Cambium Release 12.2 PMP 430 to PMP 450 upgrade recommendations

Cambium Networks

Introduction

Cambium System Release 12.2 introduces the interoperability feature, which allows PMP 430 subscriber modules (SMs) to communicate with PMP 450 access points (APs) in the 5 GHz band. The PMP 430 subscriber modules need to be upgraded to Release 12.2 for all MAC and PHY layer features to match the PMP 450 AP.

The PMP 450 AP can simultaneously communicate with PMP 430 SMs and PMP 450 SMs in the same sector. This means that a mixed population of PMP 430 and PMP 450 SMs can be supported by the PMP 450 AP in one sector. The PMP 450 AP communicates in SISO mode with the PMP 430 SMs and it communicates in MIMO mode with the PMP 450 SMs, reverting to SISO mode only when the channel conditions do not allow reliable communication in MIMO mode.

This white paper focuses on differences between PMP 430 and PMP 450 deployments, it provides recommendations on how to upgrade a PMP 430 network to a PMP 450 network, and it summarizes the expected performance of the two networks.

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Migration path from PMP 430 network to PMP 450 network

With release R12.2 a currently deployed PMP 430 sector can be migrated to a PMP 450 sector using the interoperability feature. Operators can keep the currently deployed PMP 430 SMs in the network, deploy more PMP 450 SMs in the same sector and/or replace the existing PMP 430 SMs with PMP 450 SMs.

Operators who want to upgrade their sector, can follow these steps:

1. Upgrade the PMP 430 sector (AP and SMs) to Release 12.1 software load using the OFDM CNUT package **CANOPY121BUILDOFFICIAL_OFDM_AES.pkg3** or **CANOPY121BUILDOFFICIAL_OFDM_DES.pkg3**, if Release 12.1 is not being currently used.
2. Upgrade the PMP 430 sector (AP and SMs) to Release 12.2 software load using the OFDM CNUT package **CANOPY122BUILDOFFICIAL_OFDM_AES.pkg3** or **CANOPY122BUILDOFFICIAL_OFDM_DES.pkg3**.

   The PMP 430 SMs automatically reboot after the upgrade and they start scanning in the last used mode, which in this case is the PMP 430 mode. Since the PMP 430 AP has not been replaced by a PMP 450 AP yet, all PMP 430 SMs will connect to the original PMP 430 AP.
3. Uninstall the PMP 430 AP and install a PMP 450 AP.

   Note: The PMP 450 AP requires a different power supply. The power supply needs to be replaced before installing the PMP 450 AP.

   The PMP 430 SMs will go out of session and start scanning again. They will scan in PMP 430 mode first, because that was the last used mode, and will not connect to the PMP 430 AP. After 10 minutes the PMP 430 SMs start scanning in PMP 450 interoperability mode, connecting to the PMP 450 AP.
4. Deploy additional PMP 450 SMs alongside the existing PMP 430 SMs and/or upgrade existing PMP 430 SMs with PMP 450 SMs.

Once the PMP 430 AP is replaced with a PMP 450 AP, the MIMO CNUT package **CANOPY122BUILDOFFICIAL_MIMO_DESAES_S.pkg3** can be used to upgrade both the PMP 430 SMs and the PMP 450 SMs connected to the PMP 450 AP.

When the PMP 450 AP and all the PMP 430 and PMP 450 SMs connected to it have been upgraded to Release 12.2 it is not possible to downgrade the sector to a release prior to Release 12.2. The reason is that Release 12.2 is the first that supports the interoperability feature, and with any prior release the PMP 430 SMs would no longer be able to connect to the PMP 450 AP.

If downgrading the PMP 430 SMs is necessary, the PMP 450 AP has to be replaced by a PMP 430 AP. In this case downgrading becomes possible and the sector is again a PMP 430 sector. If any PMP 450 SMs were deployed in the sector, they will not be able to connect to a PMP 430 AP.

