Cambium Networks™

Using the ePMP Link Budget Tool

The ePMP Series Link Budget Tool can offer a help to determine the expected performances in terms of distances of a ePMP Series system operating in line-of-sight (LOS) propagation condition.

ePMP Series introduction

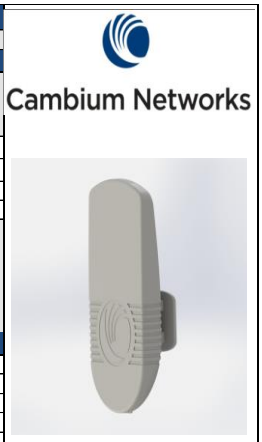
The purpose of this document is to provide a quick description on how to use the ePMP Series Link Budget Tool. The Cambium Networks ePMP Series is a wireless access system designed to create a radio local area network (RLAN) through microwave links in a point-to-multipoint mode operating in the 5 GHz unlicensed bands. The ePMP Series Link Budget Tool can offer a quick help to determine the expected performances in terms of distances of a ePMP Series system operating in line-of-sight (LOS) propagation condition according to the configuration of several system parameters like channel bandwidth and antenna selection.

ePMP LINK BUDGET CALCULATOR

Cambium Networks confidential, not commercially binding

SYSTEM CONFIGURATION

Country	**FCC**				
Frequency band	**5.7/5.8** [GHz]	Lower frequency	**5725** [MHz]		
Fade Margin	**0** [dB]	Upper frequency	**5875** [MHz]		
Channel Bandwidth	**20** [MHz]	AP EIRP limit	**36** [dBm]	4.000 [Watts]	
AP antenna system	**90° sector**	Max AP Tx Power	**23** [dBm]	200 [mWatts]	
Environment	**rural**	STA EIRP limit	**-** [dBm]	- [Watts]	
Max range	**5** [miles]	Max STA Tx Power	**23** [dBm]	200 [mWatts]	
Max range limit	15.93 [miles]				
Frame duration	**5.0** [ms]				
Number of STAs/sector	**20**				
Duty cycle	**50/50**				
UDP payload size	**1472** [bytes]				
Interference level	**0** [dBm]				



DOWNLINK BUDGET (AP to STA)				UPLINK BUDGET (STA to AP)			
AP Tx Power per chain	**20** [dBm]	0.100 [Watts]		STA Tx Power per chain	**20** [dBm]	0.100 [Watts]	
Cable Loss	**1.0** [dB]	0.001 [Watts]					
AP Antenna Gain	**15** [dBi]	90° sector		STA Antenna Gain	**13** [dBi]	Internal SM antenna	
AP EIRP	**34** [dBm]	2.512 [Watts]		STA EIRP	**33** [dBm]	2.0 [Watts]	
STA Rx Sensitivity	**-68** [dBm]	64QAM 5/6	MCS15	AP Rx Sensitivity	**-70** [dBm]	64QAM 5/6	MCS15
	-70 [dBm]	64QAM 3/4	MCS14		**-71** [dBm]	64QAM 3/4	MCS14
	-73 [dBm]	64QAM 2/3	MCS13		**-73** [dBm]	64QAM 2/3	MCS13
	-77 [dBm]	16QAM 3/4	MCS12		**-78** [dBm]	16QAM 3/4	MCS12
	-82 [dBm]	16QAM 1/2	MCS11		**-81** [dBm]	16QAM 1/2	MCS11
	-83 [dBm]	QPSK 3/4	MCS10		**-84** [dBm]	QPSK 3/4	MCS10
	-87 [dBm]	QPSK 1/2	MCS9		**-86** [dBm]	QPSK 1/2	MCS9
	-90 [dBm]	QPSK 1/2 SS	MCS1		**-89** [dBm]	QPSK 1/2 SS	MCS1
STA CINR	**28** [dB]	64QAM 5/6	MCS15	AP CINR	**30** [dB]	64QAM 5/6	MCS15
	27 [dB]	64QAM 3/4	MCS14		**28** [dB]	64QAM 3/4	MCS14
	25 [dB]	64QAM 2/3	MCS13		**25** [dB]	64QAM 2/3	MCS13
	20 [dB]	16QAM 3/4	MCS12		**21** [dB]	16QAM 3/4	MCS12
	17 [dB]	16QAM 1/2	MCS11		**16** [dB]	16QAM 1/2	MCS11
	14 [dB]	QPSK 3/4	MCS10		**15** [dB]	QPSK 3/4	MCS10
	12 [dB]	QPSK 1/2	MCS9		**11** [dB]	QPSK 1/2	MCS9
	9 [dB]	QPSK 1/2 SS	MCS1		**8** [dB]	QPSK 1/2 SS	MCS1
STA Antenna Gain	**13** [dBi]	Internal SM antenna		Cable Loss	**1.0** [dB]	0.001 [Watts]	
				AP Antenna Gain	**15** [dBi]	90° sector	

