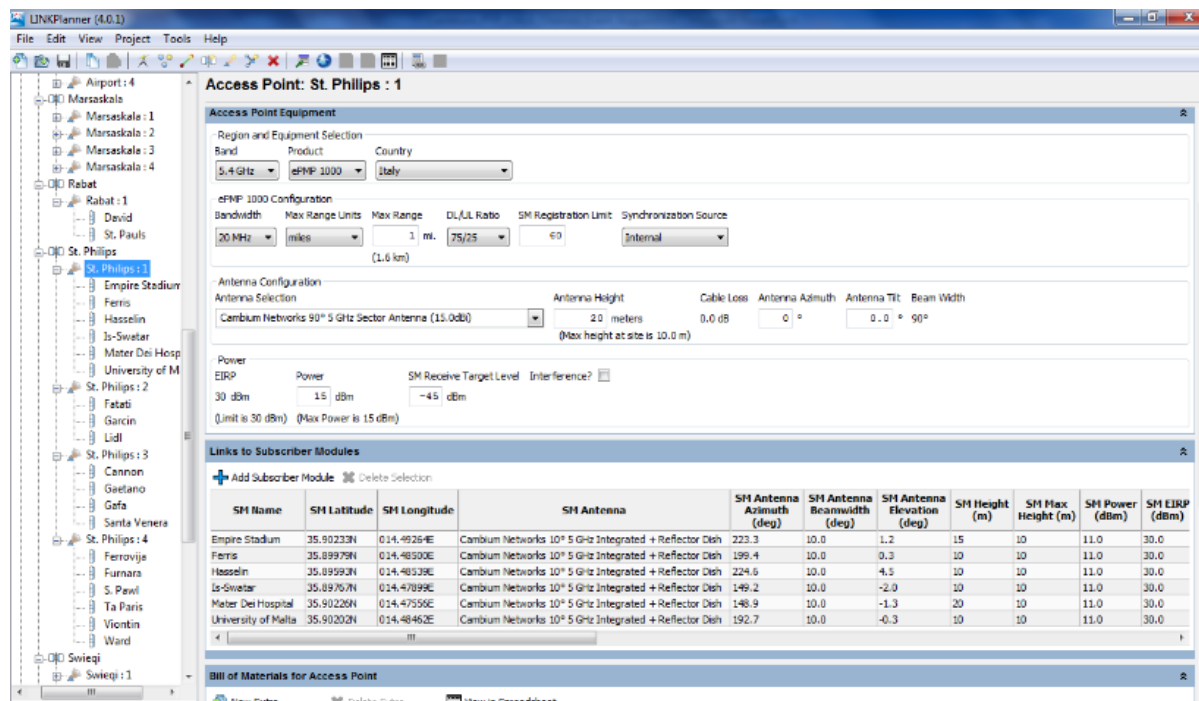


LINKPlanner supports *cnMedusa*™



LINKPlanner Update

- Input existing sector to LINKPlanner
- “Swap” existing 450 or 450i AP with new 450m
- Compare the expected throughput gain before even purchasing equipment



Planning for cnMedusa™ in LINKPlanner

Choose PMP 450m
from product list

Choose Sector to show legacy mode
Choose Downlink MuMIMO for MuMIMO prediction

Access Point Equipment

Region and Equipment Selection

Band	Product	Country	Sync Input	Operating Mode
5.8 GHz	PMP450m	United States	Generate Sync	Sector

PMP450m Configuration

Bandwidth	Color Code	Range Units	SM Range	Frame Period	Downlink Data	Contention Slots	Broadcast Repeat Count	Total Virtual Circuits
20 MHz	0	miles	10.0 mi. Max: 10 mi.	2.5 ms	75 %	3	0	112

Antenna Configuration

Antenna Selection	Antenna Height	Antenna Azimuth	Antenna Tilt	Beam Width
Cambium Networks 90° PMP 450m Integrated Antenna (16.0dBi)	61 meters (Max height at site is 70.0 m)	300 °	0.0 °	90°

