Cambium Networks™

Maximize Narrowband Network Capacity and Spectral Efficiency with cnReach™ Synchronization

Overview

Wireless point-to-point (PTP) and point-to-multipoint (PMP) wireless networks utilizing narrowband sub-1 GHz spectrum are widely used in Industrial IOT (IIOT) applications to facilitate the data communications of supervisory control and data acquisition (SCADA) systems. These SCADA networks typically incorporate programmable logic controller (PLC) masters at the control center and remote terminal units (RTU) at the remote sites. As the density of these networks increase and the demand for more capacity expands, efficient use of the available spectrum becomes critical.

Noise floors in field area networks (e.g., oil well fields and electrical substations) are notoriously high. The rising noise floors can limit capacity by lowering radio modulations, increasing packet re-tries, and preventing connections altogether. A significant contributor to poor network performance by noise is self-interference – the unintended spectral interaction between the radios comprising the network itself.

Because RF availability is finite, network operators are constantly challenged to maximize spectral efficiency (bits/s/Hz) to support the increasing network capacity demand. To optimize spectral efficiency, network operators work to open up additional capacity where it does not presently exist by addressing self-interference and channel reuse.

Cambium Networks, a market leader in wireless IIOT networks, offers a range of narrowband products – the cnReach™ product line supports frequency bands of 900MHz (both ISM and MAS), 700MHz, 400MHz and 220MHz, with excellent options for channel reuse and network scalability.

This whitepaper outlines the theory behind self-interference in narrowband systems and presents a number of techniques available to users of cnReach narrowband radios to maximize spectral efficiency including TDD synchronization, alternating antenna polarizations, and strategic channel planning.

Wireless IIOT Deployment Scenarios

cnReach networks are commonly connected in Point-to-Multipoint (PMP) topologies with the SCADA master at or behind the Access Points (AP) while the RTUs are connected to the End Points (EP).

There are three general scenarios of wireless IIOT deployments:

1. **Small-scale single Access Point (AP)** with a small number of EPs, e.g. up to 60 EPs, as illustrated in Figure 1.

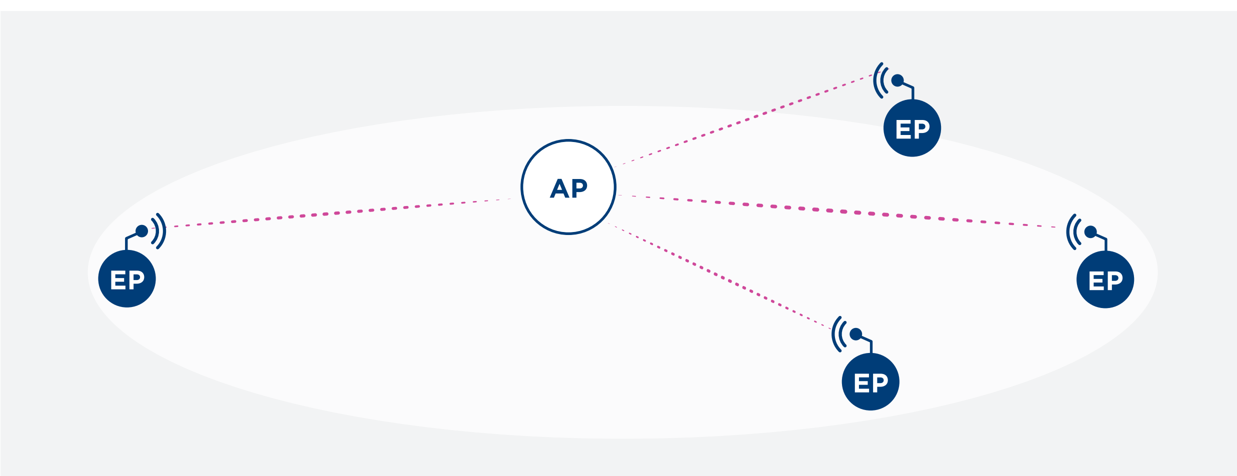

Figure 1 Single-AP Single Hub Deployment

In this scenario, optimizing network performance is straightforward and dependent on selection of the modulation mode and radio frame size. There is no need to consider self-interference and RF channel reuse as the cnReach radio operates with a scheduled TDD (Time-Division Duplex) air interface, and only one radio is transmitting at any point in time.