The link is **uplink** limited by **1 dB**

COVERAGE AND CAPACITY

Modulation		System Gain		Potential Range				Max DL Throughput		Max UL Throughput		Max Total Throughput		Capacity (Mbps)	
64QAM 5/6	MCS15	**115.0**	dB	**1.42**	mi	**2.28**	km	**39.6**	Mbps	**30.4**	Mbps	**70.0**	Mbps	**DL**	**21.8**
64QAM 3/4	MCS14	**117.0**	dB	**1.79**	mi	**2.88**	km	**36.0**	Mbps	**26.2**	Mbps	**62.2**	Mbps	**UL**	**16.6**
64QAM 2/3	MCS13	**120.0**	dB	**2.52**	mi	**4.06**	km	**32.4**	Mbps	**24.2**	Mbps	**56.6**	Mbps	**Total**	**38.3**
16QAM 3/4	MCS12	**124.0**	dB	**4.00**	mi	**6.44**	km	**23.4**	Mbps	**18.2**	Mbps	**41.6**	Mbps		
16QAM 1/2	MCS11	**128.0**	dB	**6.34**	mi	**10.20**	km	**16.2**	Mbps	**12.2**	Mbps	**28.4**	Mbps	**Scheduling latency (ms)**	
QPSK 3/4	MCS10	**130.0**	dB	**7.98**	mi	**12.85**	km	**12.6**	Mbps	**8.0**	Mbps	**20.6**	Mbps	**DL**	**17.5**
QPSK 1/2	MCS9	**133.0**	dB	**11.27**	mi	**18.14**	km	**7.2**	Mbps	**6.0**	Mbps	**13.2**	Mbps	**UL**	**16.1**
QPSK 1/2 SS	MCS1	**136.0**	dB	**15.93**	mi	**25.63**	km	**3.6**	Mbps	**2.0**	Mbps	**5.6**	Mbps	**Total**	**33.6**

The ePMP System creates a point-to-multipoint wireless broadband connection transmitting a radio signal with OFDM modulation and MIMO transmission technique.

OFDM (Orthogonal Frequency Division multiplexing) is a multi-carrier radio signal modulation based on the subdivision of the broadband channel into orthogonally-positioned subcarriers, each of which is modulated based on a conventional modulation

scheme. With the OFDM technique, a very high data rate can be obtained increasing the system's spectrum efficiency.
The following are the subcarriers modulation schemes which can be used by the ePMP System:

- QPSK
- 16-QAM
- 64-QAM

Each modulation supports multiple coding rates. For example 64-QAM supports coding rates 5/6, 3/4 and 2/3.
The OFDM channel bandwidth can be configured with one of two possible values: 20 MHz and 40 MHz. 40 MHz channel bandwidth configurations allow for greater connection capacity as the signal occupies a larger portion of the spectrum. The narrower channel bandwidth (20 MHz) increases reception sensitivity and allows for more opportunities to operate in spectrum-constrained RF environments.
The channel bandwidth must be configured with the same values in both the AP and SM modules of the ePMP System.

