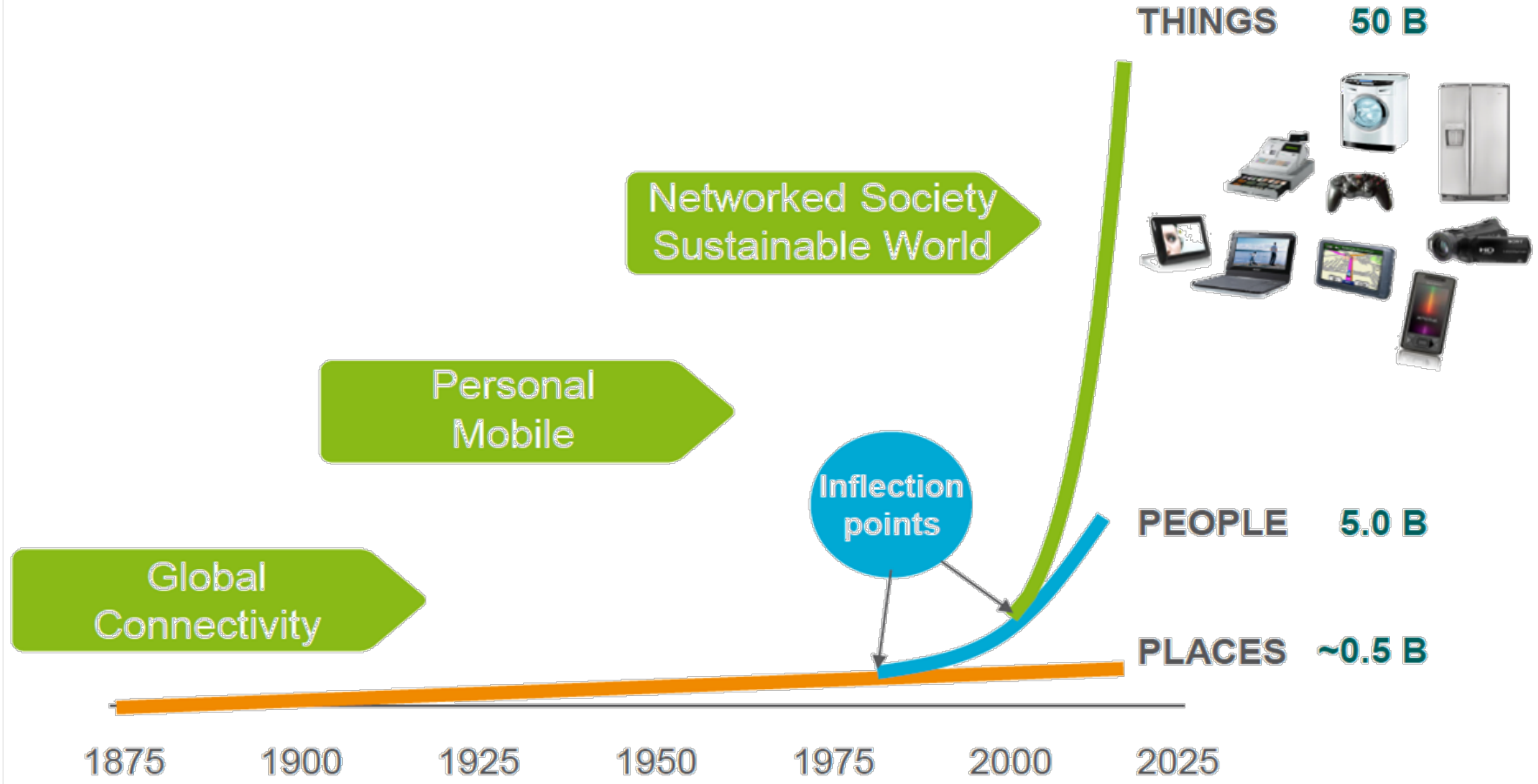
Connecting the Unconnected with Fixed Wireless Broadband A Compelling Solution Even in Unlicensed Band .

Expanding the network to new places and different applications

Sept 2016

Cambium Networks™

The World is Getting Digitized:
The Internet of Things



Source: Ericsson AB, "Infrastructure Innovation – Can the Challenge be met?"

Machine to Machine Connectivity Will Drive Exponential Traffic and Data Backhaul Needs

Need to solve connectivity challenge

Connect the under- and un-connected

Access
Broadband service anywhere

- Fiber connectivity may never be available
- Existing copper may not be suitable for higher capacity
- Geographic terrain and spectrum is cost prohibitive

Backhaul
Edge-to-edge connectivity

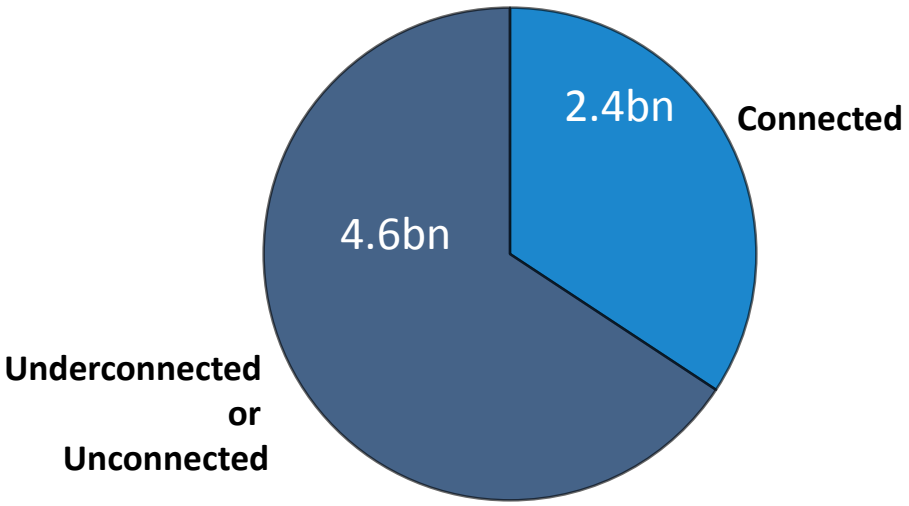
- Need to alleviate congestion and expand coverage
- Deployment must meet varying outdoor environments and municipal regulations
- High performance must be coupled with high reliability and security

Transport
Reliable multi-mode services

- Need to support multi-mode traffic, e.g. 2G, 3G, 4G/LTE, WiFi, etc
- Need to support voice, video, and data
- Need to support circuit- and packet-based traffic