2. **Medium size networks** with multiple single AP clusters scattered in a deployment area as illustrated in Figure 2

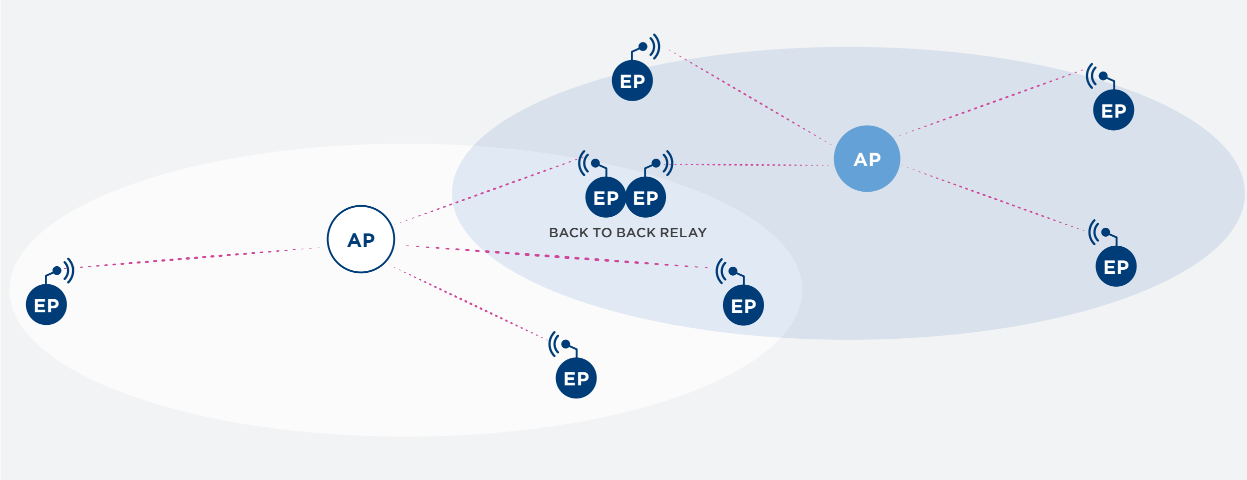

Figure 2 Multi-cluster Network

In this deployment scenario, the operator has multiple APs distributed across the field, each serving a number of EPs. The clusters could even be connected using a back-to-back relay configuration for backhaul. In this scenario, the operator is typically using the same RF band for each AP. They may use different channels, but in the case of the same channel, the operator must consider self-interference to optimize network performance as the AP clusters are operated independently.

3. **Large-scale network** with collocated APs forming a hub and multiple hubs covering a geographical area, as illustrated in Figure 3.