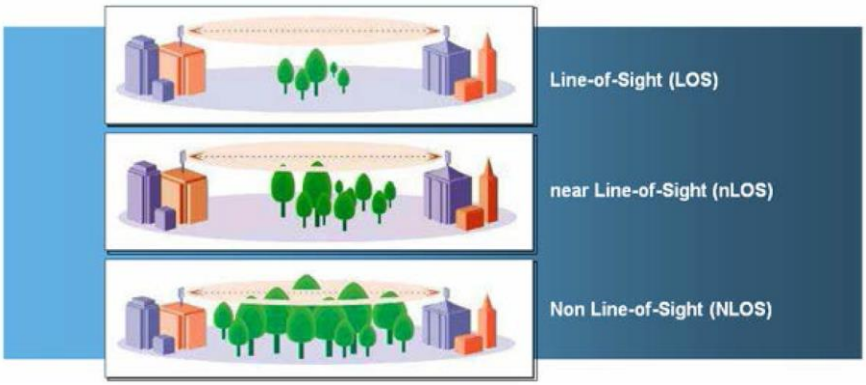
MIMO (Multiple Input Multiple Output) radio transmission offers the capability of increasing the capacity of a radio connection by transmitting and receiving parallel signals on separate Tx/Rx chains. When the benefits of the MIMO techniques are combined with OFDM signaling and high system gain, operators can achieve a highly robust radio connection in conditions of non-line-of-sight (NLOS) propagation. The ePMP System uses 2x2 MIMO with two radio receivers and two transmitters in both the AP module and the STA module, transmitting in both directions two radio signals in the same frequency. One signal is vertically polarized and the other signal is horizontally polarized, with dual stream mode: the system transmits two distinct parallel data flows – one by way of the vertically polarized radio signal and the other by way of the horizontally polarized radio signal. In this way, the ePMP System doubles its transmission capacity.
The ePMP system also offers a single stream mode, in which both transmit chains transmit the same data, which is then combined at the receiver. This mode improves the sensitity of the system and increases the range.

Cambium Networks offers two section antennas to be used with the AP module of the ePMP System to create the RF coverage of service areas in multisector sites. The antennas provided by Cambium Networks are specifically designed to optimize the performance in terms of radio coverage of the ePMP System:

- 90° sector antenna for sites with up to 4 AP modules
- 120° sector antenna for sites with up to 3 AP modules

The ePMP Series can provide LOS (Line-Of-Sight), nLOS (near Line-Of-Sight) connectivity and NLOS (Non-Line-Of-Sight) connectivity. A definition of these different propagation conditions are the following.

- **LOS**: the optical line between the AP and the SM and the first Fresnel zone are clear.
- **nLOS**: the optical line between the AP and the SM is clear, but a portion of the first Fresnel zone is blocked.
- **NLOS**: the optical line between the AP and the SM and a portion or even much of the first Fresnel zone are blocked, but subsequent Fresnel zones are open.



Link budget calculation is applied to a wireless broadband system based on ePMP Series that is designed in order to operate in LOS propagation conditions with clearance of the first Fresnel zone.
Attenuation due to building clutter or foliage obstruction can be accounted for by increasing the fade margin in the link budget calculation.

Link budget calculation

The link budget is the list of all the gains and losses that contribute to the propagation of the radio frequency signal that travels from the transmitter to the receiver.
The parameters that are taken into account for the calculation of the link budget are described below:

Transmitter output power: the median power level of the transmitter in the transmission channel experessed in dBm (relative to milliwatt). This level is configured for the AP transmitter by the regulatory limits and is automatically adjusted in the SM transmitter through ATPC (Automatic Transmit Power Control) functionality in order to get the maximum value.

Cable loss: the loss expressed in dB associated with the coaxial cable used to connect the transmitter with the antenna. The loss tipically depends on the length of the cable and its quality.

Transmitter antenna gain: assuming that the transmitter antenna main axis is oriented in the direction of the receiver antenna, the maximum gain given in dB declared by the manufacturer is used.

EIRP (Effective Isotropic Radiated Power): is the sum of the transmitter output power and transmitter atenna gain minus the cable loss, expressed in dBm.