Notes and recommendations

- Guard Bands

  One difference between a PMP 450 deployment and a mixed PMP 450 – PMP 430 deployment using the interoperability feature is that in a PMP 450 deployment adjacent sectors can operate with adjacent frequencies, while in a mixed PMP 450 – PMP 430 deployment using the interoperability feature a guard band is needed. The guard band is equal to 5 MHz between two adjacent 20 and 10 MHz channels, and it is equal to 2.5 MHz between two adjacent 5 MHz channels.

  The interoperability feature will typically be used in two possible scenarios: for upgrading a PMP 430 network to a PMP 450 network, or for adding PMP 430 SMs to a Greenfield PMP 450 deployment.

  - Upgrade of a PMP 430 network to a PMP 450 network

    During network planning of a PMP 430 network, the recommendation is not to use adjacent channels on adjacent sectors, but to leave a 5 MHz guard band between adjacent channels when used on adjacent sectors. If the 5 MHz guard band is already present between adjacent channels, then this is a sufficient guard also between a PMP 430 channel and a PMP 450 channel, so the upgraded PMP 450 sector does not need additional guard bands.

  - Add PMP 430 SMs to a Greenfield PMP 450 deployment

    In a Greenfield PMP 450 deployment there is no requirement for guard bands between adjacent channels, so it is possible that the network was deployed with adjacent channels on adjacent frequencies. If PMP 430 SMs are added to the sector, it is necessary to update the network planning in order to leave a gap of 5 MHz between two adjacent 20 or 10 MHz channels, and a gap of 2.5 MHz between two adjacent 5 MHz channels when operating on adjacent sectors.

- Stranded SMs

  If some PMP 430 SMs are turned off during the upgrade process, they will require a truck roll to be upgraded to Release 12.2, because they will not be able to connect to the PMP 450 AP without running R12.2 software.

- Upgrade path

  In order to use the interoperability feature, the PMP 430 AP and SMs running Release 11.2 or Release 11.2.1 need first to be upgraded to Release 12.1, and then they can be upgraded to Release 12.2.

- Cyclic Prefix

  Since the PMP 450 AP supports CP=1/16 only, the upgraded PMP 430 SMs in interoperability mode also support CP=1/16 only. The PMP 430 SMs will automatically be defaulted to CP=1/16 when connected to a PMP 450 AP; the other CP values can be selected when registering to a PMP 430 AP.

- Channel bandwidth

  For the PMP 430 SMs to connect to the PMP 450 AP in interoperability mode, the PMP 430 bandwidth selected in the GUI needs to match the PMP 450 AP bandwidth. The PMP 430 SM does not support the band scan feature, and initial scanning only uses the selected bandwidth.

- Number of PMP 450 and PMP 430 SMs

  The operator can see how many PMP 450 SMs and how many PMP 430 SMs are connected by looking in the Session Page, which lists all connected subscriber modules. The PMP 450 SMs are listed as “PMP 450 MIMO OFDM” subscriber modules; while the PMP 430 SMs are listed as “PMP 430 SISO OFDM” subscriber modules. Also, in CNUT the PMP 450 SMs and the PMP 430 SMs are shown with two different icons.

- Color codes

  When the operator replaces a PMP 430 AP with a PMP 450 AP it is recommended that they use the same color code.

- Power requirements

  Since the power requirements of a PMP 430 AP are different than that of a PMP 450 AP, operators will need to make sure they can power their PMP 450 AP at the PMP 430 AP site.

  The PMP 430 AP requires 56V; the PMP 450 AP requires 30V. If the existing AP site has a CMM4, it will be necessary to add a 30V power supply and then configure the CMM4 for 30V in the GUI. If a power injector is used, it will be necessary to replace the 56V one with a 30V one.

  At the customer location, if a PMP 430 SM is replaced with a PMP 450 SM, no power change is needed because both the PMP 430 SM and the PMP 450 SM use the same power (30V).