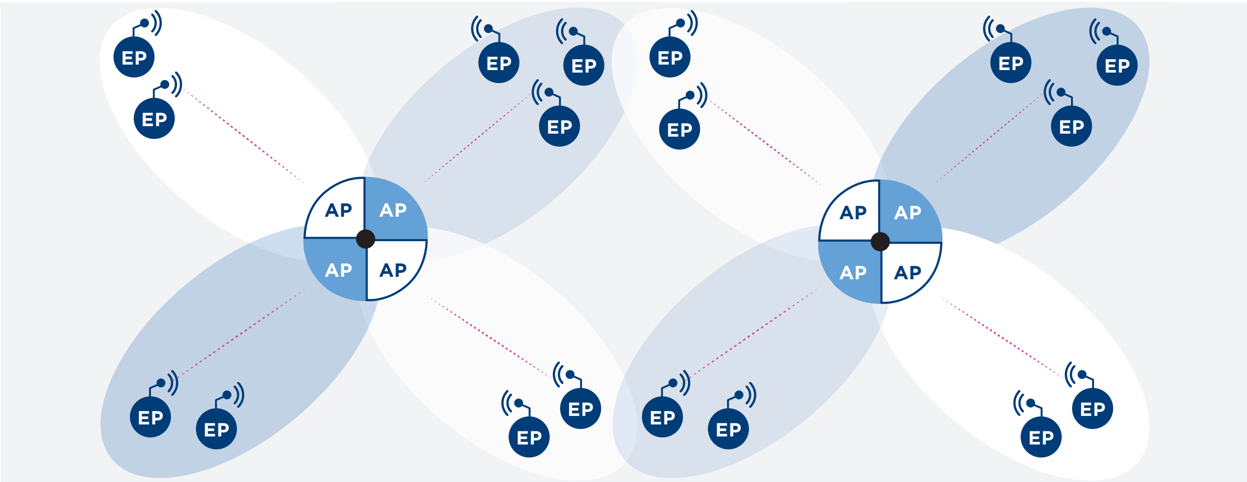

Figure 3 Multi-AP-hub, Multi-hubs Deployment

These more complex deployments are driven by the need for higher capacity in areas where a single AP may fail to provide sufficient range, data capacity, or EP density, given narrow channel sizes. The operator may choose to deploy multiple APs at a hub location using directional antennas, often mounted within feet or meters of each other. Channel planning and mitigation of self-interference becomes especially important in these scenarios.

What causes self-interference?

Self-interference arises when multiple radios in an area are transmitting at the same time, and the wanted signal vs. the unwanted signal (Signal to Noise ratio or SNR) becomes lower than required for a specific modulation mode, and the radios are unable to demodulate the wanted signal. This will happen when the radios are not only operating in the same frequency (channel), but also when they are operating in different channels in the same frequency band.

cnReach uses TDD based technology for data transmission; TDD systems operate by transmitting part of the time and receiving part of the time on a frame basis. The AP controls which EP radio is transmitting by scheduling the air interface to prevent multiple EPs from transmitting at the same time. Self-interference occurs when a system is comprised of multiple APs, each operating independent of the other, which collectively compromises their individual TDD capability.

In this situation, there are two types of self-interference:

1. **Co-channel interference** occurs when two or more AP clusters are operating on the same frequency.
2. **Adjacent/Alternate Channel Interference** occurs when two or more AP clusters are operating in the same RF band, but not on the exact same channel. The interference occurs when a radio is transmitting in one channel and its energy spills over into neighboring channels. A transmission on a carrier channel is not perfect in the sense that the desired emission does not and cannot "fall off" as sharply as wanted. Inevitably, "out of band emissions" occur and interfere with adjacent channels.

While different frequency bands have different requirement for the "roll off", an example of transmission emission mask is shown below to make the point:

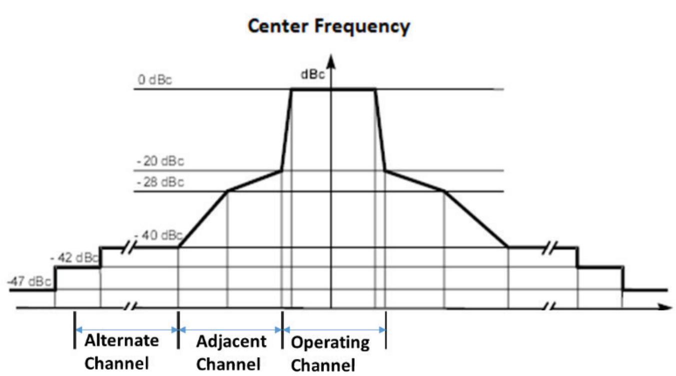

Figure 4 Example of a Transmission Emission Mask

One can see that the transmitter will transmit into the adjacent channel at 20 dB lower, and into the alternate or second adjacent channel at 40 dB lower, than the center frequency.

Taking a 900 MHz radio with alternate channel deployment as an example: consider two APs installed on the same tower; one AP (AP1) is operating in Channel 1, and the other AP (AP2) is operating in Channel 3 (one channel separation) in the same licensed frequency band. If AP1 is receiving from the EP at a very strong signal level of -70 dBm, this would usually allow the signal to be modulated at the highest modulation in an environment without interference (SNR > 40 dB). However, if AP2 is transmitting at the same time that AP1 is receiving, the signal feeding into AP1 could be as high as -30 dBm – assuming AP1 Tx Power of 30 dBm (1Watt), space loss of 40 dB (~2 meters separation), and signal "fall off" of 40 dB. The unwanted signal from AP2 to AP1 is 20 dB higher than the wanted signal from the EP to AP1, making the wanted signal completely undecodable.