Receiver antenna gain: assuming that the receiver antenna main axis is oriented in the direction of the transmitterer antenna, the maximum gain given in dB declared by the manufacturer is used.

Fade margin: the amount of power given in dB that represents the difference between the median signal level at the receiver input and the receiver sensitvity. When the link fades exceeding the fade margin an outage occurs. Fade margin must be selected by the user according to the link availability target that must be met.

Receiver sensitivity: the minimum median signal level needed at the input of the receiver to achieve a receiver output quality specific to a particular modulation scheme. Higher order modulation schemes require higher quality receiver output and higher received power signal levels.

System Gain: the difference, expressed in dB, between the EIRP and the lowest order modulation receiver sensitivity and cable loss. It conventionally refers to the minimum of the uplink and downlink system gains and represents the maximum FSPL achievable with a particular system configuration.

FSPL (Free Space Path Loss): it represents the radio frequency propagation calculation used in the tool and is the attenuation between the transmitter antenna and the receiver antenna in free-space given by the Friis formula:

- FSPL [dB] = $32.44 + 20\log f + 20\log d$

Where f is expressed in MHz and d is expressed in kilometers

- FSPL [dB] = $36.6 + 20\log f + 20\log d$

Where f is expressed in MHz and d is expressed in miles

This link budget calculation can be considered a valid approximation for LOS propagation in flat fading conditions where the operating bandwidth is less that the coherence bandwidth of the radio channel, that is when the same degree of fading affects all frequencies of the signal bandwidth. In case the radio channel is experiencing frequency-selective fading effect the LOS range results may not be valid.

Tool settings

The user interface of the Link Budget tool is divided in three main parts: System Configuration, Downlink & Uplink Budgets and Coverage & Capacity.
In the **SYSTEM CONFIGURATION** menu the fields in green color represent the parameters that can be set by the user according to the system configuration that is applied to the ePMP Series. The fields in white are just output values to be used as references for the input parameters setting.

SYSTEM CONFIGURATION					
Country	**FCC**				
Frequency band	**5.7/5.8** [GHz]		Lower frequency	**5725** [MHz]	
Fade Margin	**0** [dB]		Upper frequency	**5875** [MHz]	
Channel Bandwidth	**20** [MHz]		AP EIRP limit	**36** [dBm]	4.000 [Watts]
AP antenna system	**90° sector**		Max AP Tx Power	**23** [dBm]	200 [mWatts]
Environment	**rural**		STA EIRP limit	**-** [dBm]	- [Watts]
Max range	**5** [miles]		Max STA Tx Power	**23** [dBm]	200 [mWatts]
Max range limit	15.93 [miles]				
Frame duration	**5.0** [ms]				
Number of STAs/sector	**20**				
Duty cycle	**50/50**				
UDP payload size	**1472** [bytes]				
Interference level	**0** [dBm]				

The reference values are the following:

Lower frequency: lower edge of the selected frequency band

Upper frequency: upper edge of the selected frequency band

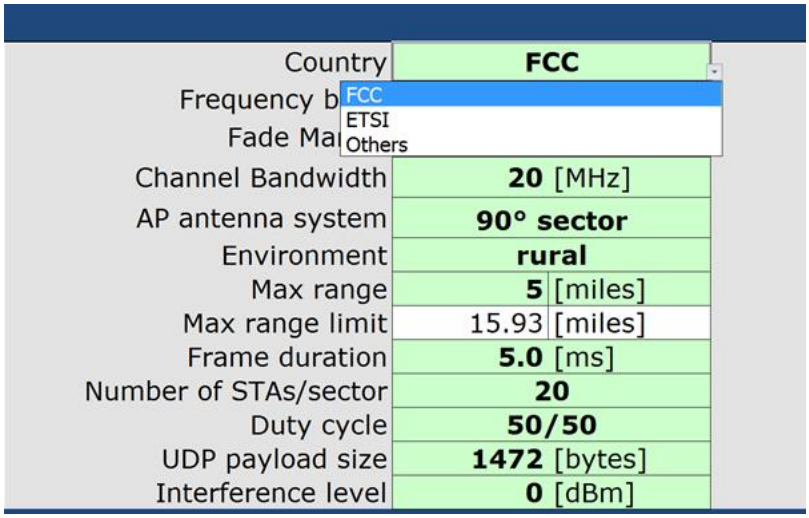
AP EIRP limit: limit of the combined power emitted by the AP antenna system, as defined by the regulatory selected. A value of "-" indicates that no limit is defined by the regulatory selected.