- CNUT support

  The OFDM CNUT package **CANOPY121BUILDOFFICIAL_OFDM_AES.pkg3** or **CANOPY121BUILDOFFICIAL_OFDM_DES.pkg3** is used to upgrade the PMP 430 AP and the PMP 430 SMs to Release 12.1 first, if the PMP 430 sector is not already running Release 12.1. After a PMP 450 AP replaces the PMP 430 AP, **CANOPY122BUILDOFFICIAL_OFDM_DESAES.pkg3** is used to upgrade the PMP430 SM to Release 12.2. After a PMP 450 AP replaces the PMP 430 AP, there is no need to rediscover the PMP 430 SMs because the PMP 430 SMs have already been updated. However, users can do so to revalidate connectivity after an upgrade is complete.

  If the devices are doing DHCP and they move to different IPs, then CNUT will need to rediscover the devices to remap the MAC to IP address associations.

- PMP 430 scanning procedure algorithm

  Once upgraded to Release 12.2 the PMP 430 SM can operate both in PMP 430 mode and in PMP 450 interoperability mode.

  The mode(s) the PMP 430 SM scans in are controlled via SMNP or GUI by checking or unchecking the two corresponding checkboxes.

  If only one checkbox is selected, the PMP 430 will scan in the selected mode only.

  If both checkboxes are selected, after a reboot the PMP 430 SM will first scan in the last used mode. If after 10 minutes it does not connect to an AP, it will switch modes and start scanning in the other mode. Since the last used mode is always the first one to be selected for scanning, having both checkboxes selected does not increase registration time.

  It is recommended to leave both checkboxes selected so that the PMP 430 always has the capability of connecting to both the PMP 430 AP and the PMP 450 AP.

- Forced switch radio mode

  In case the PMP 430 SM receives a strong enough signal to connect to both a PMP 430 AP and a PMP 450 AP, it is possible to control the AP the SM connects to by using the forced switch radio mode functionality.

  The “Switch Radio Mode and Reboot” command instructs the PMP 430 SM to reboot and switch mode, as opposed to reboot and use the current mode, like it was described in the previous section.

  This functionality can be used for example if a PMP 450 AP is installed alongside a PMP 430 AP before the PMP 430 AP is removed from the sector. In this scenario, without the forced switch radio mode functionality, after a reboot the PMP 430 SMs start scanning in the last used mode, which is PMP 430 mode; they see the PMP 430 AP and always connect to it. The forced switch radio mode forces the PMP 430 SMs to start scanning in PMP 450 interoperability mode instead. In this mode they see the PMP 450 AP signal and connect to it instead of the PMP 430 AP.

Figure 1 - Radio configuration – AP registration options

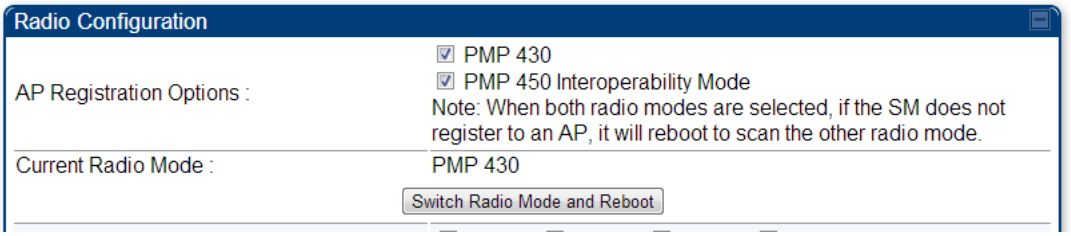

Table 1 - Switched radio mode SNMP object

Name	switchRadioModeAndReboot!@#.iso.org.dod.internet.private.enterprises.mot.whispRoot.whispProducts.whispSm.whispSmConfig.switchRadioModeAndReboot
OID	.1.3.6.1.4.1.161.19.3.2.1.146
MIB	WHISP-SM-MIB
Syntax	INTEGER {finishedReboot(0), switchRadioModeAndReboot(1)}
Access	read-write
Status	current
DefVal	
Indexes	
Descr	Setting the variable to 1 will reboot the unit. When the unit finishes rebooting, it will be in finishedReboot state. PMP430 SM only.

- Antenna gain

  Comparing the SM antenna gain and augmentation options for a PMP 430 SM and a PMP 450 SM, the PMP 430 SM has higher gain.