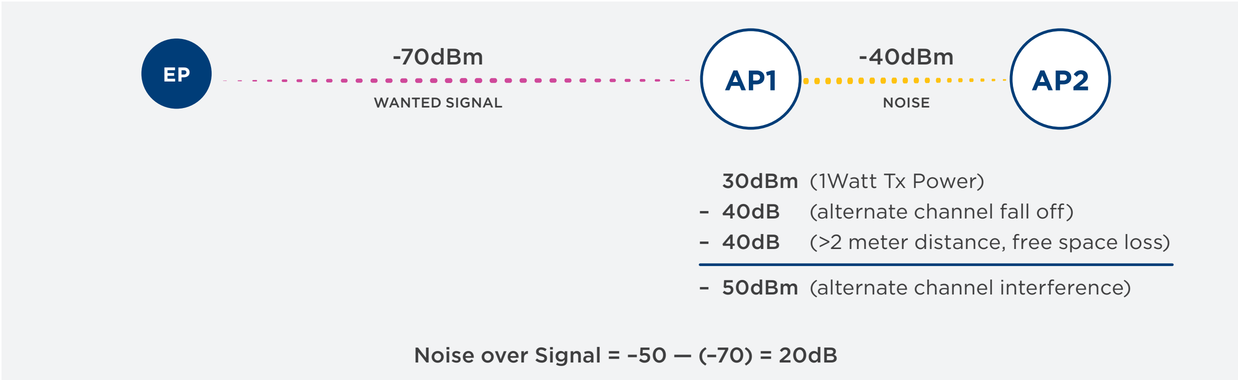

Figure 5 Example of Self-interference between Colocated APs Operating on Alternate Channels

We will explore three ways to address this using cnReach: TDD Sync, alternating antenna polarizations, and channel planning.

TDD Synchronization of cnReach radios and Networks

The TDD sync feature on cnReach enables the network operator to control a group of radios such that they each transmit and receive at the same time. With TDD sync, the operator can set all the APs in a network to transmit concurrently with all the EPs receiving.

Consider again the case explained in Figure 5 – when AP1 is receiving from the EP1 with sync and AP2 is NOT transmitting anymore (because it is also in receiving mode), so with -70 dBm of receive signal level (RSL), the link could be running at highest modulation mode. One could argue that when AP1 is receiving from EP1, AP2 is also receiving from EP2 – so EP2 signal will appear as noise to AP1. However, because AP1-EP1 and AP2-EP2 are operating in alternate channels, the interference caused by EP2 to AP1 would be at least 40 dB lower than the wanted signal – enabling the highest modulation to succeed.

Customer field experiences have proven that enabling TDD sync on licensed deployments yields significant improvements in network performance regarding both capacity and stability.

In one customer deployment, the network master stations were operating in alternate channels (not adjacent channels) without synchronization. The network was unstable and aggregate throughput was much lower than expected when all radios were operating. Once TDD sync was enabled, the network started to perform reliably and at top modulation mode.

With TDD sync, adjacent channel deployment will also work, but not necessarily at top modulation mode.

Achieving Channel Reuse with alternating antenna polarizations and front to back isolation

There are three scenarios for channel reuse.

SCENARIO #1.	Multiple APs at a hub site (refer to figure 3, but consider a single hub only)
SCENARIO #2.	Multiple APs scattered around the area, each covering a sub area (refer to figure 2).
SCENARIO #3.	Multiple hub sites, each hub site with multiple APs (refer to figure 3, consider all hub sites shown).

For scenario #1, the solution to achieve channel reuse is via antenna Front-to-Back (F/B) isolation, combined with TDD synchronization. To simplify the analysis, consider the following diagram where two APs are situated back-to-back and operating in the same frequency.