Power

EIRP	Power	SM Receive Target Level	Interference?
36 dBm (Limit is 36 dBm)	21 dBm (Max Power is 21 dBm)	-60 dBm	<input type="checkbox"/>

Channel Selection


Channel Plan	Channel
Channel Plan 1	5795.0 MHz (Ch 1)

All other parameter settings are the same as for PMP 450

Comparing performance with PMP 450

PMP 450 AP Performance Summary

Performance Summary (ITU-R)

 View in Spreadsheet

SMs per DL modulation

x8 (256QAM MIMO-B)	0	0.0%	0.00 Mbps
x6 (64QAM MIMO-B)	11	9.9%	3.32 Mbps
x4 (16QAM MIMO-B)	62	55.9%	18.72 Mbps
x2 (QPSK MIMO-B)	32	28.8%	9.66 Mbps
x4 (256QAM MIMO-A)	0	0.0%	0.00 Mbps
x3 (64QAM MIMO-A)	0	0.0%	0.00 Mbps
x2 (16QAM MIMO-A)	0	0.0%	0.00 Mbps
x1 (QPSK MIMO-A)	6	5.4%	1.81 Mbps
Total	111	100.0%	33.52 Mbps

SMs per UL modulation

x8 (256QAM MIMO-B)	0	0.0%	0.00 Mbps
x6 (64QAM MIMO-B)	12	10.8%	1.30 Mbps
x4 (16QAM MIMO-B)	63	56.8%	6.84 Mbps
x2 (QPSK MIMO-B)	32	28.8%	3.47 Mbps
x4 (256QAM MIMO-A)	0	0.0%	0.00 Mbps
x3 (64QAM MIMO-A)	0	0.0%	0.00 Mbps
x2 (16QAM MIMO-A)	0	0.0%	0.00 Mbps
x1 (QPSK MIMO-A)	4	3.6%	0.43 Mbps
Total	111	100.0%	12.04 Mbps

Total Mean Predicted Throughput

x8 (256QAM MIMO-B)	0.00 Mbps
x6 (64QAM MIMO-B)	4.62 Mbps
x4 (16QAM MIMO-B)	25.56 Mbps
x2 (QPSK MIMO-B)	13.14 Mbps
x4 (256QAM MIMO-A)	0.00 Mbps
x3 (64QAM MIMO-A)	0.00 Mbps
x2 (16QAM MIMO-A)	0.00 Mbps
x1 (QPSK MIMO-A)	2.25 Mbps
Total	45.57 Mbps

PMP 450m Performance Summary for the same SMs

Performance Summary (ITU-R)

 View in Spreadsheet

SMs per DL modulation

x8 (256QAM MIMO-B)	0	0.0%	0.00 Mbps
x6 (64QAM MIMO-B)	11	9.9%	10.80 Mbps
x4 (16QAM MIMO-B)	62	55.9%	60.85 Mbps
x2 (QPSK MIMO-B)	32	28.8%	31.40 Mbps
x4 (256QAM MIMO-A)	0	0.0%	0.00 Mbps
x3 (64QAM MIMO-A)	0	0.0%	0.00 Mbps
x2 (16QAM MIMO-A)	0	0.0%	0.00 Mbps
x1 (QPSK MIMO-A)	6	5.4%	5.89 Mbps
Total	111	100.0%	108.93 Mbps