  The integrated antenna gain of the PMP 430 SM is 10 dB vs. 9 dB of the PMP 450 SM.

  The additional gain provided by the LENS for a PMP 430 SM is 6 dB vs. 5 dB for the PMP 450 SM.

  The additional gain provided by the Dish for a PMP 430 SM is 15 dB vs. 14 dB for the PMP 450 SM.

  If a PMP 430 network is upgraded to a PMP 450 network, users with PMP 430 SMs will experience a lower system gain when the PMP 430 SM is replaced by a PMP 450 SM. This lower system gain may change the modulation mode used for communication to a lower (more robust) mode, but it does not necessarily result in a lower throughput, because the PMP 450 SM is capable of communicating in MIMO mode.

- Sensitivity

  For each modulation mode, the PMP 430 system has 3 dB lower sensitivity values than the PMP 450 system, as shown in the following table.

Table 2 - PMP 430 and PMP 450 Sensitivity

Modulation	MIMO/SISO	PMP 430 Sensitivity	PMP 450 Sensitivity
QPSK	SISO	-87 dBm	-87 dBm
QPSK	MIMO	-	-84 dBm
16 QAM	SISO	-80 dBm	-
16 QAM	MIMO	-	-77 dBm
64 QAM	SISO	-73 dBm	-
64 QAM	MIMO	-	-70 dBm
256 QAM	MIMO	-	-60 dBm

When the PMP 430 AP is replaced by the PMP 450 AP, the uplink sensitivity values for each modulation are now higher, meaning that the PMP 430 SM may now support a lower modulation mode in the uplink transmission. Since the PMP 430 SM can only transmit in SISO mode, the MIMO reception capability of the PMP 450 AP is not utilized.

If the PMP 430 SM is replaced by a PMP 450 SM, the downlink sensitivity values are also higher now, again possibly resulting in a lower modulation mode being used in the downlink. However, the PMP 450 AP – PMP 450 SM pair can now transmit and receive using MIMO modulation, therefore doubling the throughput for each modulation mode.

Because of the different sensitivity values between a PMP 430 system and a PMP 450 system, some PMP 430 SMs may need antenna augmentation in order to connect to the PMP 450 AP. More details are given in the Link Budget comparison section below.

- Throughput

  The peak throughput of a PMP 430 sector using a 20 MHz channel is around 48 Mbps.

  The peak throughput of a PMP 450 sector using a 20 MHz channel is around 128 Mbps.

  The peak throughput of a sector having a PMP 450 AP and PMP 430 SMs using a 20 MHz channel is around 48 Mbps.

  The difference between the PMP 430 sector throughput and the PMP 450 sector throughput is given by the fact that the PMP 450 system can communicate in MIMO mode, which doubles the throughput for each modulation mode, and also by the fact that PMP 450 can communicate in 256 QAM mode, which provides a 33% increase in throughput compared to the 64 QAM mode.

The following tables summarize the total (DL+UL) expected throughputs.

Table 3 - PMP 430 AP to PMP 430 SM sector throughput

PMP 430 AP to PMP 430 SM	QPSK	16QAM	64QAM
5 MHz	3.5 Mbps	7 Mbps	10.5 Mbps
10 MHz	7.5 Mbps	15 Mbps	22.5 Mbps
20 MHz	16.5 Mbps	32 Mbps	48.5 Mbps

Table 4 - PMP 450 AP to PMP 450 SM sector throughput

PMP 450 AP to PMP 450 SM	QPSK-S	QPSK	16QAM	64QAM	256QAM
5 MHz	2 Mbps	4 Mbps	8 Mbps	14 Mbps	18 Mbps
10 MHz	6 Mbps	13 Mbps	26 Mbps	42 Mbps	55 Mbps
20 MHz	13 Mbps	30 Mbps	60 Mbps	98 Mbps	128 Mbps