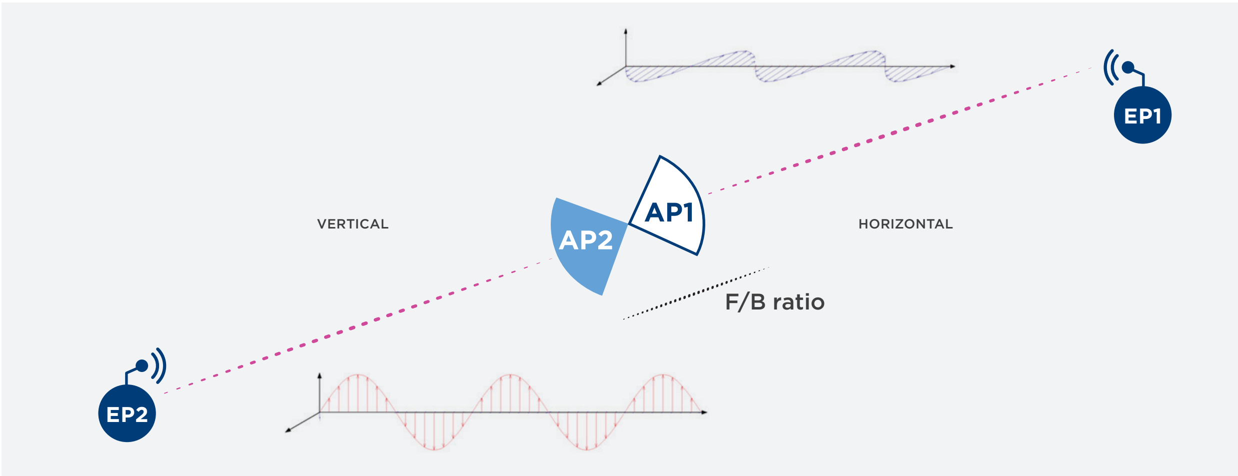

Figure 6 Channel Reuse for Two APs at the Same Site

There are three challenges to overcome:

1. Collocated APs self-interference – AP1 and AP2 interfering with each other
2. Interference to one AP coming from EPs of another AP, for example, EP2 causing interference to AP1 when AP1 is receiving from EP1.
3. Interference to an EP coming from another AP which the EP is not talking to. For example, AP2 causing interference to EP1 when EP1 is receiving from AP1.

cnReach radio spec shows that if the SNR is greater than ~40dB, given good RSL, a cnReach radio link should achieve top modulation mode. To support this, the EP2 signal to AP1 should ideally be 40db lower than EP1 to AP1 if possible.

The first challenge can be easily addressed by activating TDD Sync throughout the network, as explained in the previous session.

For the other two challenges, we can use directional antennas and polarity isolation.

With directional/sector antenna installed on the APs, a front to back (F/B) ratio of 15dB or higher can be achieved depending on the antenna design. So, assuming that the signal coming to the APs from the EPs are the same strength, EP2 to AP1 is lower than EP1 to AP1 by at least 15dB. To achieve higher isolation, we can use different RF polarities for AP1 cluster and AP2 cluster. For example, antennas for AP1 cluster use H-Pole and AP2 cluster uses V-Pole. (Note that all EP's in that sector must also use the same H or V polarization). This will add another 20-25dB of isolation, resulting in 35-40dB of isolation between the two clusters and enabling channel reuse. Please note that SNR of 40dB is NOT mandatory. If the application requirements can be met at a lower modulation mode (for example 900 MHz MAS at 25 KHz channel size only requiring SNR of 20 dB to operate at QPSK), it may not be necessary to implement all these options.

The same logical analysis can be applied to the interference caused by AP2 to EP1.

The analysis above assumed that EP1 and EP2's RSL to the hub site is almost identical. What if signal strength for EP2 to the hub site is much stronger than coming from EP2? In this case, the isolation achieved using polarization and F/B radio may not be enough to reduce the noise level to the victim link. In this case, some level of transmission power control is very helpful. The operator can deploy the network in such a way that the signal strength to the hub site is close enough.

Figure 6 only shows coverage of 180 degrees. To cover the remaining 180 degrees, another channel should be used. Cambium Networks recommends using an alternate channel for better SNR performance – Figure 7 shows an example of that type of deployment.