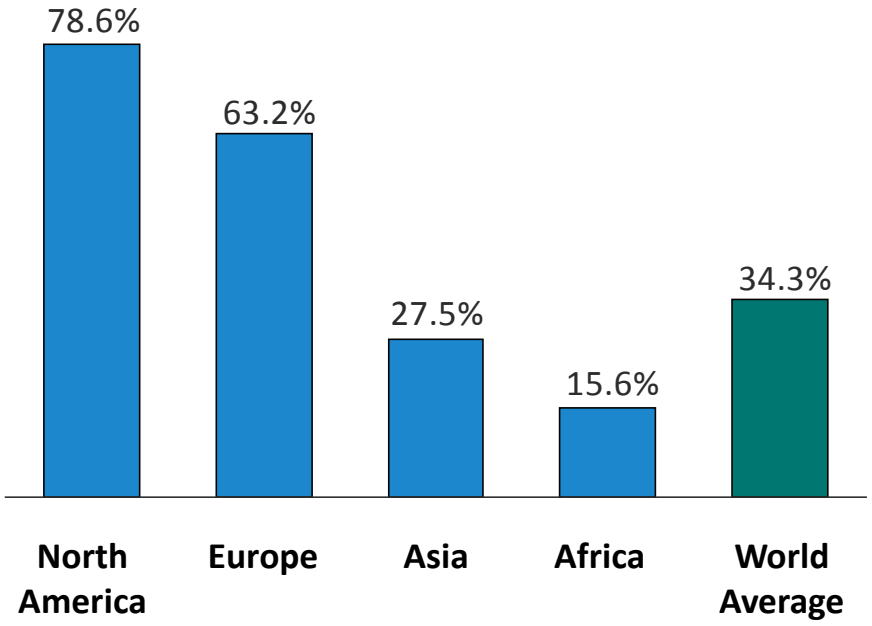
The Market Need

Vast Majority of People do Not Have Access to the Internet



Source: OECD Broadband Portal, 18-July-2013

Significant Disparity in Internet Penetration by Region

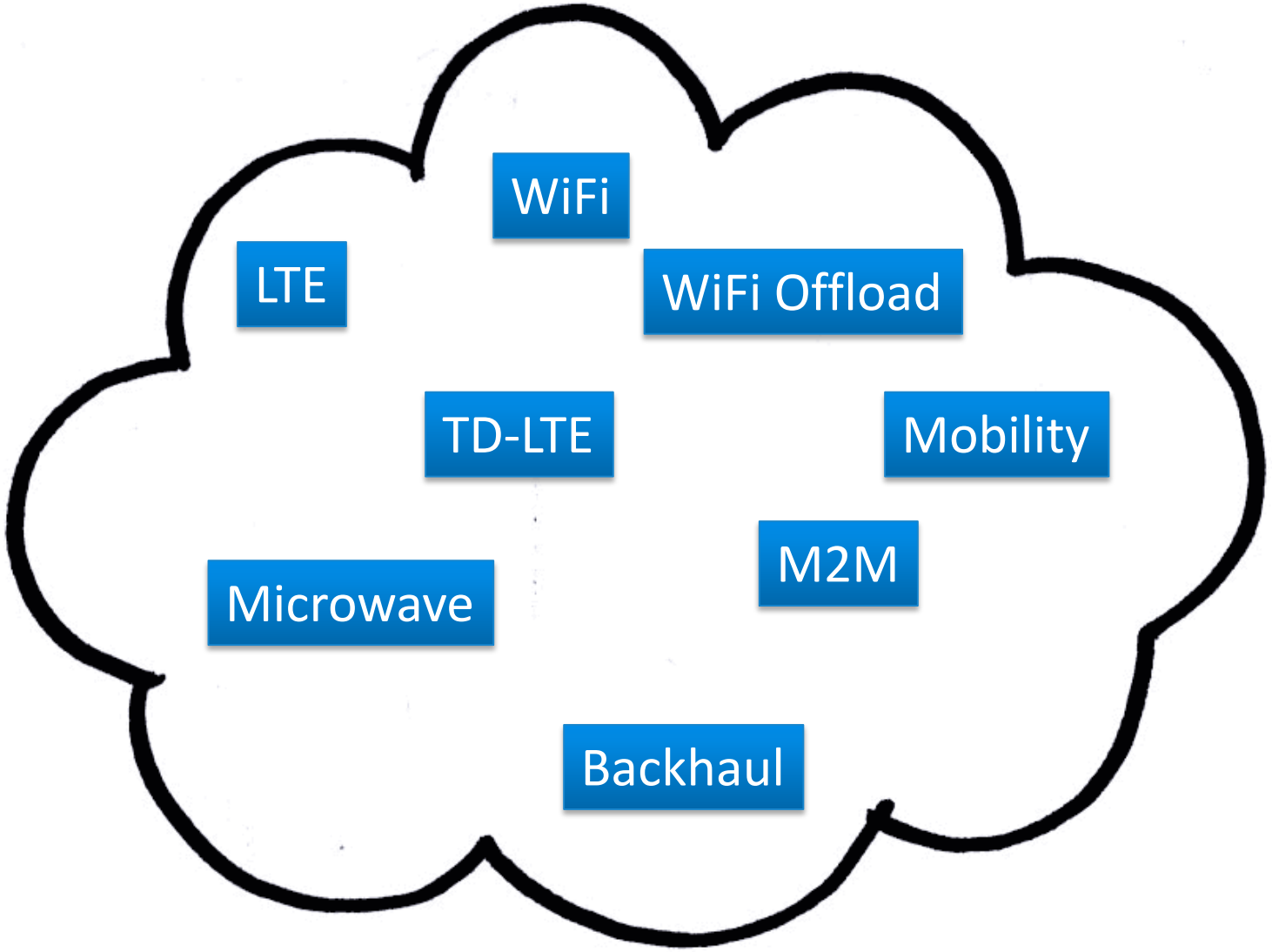


The Cambium Opportunity is to Connect the Un-Connected and Under-Connected Around the World

Wireless Broadband

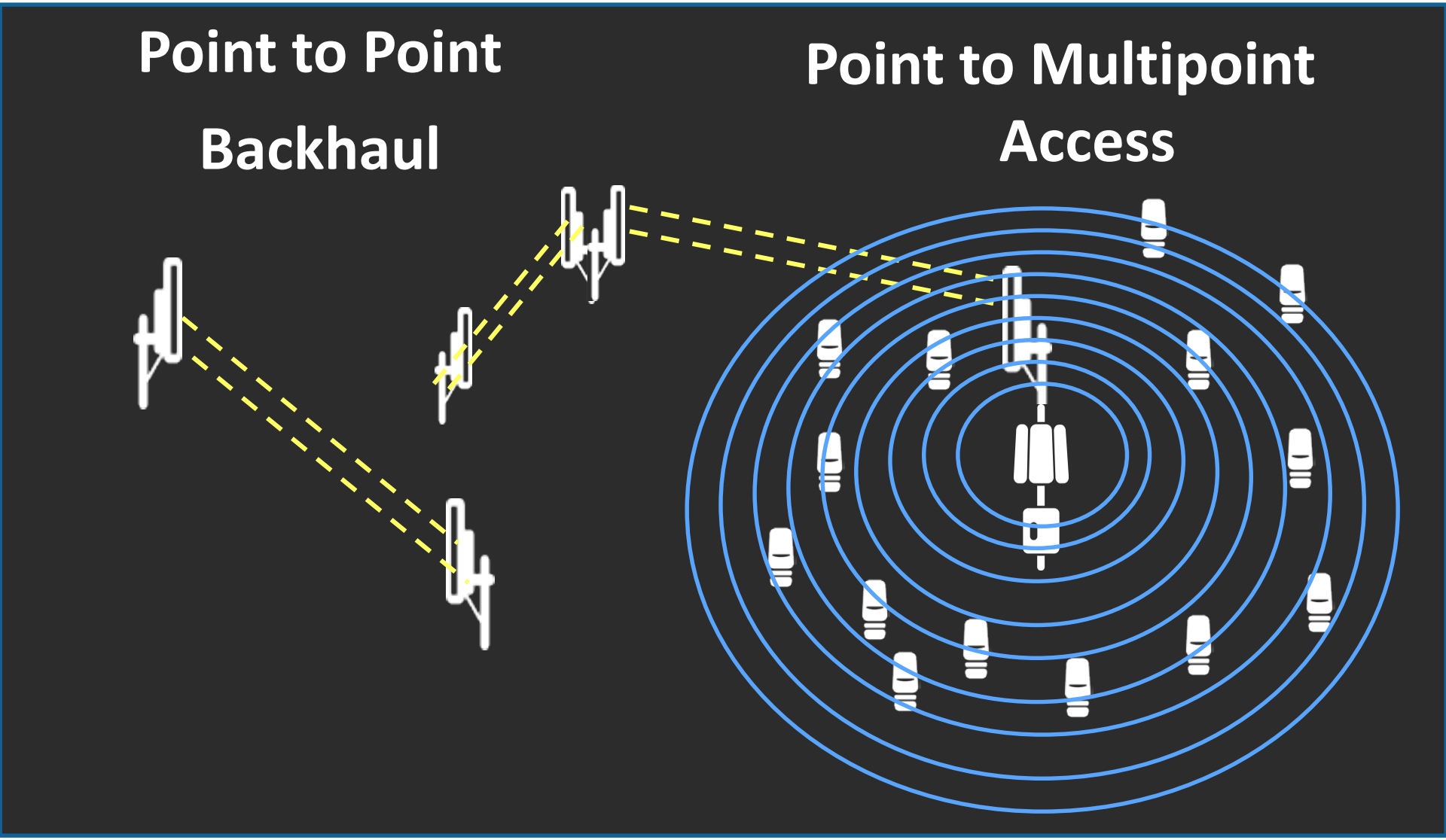
What does Wireless Broadband mean to you?

The Wireless Broadband Industry Buzz



What is Fixed Wireless Broadband?

It's NOT WiFi and it's NOT LTE



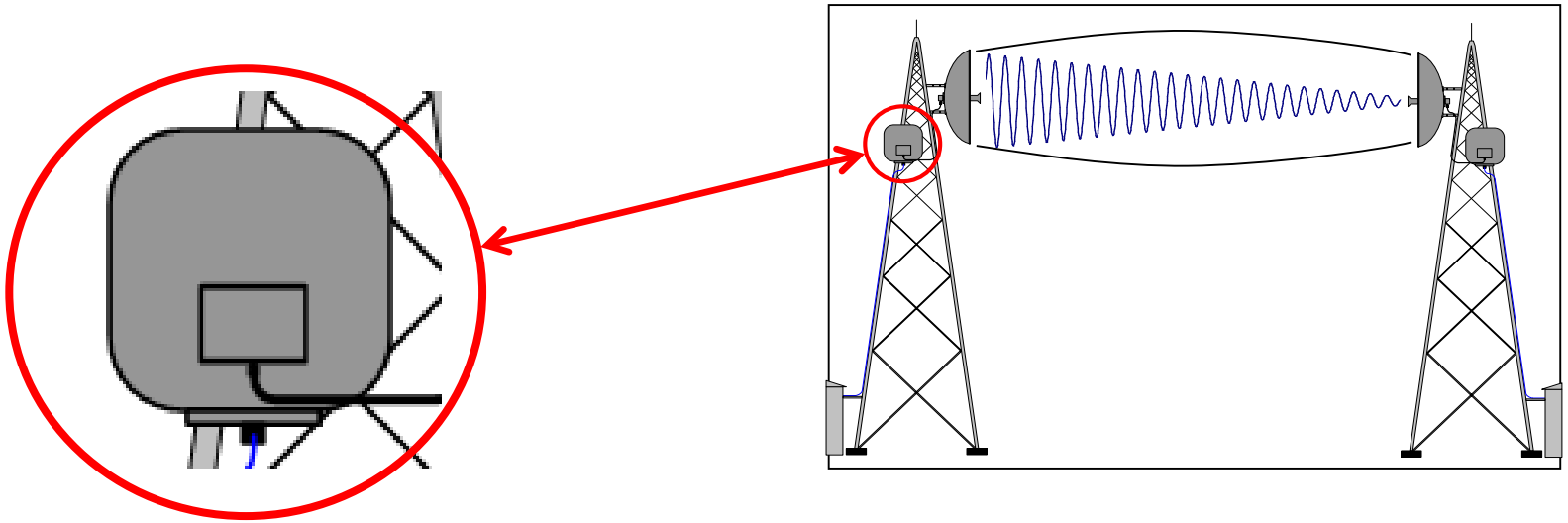
Outdoor Wireless Broadband

Connect People	Connect Vehicles	Connect Buildings	Connect Equipment	Connect People
				