Table 5 - PMP 450 AP to PMP 430 SM sector throughput

PMP 450 AP to PMP 430 SM	QPSK	16QAM	64QAM
5 MHz	2 Mbps	4 Mbps	7 Mbps
10 MHz	6 Mbps	12 Mbps	20 Mbps
20 MHz	13 Mbps	28 Mbps	48 Mbps

The throughput of a link between a PMP 450 AP and a PMP 430 SM is approximately equal to half the throughput of a link between a PMP 450 AP and a PMP 450 SM with the same modulation because the PMP 430 SM can only communicate in SISO mode, while the PMP 450 SM can communicate in MIMO mode. The exception is for SMs very close to the AP, because the PMP 450 SMs can support 256 QAM mode, while the PMP 430 SMs cannot.

The throughput of a link between a PMP 450 AP and a PMP 430 SM is slightly lower than the throughput of a link between a PMP 430 AP and a PMP 430 SM.

Note that both systems have the same CP selection equal to 1/16, but the 1/16 CP in the two systems corresponds to two different CP lengths in µs. A PMP 450 system with CP equal to 1/16 has the same CP time in µs as a PMP 430 system with CP equal to 1/8. The shorter CP time in µs for the PMP 430 system with 1/16 CP leaves more time for data transmission and therefore leads to a higher throughput.

The peak throughput of a PMP 450 AP connected to both PMP 430 SMs and PMP 450 SMs depends on the ratio of the PMP 430 SMs and PMP 450 SMs. If most of the SMs connected to the PMP 450 AP are PMP 430 SMs, then the PMP 450 AP throughput will be closer to 47 Mbps; if most of the SMs connected to the PMP 450 AP are PMP 450 SMs, then the PMP 450 AP throughput will be closer to 130 Mbps.

PMP 430 – PMP 450 Link Budget comparison

The following table summarizes expected performance for a PMP 430 system in a 20 MHz channel.

Table 6 - Link budget and expected range for a PMP 430 system

AP	SM	SM Ant Config	MIMO/SISO	Mod	Link Budget	Range (w/FD Margin)		
						LOS (best)	LOS (99.5%) or nLOS	NLOS
					FM -->	0	5	15
					dB	miles	miles	miles
PMP 430 AP	PMP 430 SM	Integ	SISO	64QAM	**117.5**	**1.9**	**1.1**	**0.3**
PMP 430 AP	PMP 430 SM	Integ	SISO	16QAM	**124.5**	**4.3**	**2.4**	**0.8**
PMP 430 AP	PMP 430 SM	Integ	SISO	QPSK	**131.5**	**9.6**	**5.4**	**1.7**
PMP 430 AP	PMP 430 SM	LENS	SISO	64QAM	**123.5**	**3.8**	**2.1**	**0.7**
PMP 430 AP	PMP 430 SM	LENS	SISO	16QAM	**130.5**	**8.5**	**4.8**	**1.5**
PMP 430 AP	PMP 430 SM	LENS	SISO	QPSK	**137.5**	**19.1**	**10.8**	**3.4**
PMP 430 AP	PMP 430 SM	CLIP	SISO	64QAM	**125.5**	**4.8**	**2.7**	**0.9**
PMP 430 AP	PMP 430 SM	CLIP	SISO	16QAM	**132.5**	**10.8**	**6.0**	**1.9**
PMP 430 AP	PMP 430 SM	CLIP	SISO	QPSK	**139.5**	**24.1**	**13.5**	**4.3**
PMP 430 AP	PMP 430 SM	Dish	SISO	64QAM	**132.5**	**10.8**	**6.0**	**1.9**
PMP 430 AP	PMP 430 SM	Dish	SISO	16QAM	**139.5**	**24.1**	**13.5**	**4.3**
PMP 430 AP	PMP 430 SM	Dish	SISO	QPSK	**146.5**	**53.9**	**30.3**	**9.6**

Notes:
- All values shown are for an ambient temperature of 55° C
- Receiver Sensitivity measured at a 1% radio fragment error rate
- FM refers to Fade Margin
- Transmit power complies with FCC regulatory requirements

The following table summarizes expected performance for a PMP 450 system in a 20 MHz channel with a mix of PMP 450 SMs and PMP 430 SMs.