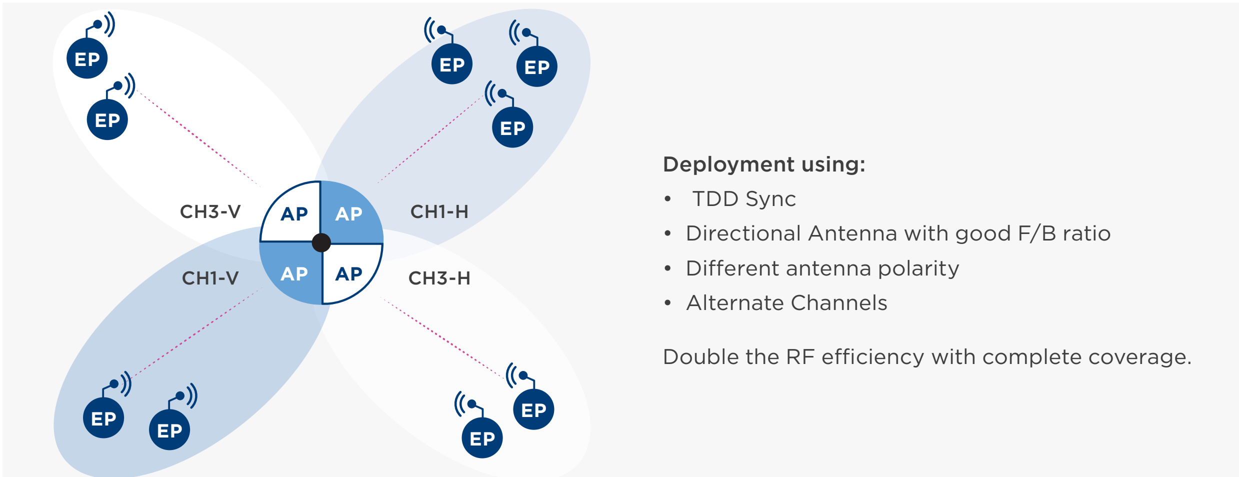

Figure 7 Hubsite with Multiple APs, where back-to-back APs Share Same Channel

For scenario #2

Using different antenna polarities for the deployment can reduce the interference between the clusters by ~20dB (could be up to 25dB). Use of TDD Sync can prevent the APs from interfering with one another - if the APs happen to be receiving strong signals from one another.

Considering the following deployment scenario.

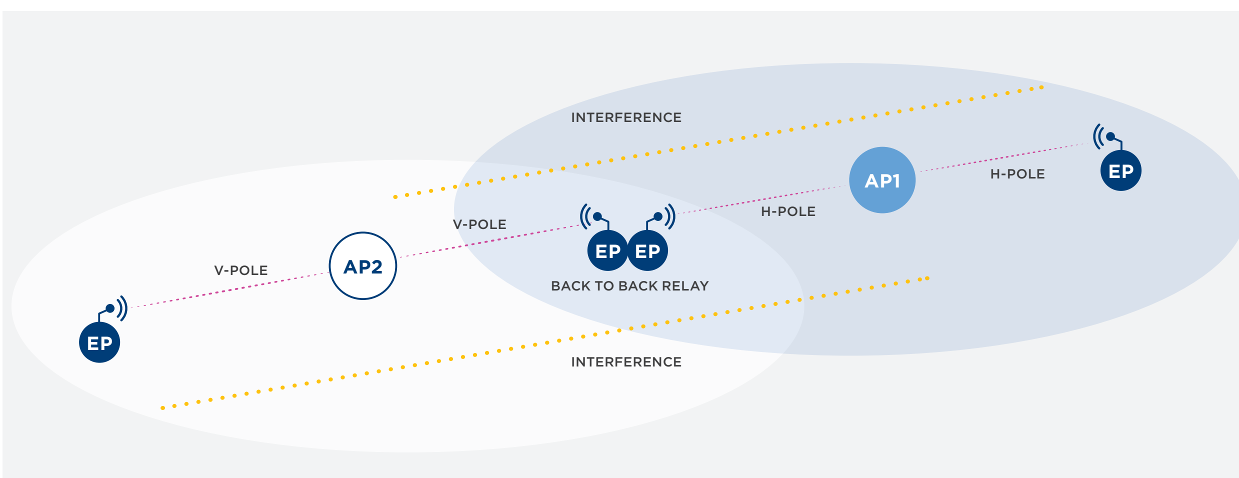

Figure 8 Multiple AP-clusters in an Area

To use the same channel on AP1 and AP2, the operator should ensure that the EP2 signal does not cause interference to AP1 when AP1 is receiving from EP1 – assuming EP1 to AP1 is the worst link for all of AP1's EPs, and EP2 to AP1 is the best link possible for AP1 to any AP2 EPs. Also assume that EP1's signal does not cause interference to AP2. In many situations, no interference between EP2 and AP1 will occur because of a non-line-of-sight path profile between the two points, which adds substantial path loss.