				
Mobile	**Mobile**	**Fixed**	**Fixed**	**Fixed**

Wireless vs Wired

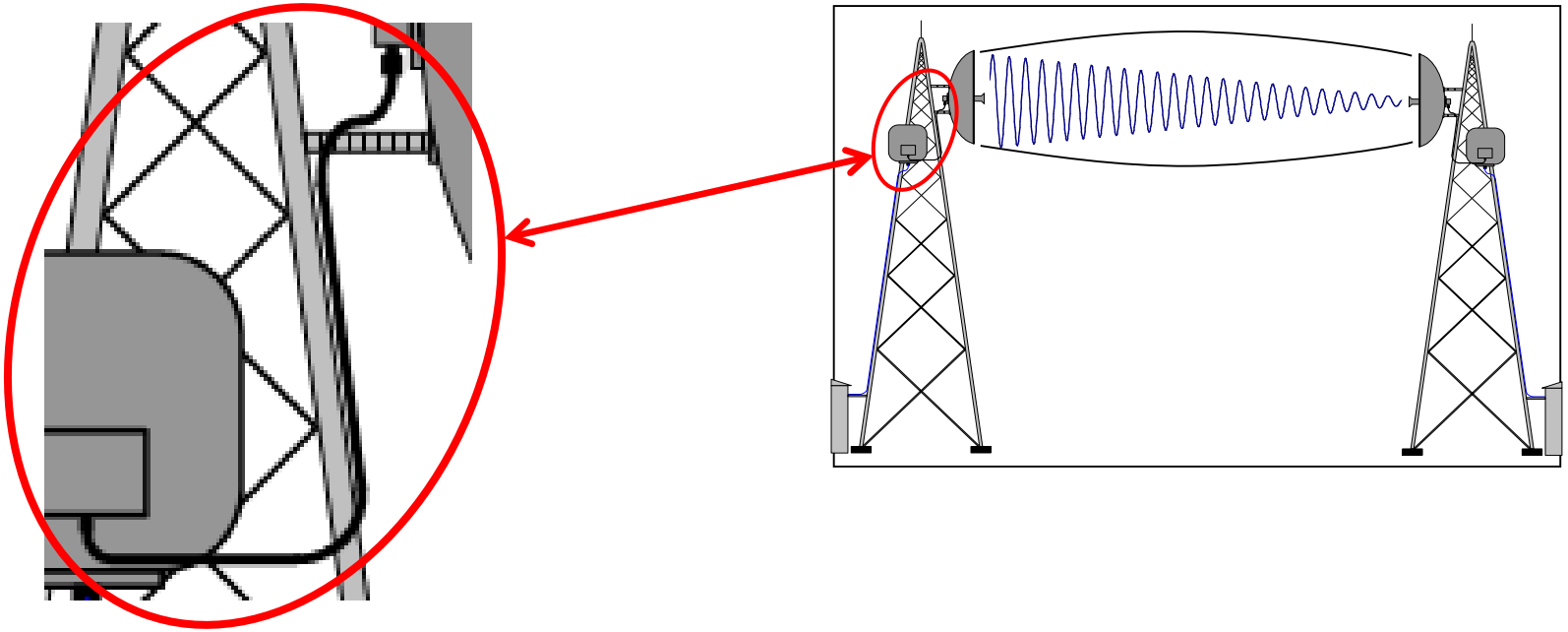
- ***The perception is that wired technology is better than wireless is still common in the market*** *and we will have to face it highlighting the benefit of wireless technology such as:*
  - **Flexibility**
  - **Capacity**
  - **Reliable – Supports DR, Video Conferencing, VoIP, CCTV, Military**
  - **Fast deployment**
  - OTC vs OPEX (if a PA invests in a wireless infrastructure become the owner of the network otherwise will have to buy broadband access from operators)
  - Pay as you grow
  - Low TCO
  - **High level of security**

Radio Basics: Making the Link – Output Power



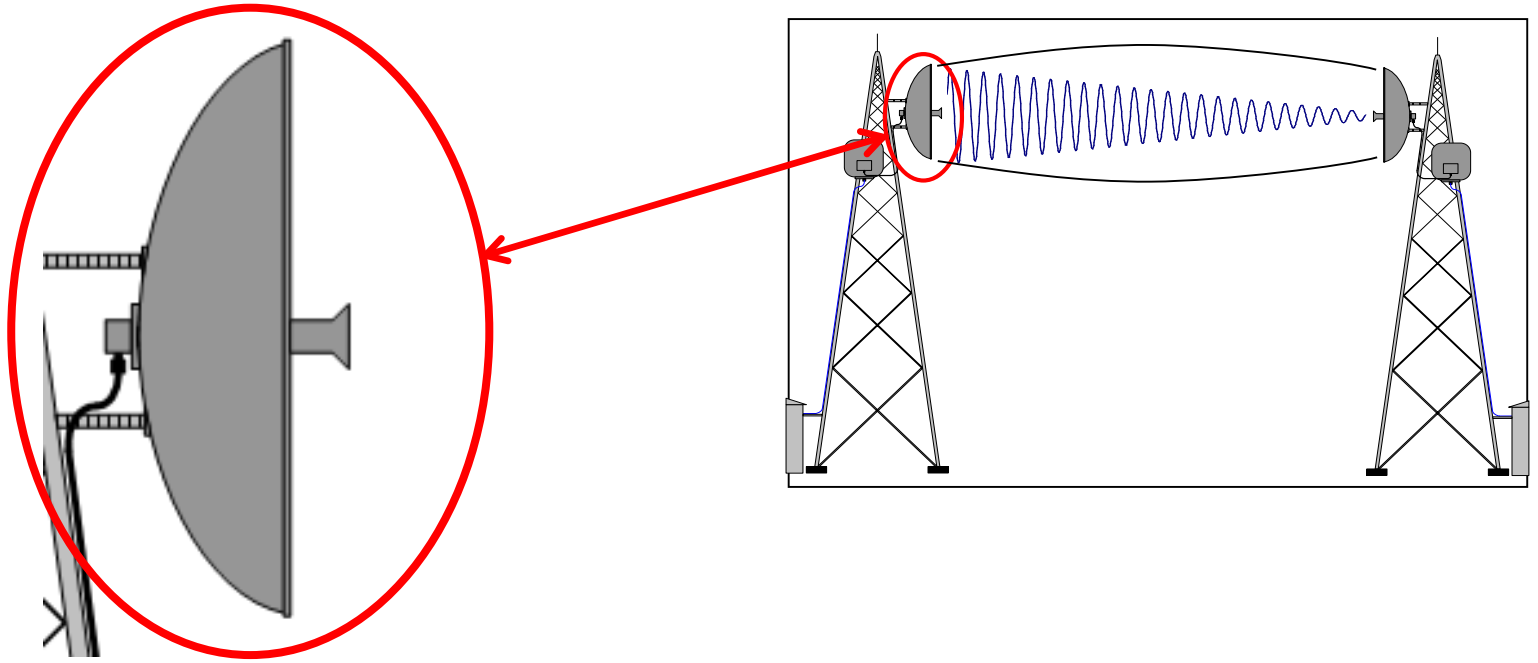
- The higher the radio's output power the better for a radio link, but this is often limited by local regulations (FCC, ETSI, ACMA in Australia).
- The output power is usually measured in dBm or Watts.

Radio Basics: Making the Link – Transmission Loss



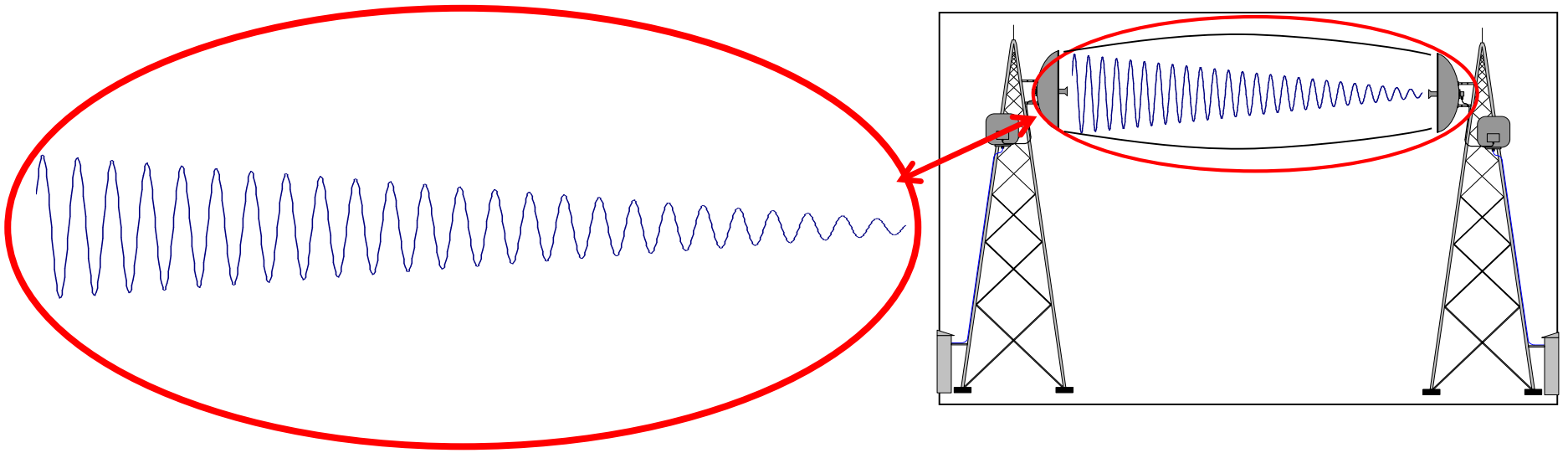
- Loss occurs in any radio cable, but usually the higher the frequency, the higher the loss.
- This RF cable should be kept as short as possible and be of a high standard.
- Radios' that have integrated Antenna's do not have this loss.