Table 7 - Link budget and expected range for a PMP 450 system with both PMP 450 subscribers and PMP 430 subscribers

AP	SM	SM Ant Config	MCS	Mod	Link Budget	Range (w/FD Margin)		
						LOS (best)	LOS (99.5%) or nLOS	NLOS
					FM -->	0	5	15
					dB	miles	miles	miles
PMP 450 AP	PMP 450 SM	Integ	MIMO	256QAM	**100.5**	**0.3**	**0.2**	**0.0**
PMP 450 AP	PMP 450 SM	Integ	MIMO	64QAM	**110.5**	**0.9**	**0.5**	**0.2**
PMP 450 AP	PMP 450 SM	Integ	MIMO	16QAM	**117.5**	**1.9**	**1.1**	**0.3**
PMP 450 AP	PMP 450 SM	Integ	MIMO	QPSK	**124.5**	**4.3**	**2.4**	**0.8**
PMP 450 AP	PMP 450 SM	Integ	SISO	QPSK-S	**127.5**	**6.0**	**3.4**	**1.1**
PMP 450 AP	PMP 450 SM	LENS	MIMO	256QAM	**105.5**	**0.5**	**0.3**	**0.1**
PMP 450 AP	PMP 450 SM	LENS	MIMO	64QAM	**115.5**	**1.5**	**0.9**	**0.3**
PMP 450 AP	PMP 450 SM	LENS	MIMO	16QAM	**122.5**	**3.4**	**1.9**	**0.6**
PMP 450 AP	PMP 450 SM	LENS	MIMO	QPSK	**129.5**	**7.6**	**4.3**	**1.4**
PMP 450 AP	PMP 450 SM	LENS	SISO	QPSK-S	**132.5**	**10.8**	**6.0**	**1.9**
PMP 450 AP	PMP 450 SM	CLIP	MIMO	256QAM	**108.5**	**0.7**	**0.4**	**0.1**
PMP 450 AP	PMP 450 SM	CLIP	MIMO	64QAM	**118.5**	**2.1**	**1.2**	**0.4**
PMP 450 AP	PMP 450 SM	CLIP	MIMO	16QAM	**125.5**	**4.8**	**2.7**	**0.9**
PMP 450 AP	PMP 450 SM	CLIP	MIMO	QPSK	**132.5**	**10.8**	**6.0**	**1.9**
PMP 450 AP	PMP 450 SM	CLIP	SISO	QPSK-S	**135.5**	**15.2**	**8.5**	**2.7**
PMP 450 AP	PMP 450 SM	Dish	MIMO	256QAM	**114.5**	**1.4**	**0.8**	**0.2**
PMP 450 AP	PMP 450 SM	Dish	MIMO	64QAM	**124.5**	**4.3**	**2.4**	**0.8**
PMP 450 AP	PMP 450 SM	Dish	MIMO	16QAM	**131.5**	**9.6**	**5.4**	**1.7**
PMP 450 AP	PMP 450 SM	Dish	MIMO	QPSK	**138.5**	**21.5**	**12.1**	**3.8**
PMP 450 AP	PMP 450 SM	Dish	SISO	QPSK-S	**141.5**	**30.3**	**17.0**	**5.4**
PMP 450 AP	PMP 450 SM	CONN	MIMO	256QAM	**103.8**	**0.4**	**0.2**	**0.1**
PMP 450 AP	PMP 450 SM	CONN	MIMO	64QAM	**113.8**	**1.2**	**0.7**	**0.2**
PMP 450 AP	PMP 450 SM	CONN	MIMO	16QAM	**120.8**	**2.8**	**1.6**	**0.5**
PMP 450 AP	PMP 450 SM	CONN	MIMO	QPSK	**127.8**	**6.3**	**3.5**	**1.1**
PMP 450 AP	PMP 450 SM	CONN	SISO	QPSK-S	**130.8**	**8.8**	**5.0**	**1.6**
PMP 450 AP	PMP 430 SM	Integ	SISO	64QAM	**114.5**	**1.4**	**0.8**	**0.2**
PMP 450 AP	PMP 430 SM	Integ	SISO	16QAM	**121.5**	**3.0**	**1.7**	**0.5**
PMP 450 AP	PMP 430 SM	Integ	SISO	QPSK	**128.5**	**6.8**	**3.8**	**1.2**
PMP 450 AP	PMP 430 SM	LENS	SISO	64QAM	**120.5**	**2.7**	**1.5**	**0.5**
PMP 450 AP	PMP 430 SM	LENS	SISO	16QAM	**127.5**	**6.0**	**3.4**	**1.1**
PMP 450 AP	PMP 430 SM	LENS	SISO	QPSK	**134.5**	**13.5**	**7.6**	**2.4**
PMP 450 AP	PMP 430 SM	CLIP	SISO	64QAM	**122.5**	**3.4**	**1.9**	**0.6**
PMP 450 AP	PMP 430 SM	CLIP	SISO	16QAM	**129.5**	**7.6**	**4.3**	**1.4**
PMP 450 AP	PMP 430 SM	CLIP	SISO	QPSK	**136.5**	**17.0**	**9.6**	**3.0**
PMP 450 AP	PMP 430 SM	Dish	SISO	64QAM	**129.5**	**7.6**	**4.3**	**1.4**
PMP 450 AP	PMP 430 SM	Dish	SISO	16QAM	**136.5**	**17.0**	**9.6**	**3.0**
PMP 450 AP	PMP 430 SM	Dish	SISO	QPSK	**143.5**	**38.2**	**21.5**	**6.8**