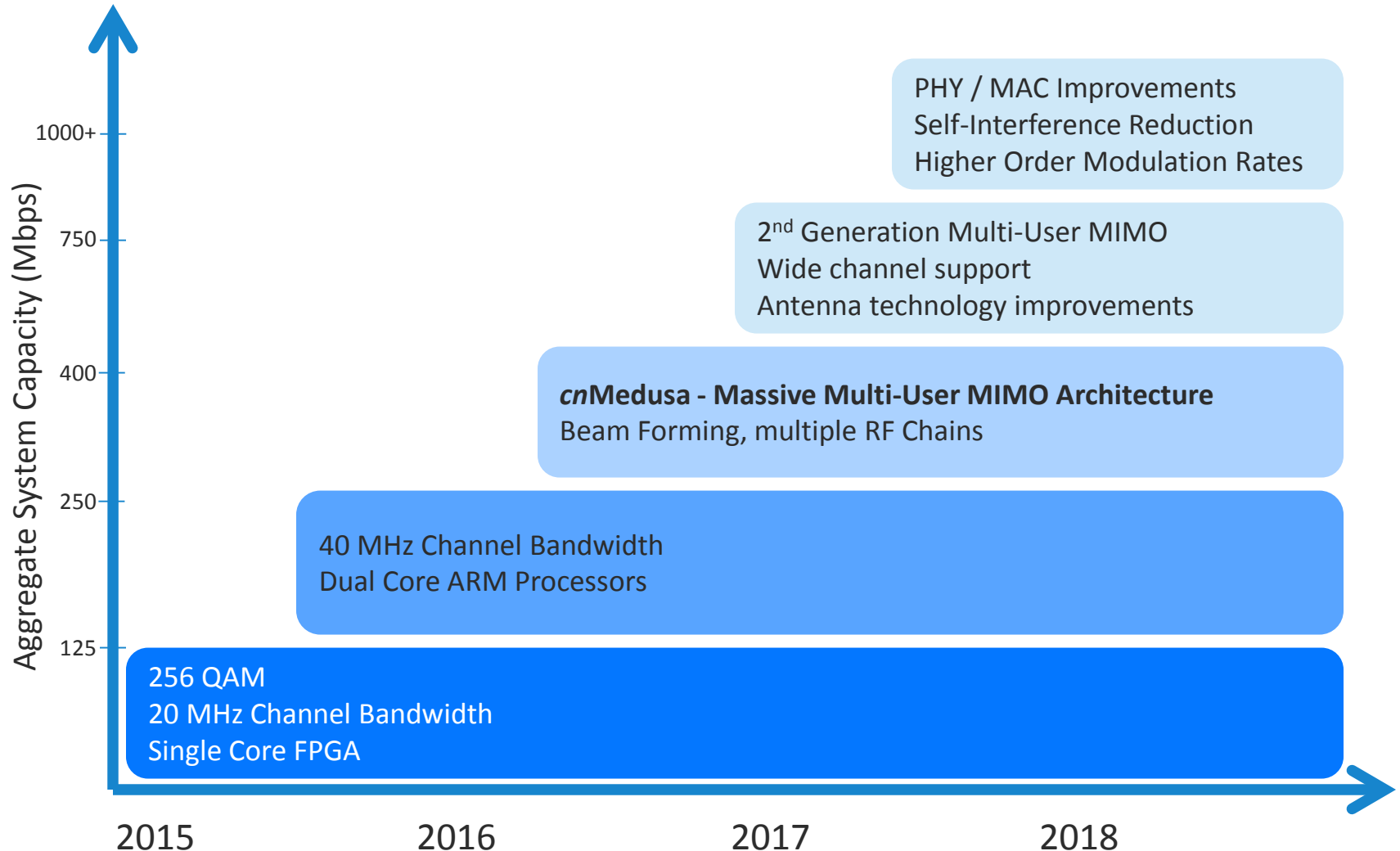
SMs per UL modulation

x8 (256QAM MIMO-B)	0	0.0%	0.00 Mbps
x6 (64QAM MIMO-B)	29	26.1%	4.19 Mbps
x4 (16QAM MIMO-B)	70	63.1%	10.12 Mbps
x2 (QPSK MIMO-B)	12	10.8%	1.73 Mbps
x4 (256QAM MIMO-A)	0	0.0%	0.00 Mbps
x3 (64QAM MIMO-A)	0	0.0%	0.00 Mbps
x2 (16QAM MIMO-A)	0	0.0%	0.00 Mbps
x1 (QPSK MIMO-A)	0	0.0%	0.00 Mbps
Total	111	100.0%	16.05 Mbps