Radio Basics: Making the Link – Antenna Gain



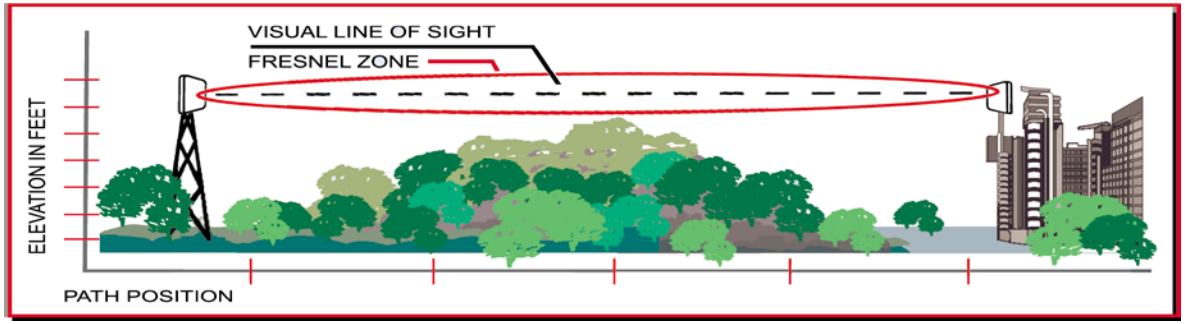
- Antennas' have gain as they focus the radio energy into a narrow beam and have large surface areas to receive more of the signal.
- In most cases larger antenna's have higher gains and narrower beam width.
- Larger antenna are harder to align, but due to there narrower beam width pick up less noise/interference.

Radio Basics: Making the Link – Path loss

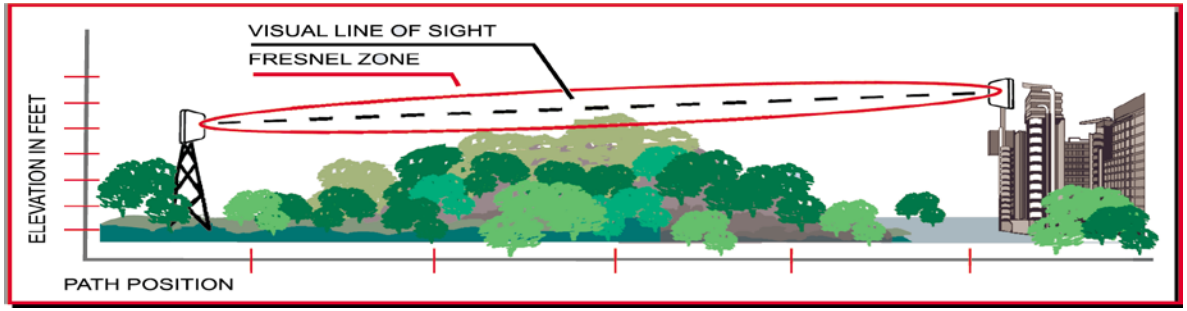


- Path loss occurs due to: distance, fading, obstacles.
- The longer the link, or bigger the obstacle the higher the path loss will be and the greater will be the effect of fading.

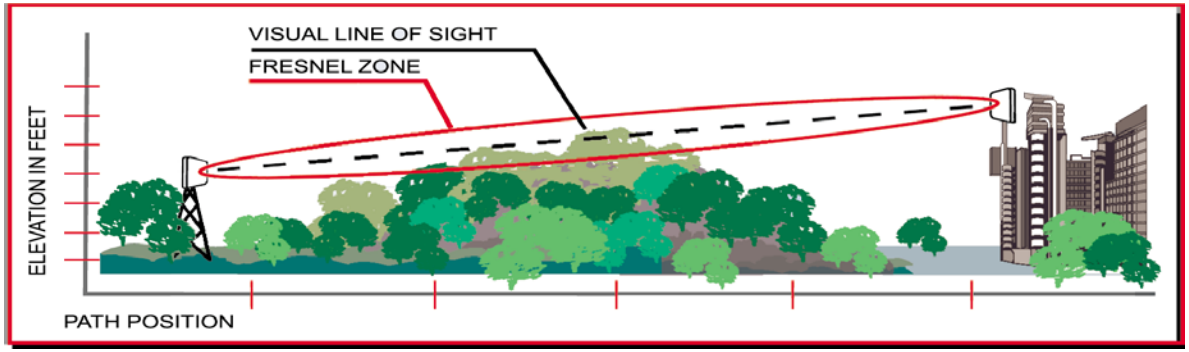
What is a clear path?



Line of Site (LOS)



near Line of Site (nLOS)



Non Line of Site (NLOS)

Radio waves do not travel in straight lines

- The Fresnel Zone is the additional path clearance required in order to achieve clear line of sight
- Size of Fresnel Zone is determined by operating frequency and path distance
- Obstacles in Fresnel Zone need to be taken into account
- The Cambium PTP LINKPlanner tool includes this in its calculations

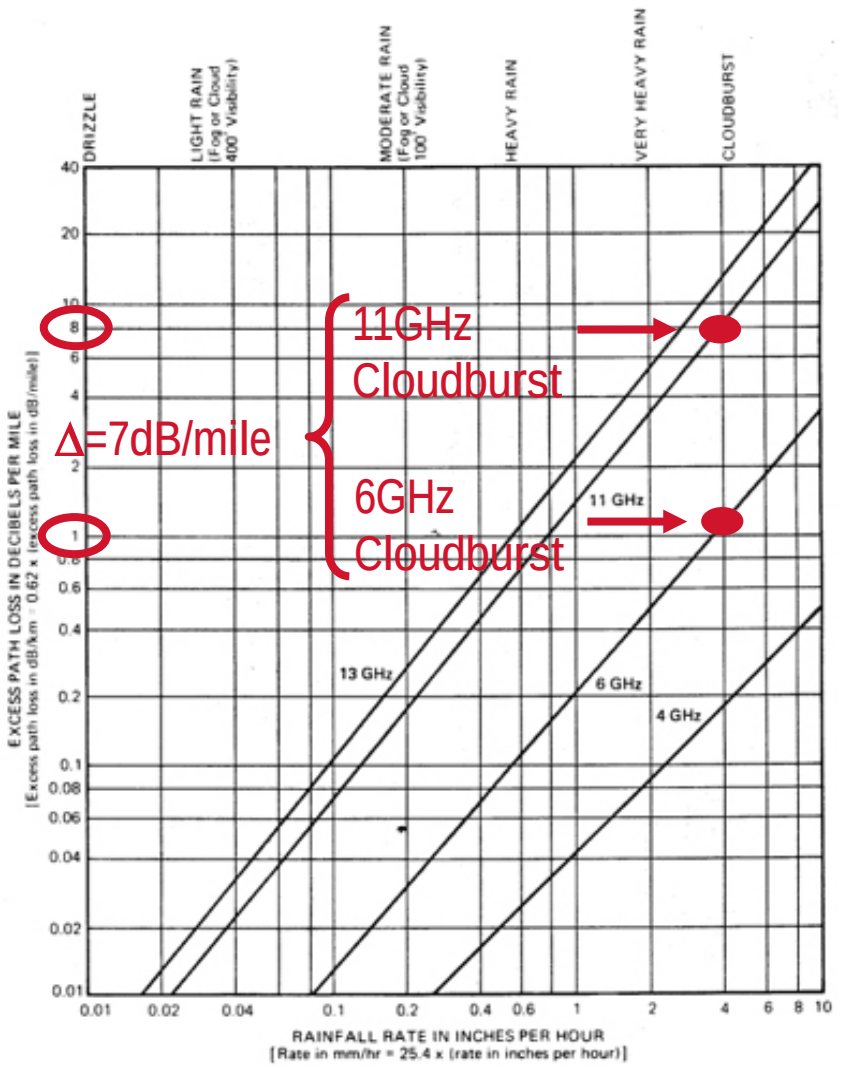
Is Rain Fade an Issue?

Little / no impact at 5.8GHz

- During cloudburst conditions additional loss is only 1 dB per mile at 5.8 GHz

Where can rain impact signal?

- More relevant for frequencies above 11GHz
- Up to 8 dB per mile additional loss at 11GHz



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Duplexing Options – Speak the Speak

Full and Half Duplex

- Full duplex is communication in both directions at the same time.
- Half duplex is communication in one direction at a time.

FDD and TDD

- Frequency Division Duplex is where communications in each direction use different frequencies.
- Time Division Duplex is where communication in one direction is at a different time than in the other direction, transmitting and receiving at the same frequency

Channel Bandwidth and Link Symmetry Control

PTP 650 Series

Channel bandwidth of the radio link (5 MHz, 10MHz, 15 MHz, 20 MHz, 30 MHz, 40MHz and 45MHz depending on the frequency band for the bandwidth choice), and configurable fixed and adaptive link symmetry. Fixed link symmetry supports:

- 5:1
- 3:1
- 2:1
- 1:1
- 1:2
- 1:3
- 1:5
- Adaptive

Channel bandwidth 5 MHz supports link symmetry 1:1 only. Adaptive link symmetry is not available in radar regions or when operating in TDD Sync mode.