Notes:
- All values shown are for an ambient temperature of 55° C
- Receiver Sensitivity measured at a 1% radio fragment error rate
- FM refers to Fade Margin
- Transmit power complies with FCC regulatory requirements

- **Example 1: Large distance - augmentation needed, doubling of throughput**
  Subscriber 1 has a PMP 430 SM at a 7 mile distance from the PMP 430 AP and no antenna augmentation. In a PMP 430 system this subscriber can communicate in QPSK mode. When the PMP 430 AP is replaced by a PMP 450 AP, this subscriber can no longer connect without antenna augmentation. If a LENS is added to the SM, it can now connect and communicate at QPSK. The throughput experienced by this subscriber is the same as the one it was experiencing before. If the PMP 430 SM is replaced by a PMP 450 SM with a LENS, the PMP 450 can now communicate in QPSK MIMO mode, doubling the SM's throughput.
- **Example 2: Medium distance - no augmentation needed, same throughput**
  Subscriber 2 has a PMP 430 SM at a 4 mile distance from the PMP 430 AP and no antenna augmentation. In a PMP 430 system this subscriber can communicate in 16 QAM mode. When the PMP 430 AP is replaced by a PMP 450 AP, the PMP 430 SM can now communicate in QPSK mode, with a throughput equal to half the original throughput. If the PMP 430 SM is replaced by a PMP 450 SM, the PMP 450 can now communicate in QPSK MIMO mode, which provides the same throughput as the original 16 QAM SISO mode.
  For this user the maximum throughput has not changed upgrading from a PMP 430 network to a PMP 450 network, but the more PMP 430 SMs are replaced with PMP 450 SMs the higher the AP sector capacity is, more than doubling the original PMP 430 AP sector capacity. Even if the peak speed of one SM is the same, all other PMP 450 users are served faster because they can communicate in MIMO mode and the whole sector can now experience a higher throughput.
- **Example 3: Small distance - no augmentation needed, doubling of throughput**
  Subscriber 3 has a PMP 430 SM at a 0.75 mile distance from the PMP 430 AP and no antenna augmentation. In a PMP 430 system this subscriber can communicate in 64 QAM mode. When the PMP 430 AP is replaced by a PMP 450 AP, the PMP 430 SM can still communicate in 64 QAM mode, with the same original throughput. If the PMP 430 SM is replaced by a PMP 450 SM, the PMP 450 can now communicate in 64 QAM MIMO mode, doubling the SM's throughput.