Cambium Networks LINKPlanner™ can be used to model this scenario, setting AP1 as the interference victim, and assuming that the RSL from EP2 to AP1 is "rsl2", and the RSL from EP1 to AP1 is "rsl1". The SNR for EP1 to AP1 will be snr1 = rsl1-rsl2+20 (db) ("20" comes from the polarity separation). Be sure that snr1 is greater than that required for the target modulation mode – per the radio spec.

For example,

If

rsl1 = -75 dBm,

rsl2 = -90 dBm,

Then

snr1=-75 - (-90) + 20 = 35 dB.

For radios operating in MAS band with 25 kHz channel size, this SNR level would allow 16QAM modulation.

Scenario #3 is a combination of scenario #1 and scenario #2. The following diagram is a simplified network which shows only 180 degree coverage with a single channel for easier analysis. The operator should use TDD Sync, and a sector antenna with both good F/B ratio and different antenna polarities. Analysis used in both scenario #1 and scenario #2 shall be applied. Interference between neighbor sites with the same antenna polarity should be analyzed with desired modulation for channel reuse feasibility.

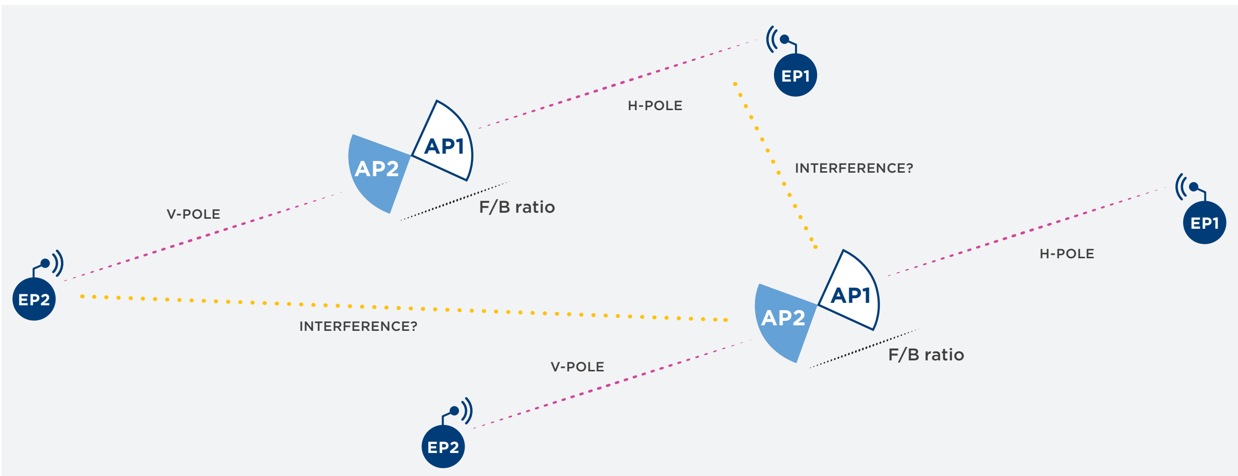

Figure 9 Multiple Complex-hubs in an Area

To achieve 360-degree coverage, alternate channels should be introduced.

Optimal Channel Planning

In deployments where multiple channels might be required to achieve enough capacity, consider arranging the channels to prevent a potential co-channel interference path. The following diagram shows four channels - A, B, C, and D. Option 2 is preferable because option 1 could create a potential co-channel interference path.