PMP450

85%/15% - in 1% increments

15%/85% - in 1% increments

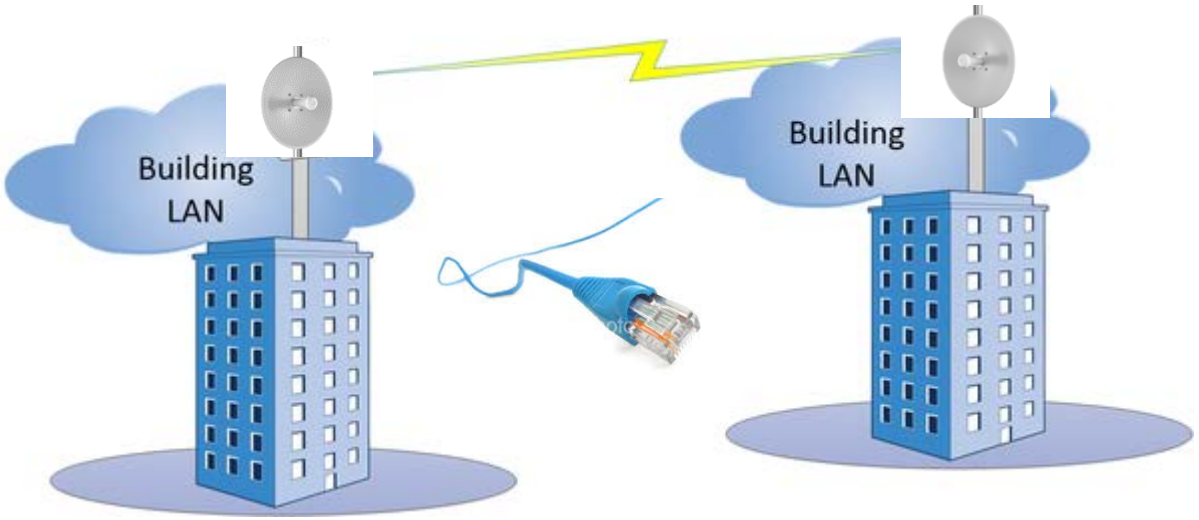
ePMP

75/25; 50/50; 30/70

Fixed Wireless Broadband Market Positioning

Fixed Indoor	Cambium Networks Fixed Outdoor	Mobile Outdoor
Large Growing Market	Exceptional Growth Ahead "The next major market"	Large Growing Market
802.11a, b, g, n, ac	Hybrid iOFDM, MIMO, DSO, FEC	GSM, EDGE, 3G, EV-DO, WiMAX, LTE, LTE-Advanced
Poor latency Poor spectral efficiency 'Best effort" Poor outdoor propagation	Highest spectral efficiency Highest throughput Lowest latency Flexible UL/DL	Mobility overhead Average latency Asymmetric UL/DL Small channel = low bandwidth

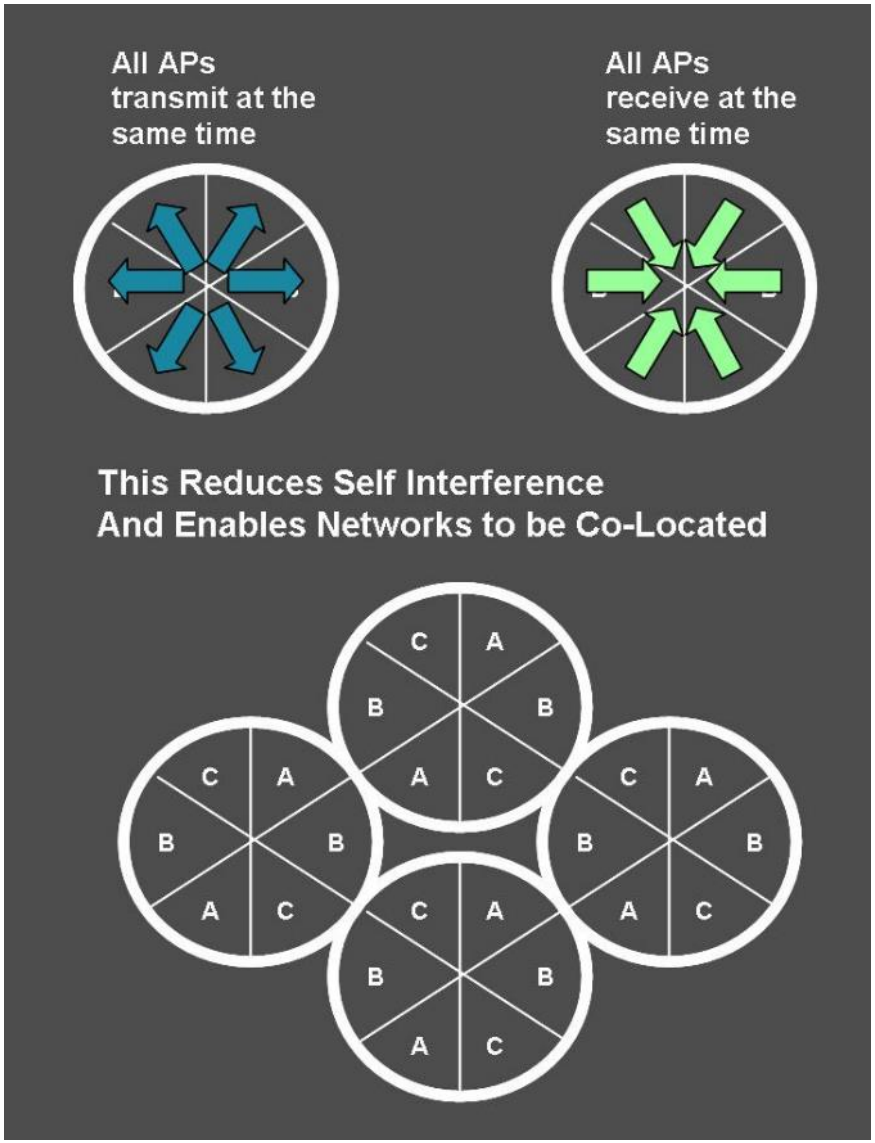
Just think of a wireless link a “blue cable in the sky”



- Secure
- Reliable
- High bandwidth
- Layer 2 – Ethernet Bridge

GPS Synchronization is vital for effective use of Spectrum for 5GHz and 2.4GHz Unlicensed Bands

- 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

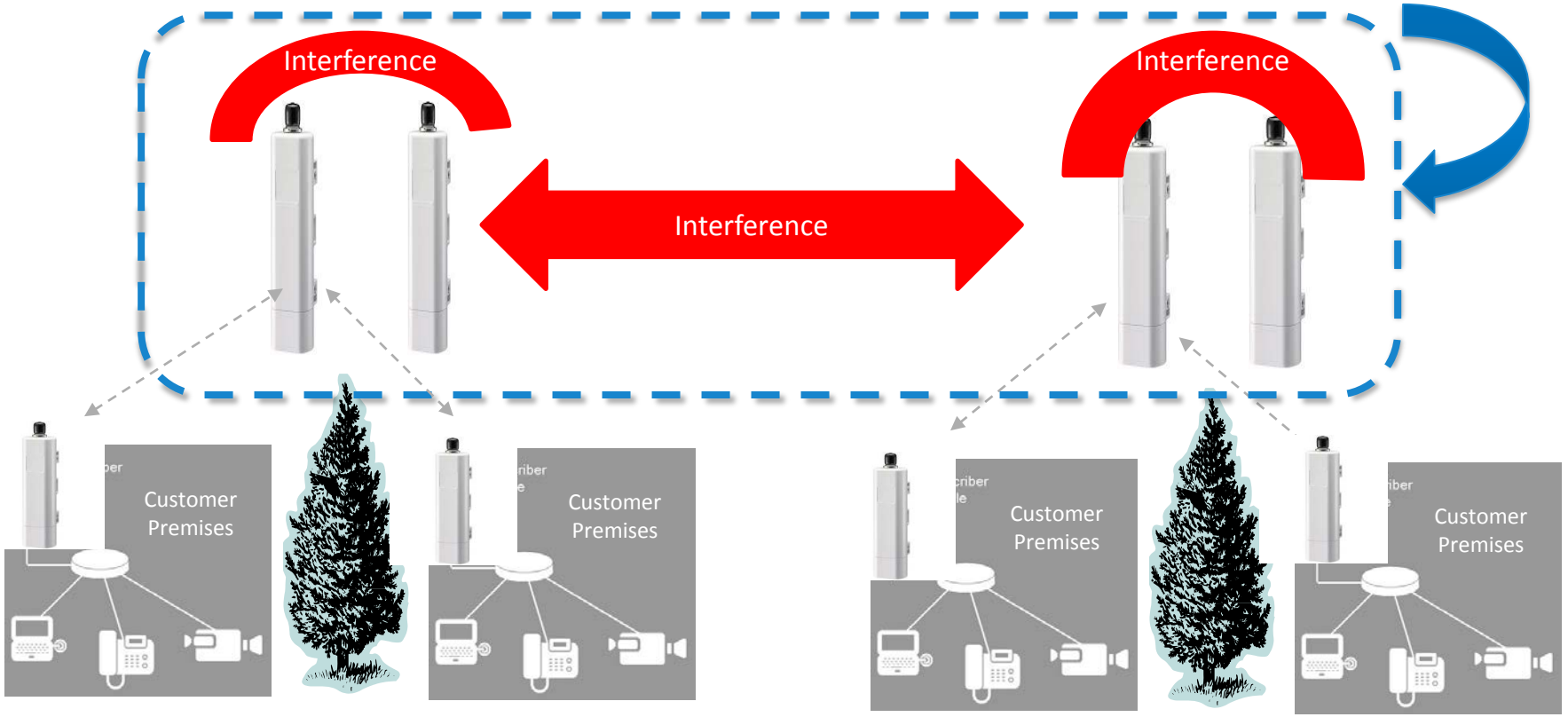


Problems with Unsynchronized Solutions

(1) Hidden Node Problem Causes “Collision Collapse”