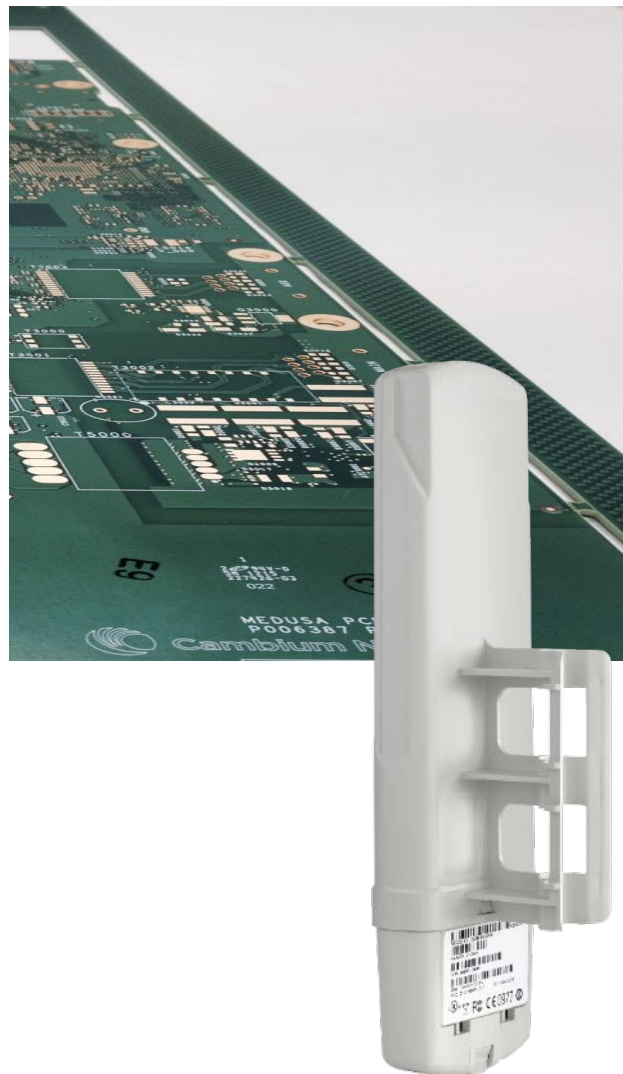
Total Mean Predicted Throughput

x8 (256QAM MIMO-B)	0.00 Mbps
x6 (64QAM MIMO-B)	14.99 Mbps
x4 (16QAM MIMO-B)	70.96 Mbps
x2 (QPSK MIMO-B)	33.14 Mbps
x4 (256QAM MIMO-A)	0.00 Mbps
x3 (64QAM MIMO-A)	0.00 Mbps
x2 (16QAM MIMO-A)	0.00 Mbps
x1 (QPSK MIMO-A)	5.89 Mbps
Total	124.98 Mbps

Data Rate Technology Advancement Horizon



Designed for the Future



- Optimized to reduce Total Cost of Ownership (TCO)
- Scales to 40 MHz operation
 - Maximum realistic channel size for outdoor unlicensed PMP
- Future Proof Platform: FPGA/Quad-Core Processor
- *cn*Medusa MU-MIMO on the PMP 450m
 - Extending life of existing deployed PMP 450 SMs
 - Will support future generation of 450 platform devices
 - Commitment to address 3 GHz next
- Rich roadmap options beyond 2016
 - Non-contiguous channel aggregation (20+20, 40+40)
 - Enhanced Capacity >750 Mbps
 - Higher order MU-MIMO
 - 50% increase in subscriber throughput
 - Re-use of Architecture, Iterative Hardware
 - Support for additional frequencies (3 GHz, 2.5 GHz, ...)
 - OMNI sector for isolated cell sites (decreased TCO)
 - Continued PPS improvements (beyond 600K)
 - Increased throughput (>1 Gbps Real World Capacity)

*Roadmap features mentioned subject to change at any time

*cn*Medusa PMP 450m

- Shipping in volume in September
- 14x14 Massive MU-MIMO supporting seven (7) simultaneous data paths
- Unprecedented spectral efficiency achieving over 40 bps/Hz or 400Mbps in a 20 MHz Channel
- Requires no Evolved Packet Core infrastructure or licensing
- Integrated antenna reduces capital & operating expenses
- Higher user capacity at higher data rates than any comparable solution in the industry

Thank You!