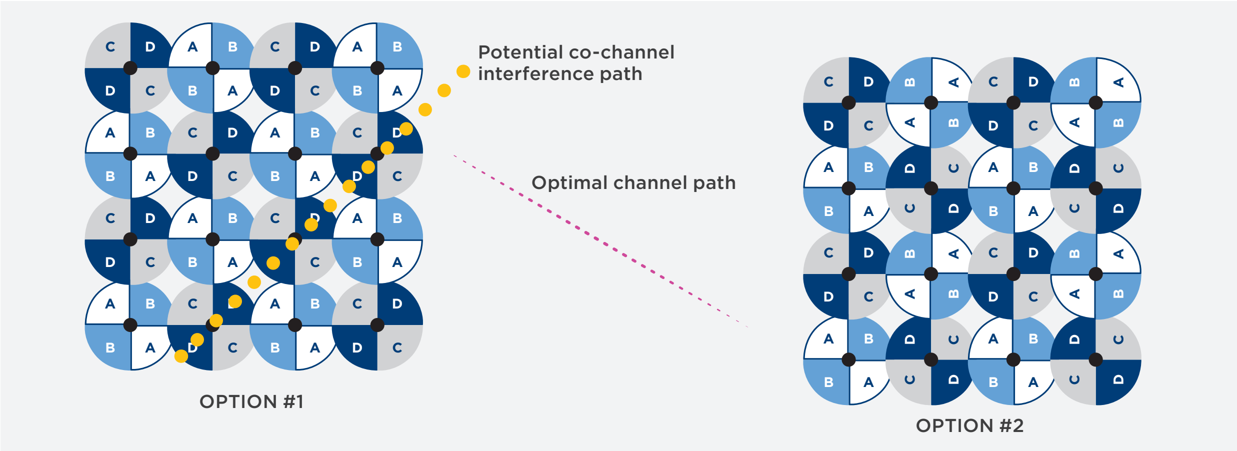

Figure 10 Channel Planning Optimization

SNR reference

The following table shows SNR requirements for different modulation modes for the 900MHz radio. Please refer to specification document for other frequencies.

ISM			MAS			
Modulation	Sensitivity (dBm)	Min SNR (dB)	Modulation	Ch Size	Sensitivity (dBm)	Min SNR (dB)
57 MSK [1]	-111	10	10 MSK	12.5	-114	14
114 MSK [1]	-109	9	19 4FSK	12.5	-106	22
153 MSK [1]	-108	9	23 QPSK	12.5	-108	20
229 MSK [1]	-105	10	34 8PSK	12.5	-101	27
663 2FSK [1]	-101	9	45 16QAM	12.5	-97	31
884 BPSK [1]	-101	7	57 32QAM	12.5	-91	37
1768 QPSK [1]	-98	11	19 MSK	25	-115	15
2651 8PSK [1]	-91	18	39 4FSK	25	-103	22
3535 16QAM	-86	23	36 QPSK	25	-110	15
3535 16PSK	-75	34	52 8PSK	25	-104	21
4419 32QAM	-83	25	70 16QAM	25	-100	30
			87 32QAM	25	-96	34
			105 64QAM	25	-90	40
			39 MSK	50	-112	15
			71 QPSK	50	-106	16
			101 8PSK	50	-101	21
			137 16QAM	50	-97	25
			175 32QAM	50	-93	34
			210 64QAM	50	-84	43

The quoted sensitivity levels are based on a BER of 10^{-4}

Table 1 Sensitivity & Minimum SNR Per Modulation Mode of 900MHz Radio

TDD Synchronization Setup and Configuration

cnReach supports self-generated sync as well as sync provided by an external 1PPS source, such as the Cambium Networks uGPS module. With self-generated sync, one of the APs is configured to be the sync source, from which all of the other radios in the network derive their sync timing. If the remote cluster cannot derive the sync from the sync-source AP, external GPS – such as Cambium uGPS – should be installed on each cluster. While the benefit of using self-generated sync is cost effectiveness, the tradeoff is compromise of the entire network's synchronization if the sync source AP goes down. Please refer to cnReach user guide for proper configuration of the TDD Sync feature.

Conclusion

cnReach™ offers operators multiple techniques to improve spectral efficiency and reduce self-interference. TDD Synchronization, alternating antenna polarization, and selective channel planning make it possible to reuse the same RF channel in the deployment, resulting in significant improvement in RF efficiency and network performance.