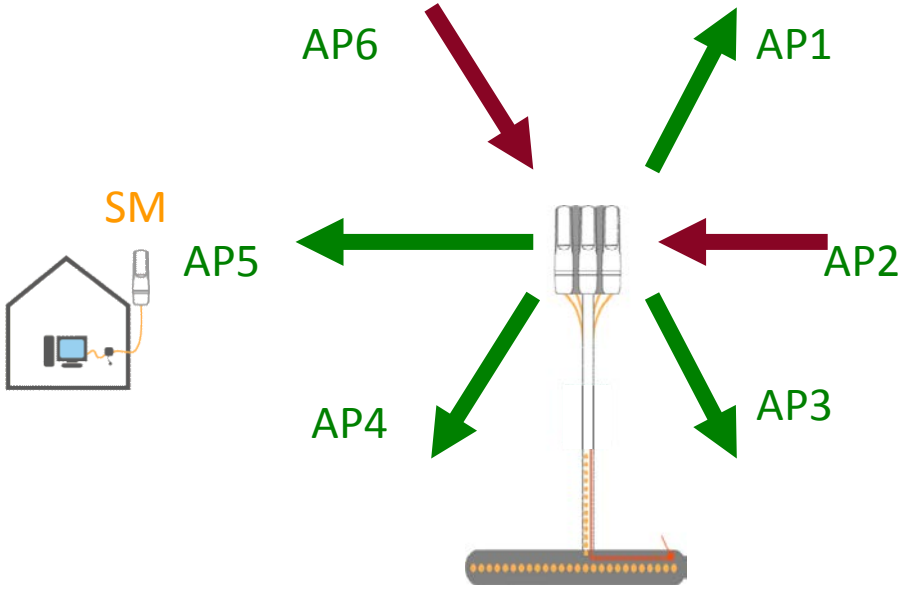
(2) AP to AP Interference when some APs Tx while others Rx
- SM to SM Interference also can occur

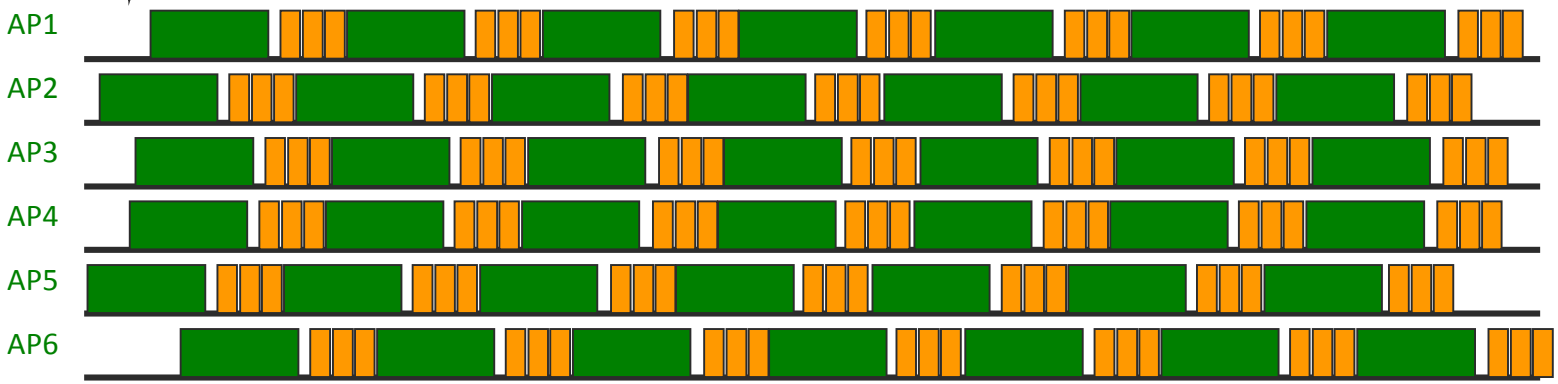
“Solution”:
- No Freq Reuse
- Large Guard Bands between frequencies



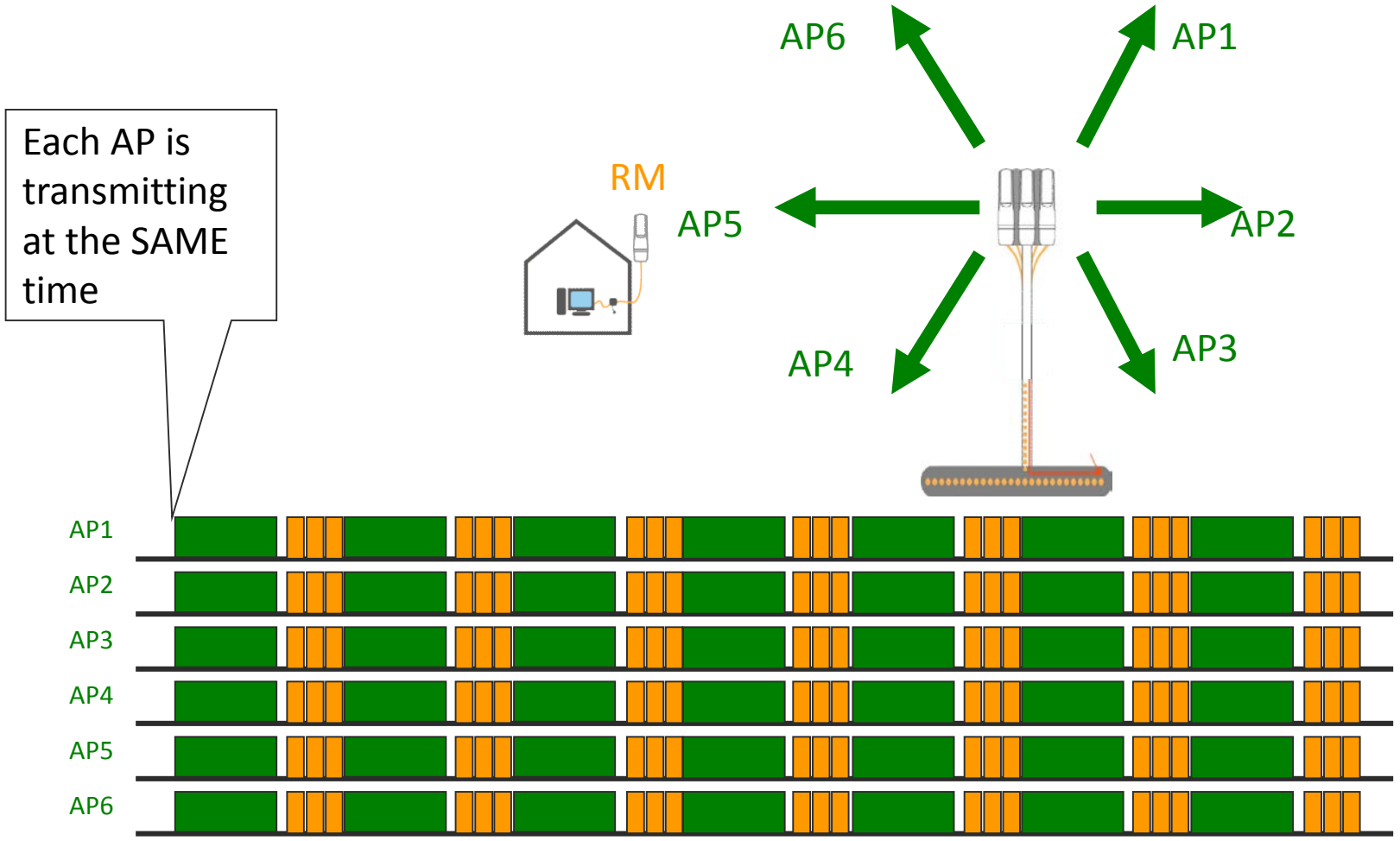
Primary Self Interference

Each AP is transmitting at a different time





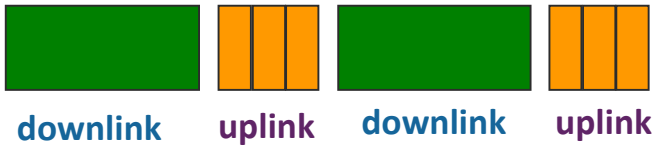
GPS Sync Eliminates Primary Self Interference



Solving the Problem Using Synchronization

Key Components

a) GPS Synchronized TDD MAC



Benefits

Eliminates “Collision Collapse” and Primary Self Interference:

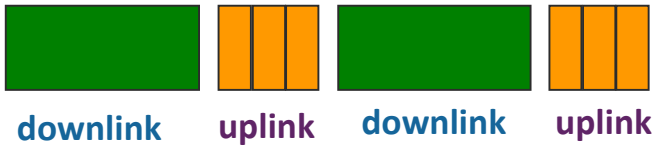
- AP to AP Interference (DL to UL)
- SM to SM Interference (UL to DL)

Allows for Reduction in Guard Bands

Solving the Problem Using Synchronization

Key Components

a) GPS Synchronized TDD MAC



b) Automatic SM Tx Power Control

c) Front-Back Antenna Isolation

Benefits

Eliminates "Collision Collapse" and Primary Self Interference:

- AP to AP Interference (DL to UL)
- SM to SM Interference (UL to DL)

Allows for Reduction in Guard Bands

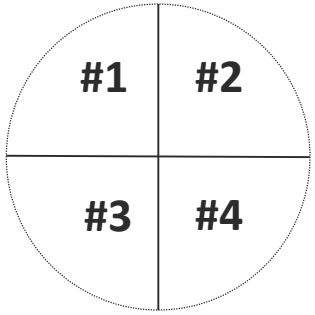
Reduces Secondary Self Interference

- SM to Other AP Interference (UL to UL)
- AP to Other SM Interference (DL to DL)

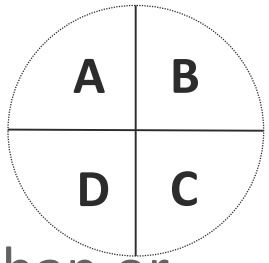
Allows for Frequency Reuse

The Importance of Spectral Efficiency

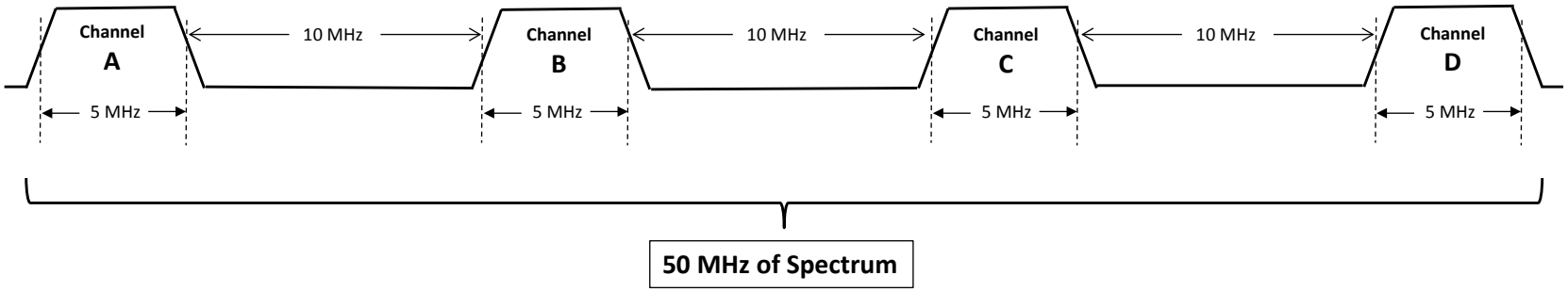
- Spectral Efficiency:
  - A measure of how efficiently a wireless solution utilizes RF spectrum
    - Defined as Throughput Achieved (bps) per Spectrum Utilized (Hz) – bps / Hz
- Clear Spectrum is a scarce resource
- A solution that makes efficient use of this scarce resource provides a superior Return 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

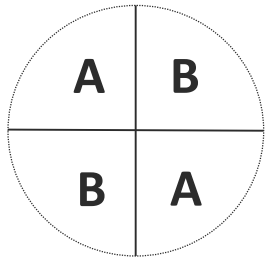


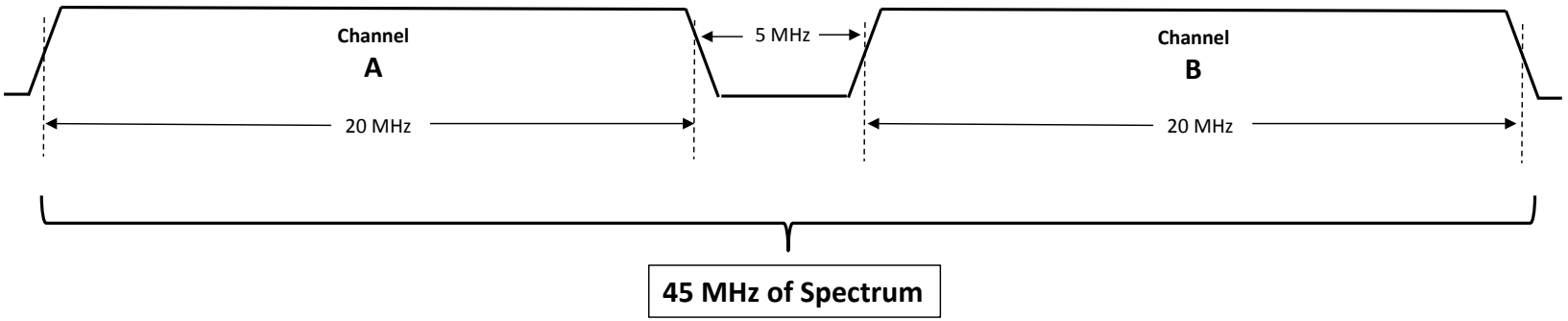
- Avg Capacity of 5 MHz channel with 6 km range = 22 Mbps
- Spectral Efficiency of Unsynchronized Deployment:

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

ePMP GPS Sync Deployment in 50MHz

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



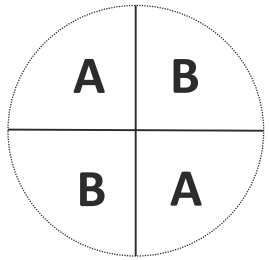


- Avg Capacity of 20 MHz channel with 6 km range = 65 Mbps
- Spectral Efficiency of Synchronized Deployment:

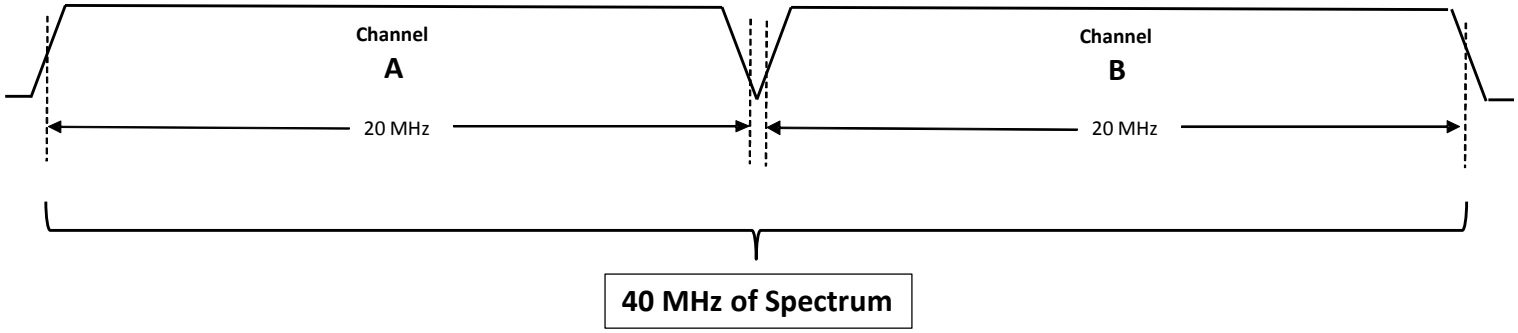
4 x 65 Mbps = 260 Mbps / 45 Mhz = 5.8 bps/Hz

> 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

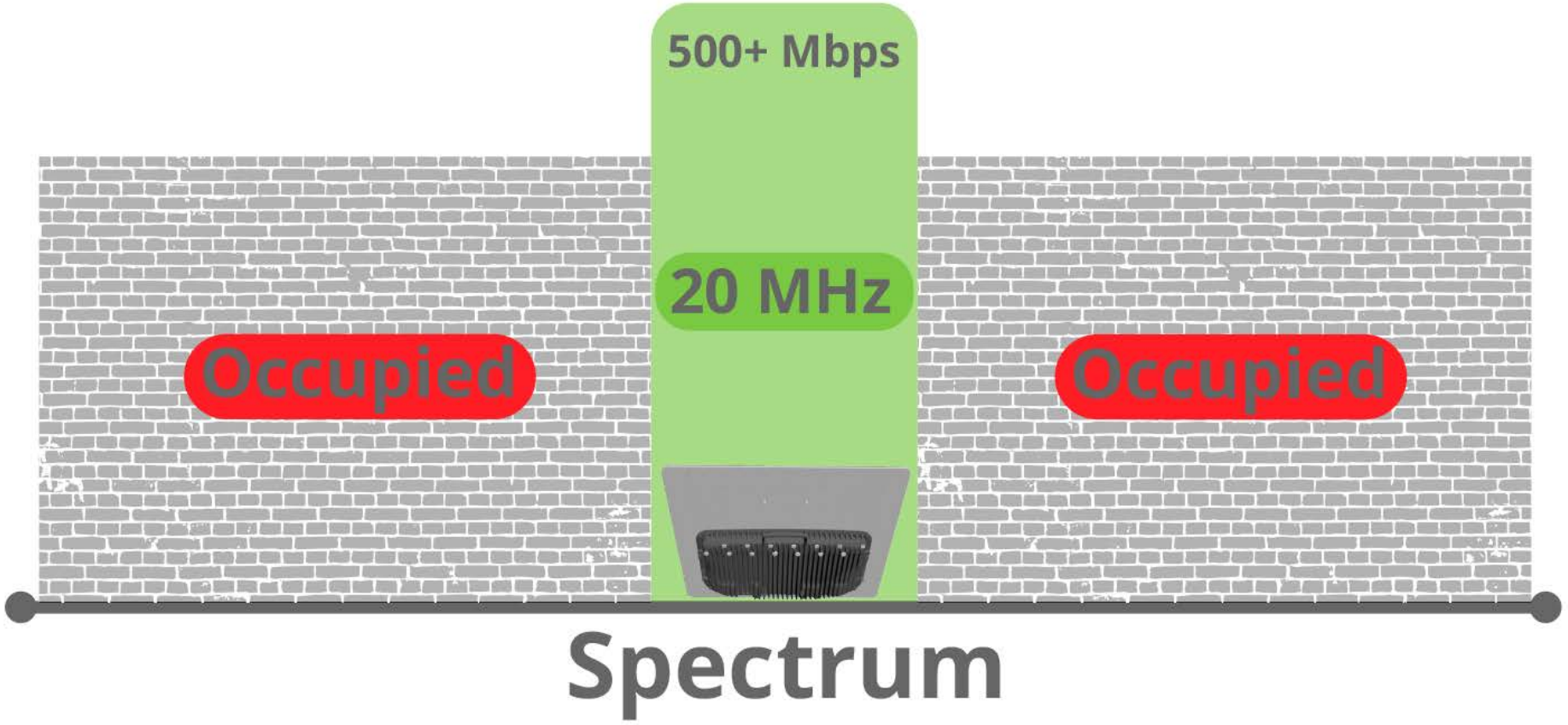
Go MASSIVE

cambiumnetworks.com/gomassive

Cambium Networks™

Why Go Massive Now?

Why not Just Increase Channel Size?



PMP 450m

- **More than 3x Capacity vs. 450/450i**
  - *cn*Medusa™ 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

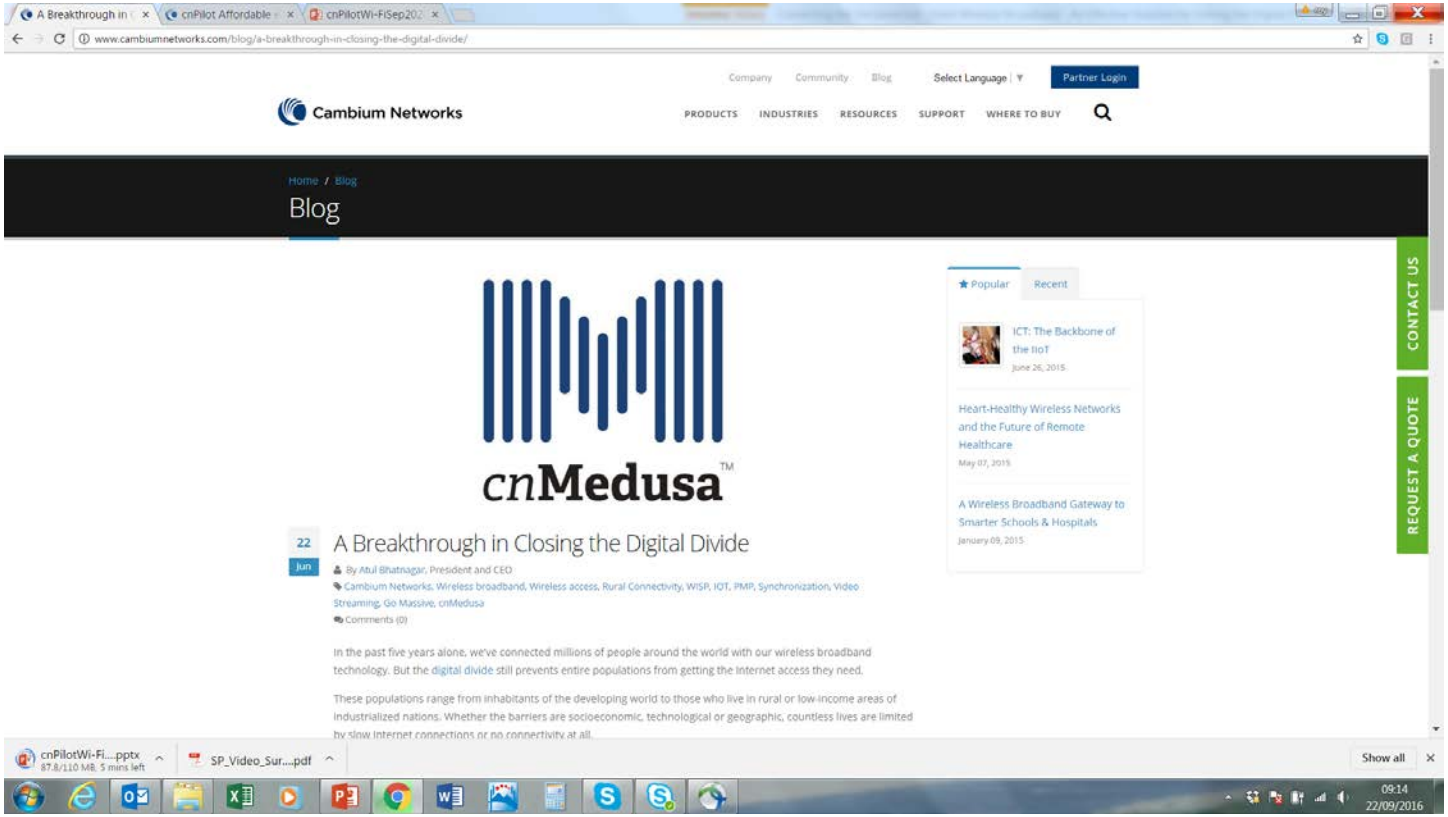
cnMedusa™

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

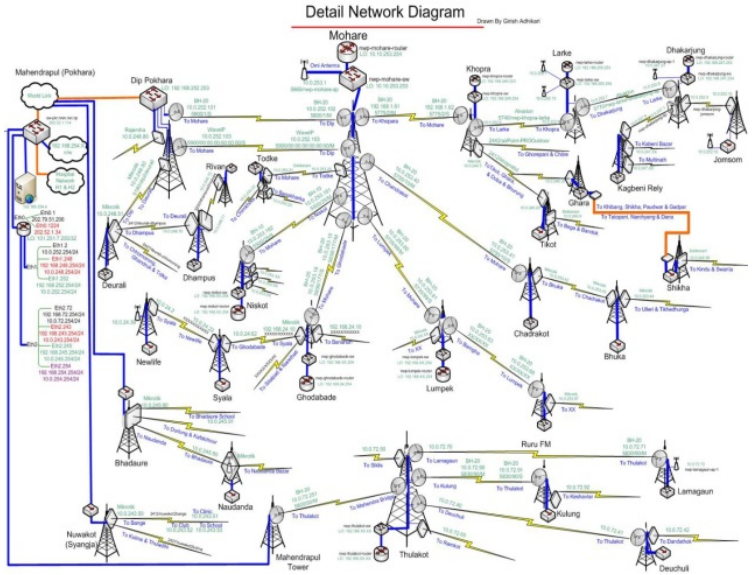
Cambium Blog – Closing the Digital Divide.

http://www.cambiumnetworks.com/blog/a-breakthrough-in-closing-the-digital-divide/



Nepal – Mahabir Pun a visionary Pioneer

Application	• Voice video and data connectivity for remote regions in the Himalayas • Medical care and e-commerce for some of the most remote regions on earth
Challenge	• No traditional carrier could cost justify building a network to connect these very remote villages with small population • Difficult mountainous terrain with harsh weather
Solution	• PTP backhaul infrastructure • PMP wireless access network • Able to provide video conferencing, health care, video surveillance and e-commerce



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Digicel Business Private Office Network PNG

Service Provider

	Papua New Guinea
Challenge	Digicel Business' Private Office Networks VPN service was developed to meet the demands of large corporate customers having various branch offices around PNG; especially those that run business applications hosted centrally. This unique service has been tailored to provide secure VPN connectivity for branch office and low latency therefore fast keystroke response.
Solution	PMP 430 access network with omni directional antenna to provide connectivity to sparsely populated areas needing high speed broadband
Results	• Customers are now experiencing usable throughput levels at about 30 Mbps down and 10 Mbps up, getting what they need for high speed Internet access for data, voice and video applications

Digicel business

Service Providers in Pacific and APAC

- Digicel - PNG, Tonga and Vanuatu (PMP450, ePMP, PTP650)
- Kordia – NZ (PMP450)
- Chunghwa – Taiwan (PTP650)
- Tata Communications – India – (PMP100)
- Reliance Communications – India (ePMP and PTP650)
- Bharti Airtel – India (ePMP)
- Globe – Philippines (ePMP)
- PLDT – Philippines (PTP650)
- SMART Communications – Philippines (PMP100)
- ToT – Thailand (ePMP)
- Lankacom – Sri Lanka (PTP650)
- Dialog – Sri Lanka (ePMP)
- Grameenphone – Bangladesh (ePMP)
- Telstra – Australia (ePMP, PMP450)
- Star (Vibo) – Taiwan – PTP650
- China Telecom
- China Unicom.
- PCCW – Hong Kong. (PTP600)

Thank you

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