Max AP Tx Power: upper limit of the combined power that can be applied to the AP antenna system, in order to be compliant to the EIRP limit

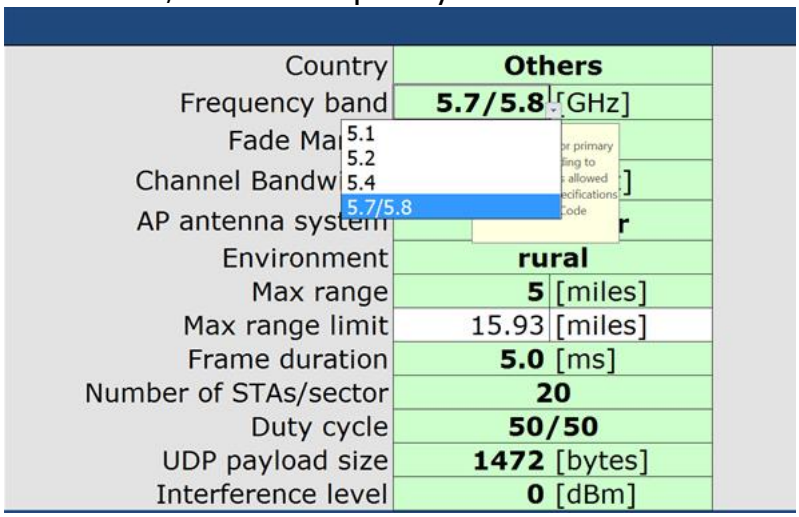
STA EIRP limit: limit of the combined power emitted by the STA antenna system, as defined by the regulatory selected. A value of "-" indicates that no limit is defined by the regulatory selected.

Max STA Tx Power: upper limit of the combined power that can be applied to the STA antenna system, in order to be compliant to the EIRP limit
The values that can be configured are the following:

Country: selection of the regulatory set of rules to be applied according to the country of operation.

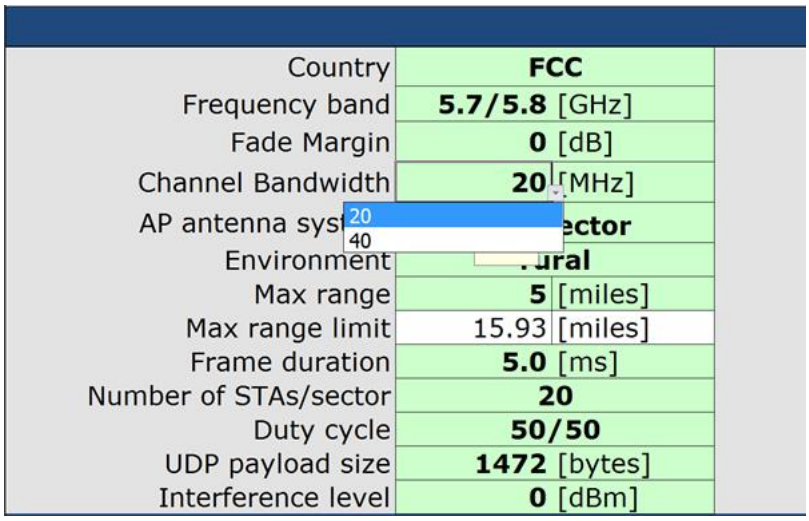


Frequency band: selection of the 5GHz spectrum band (5.1 GHz, 5.2 GHz, 5.4GHz or 5.7/5.8GHz). Not all frequency bands are available in all countries.

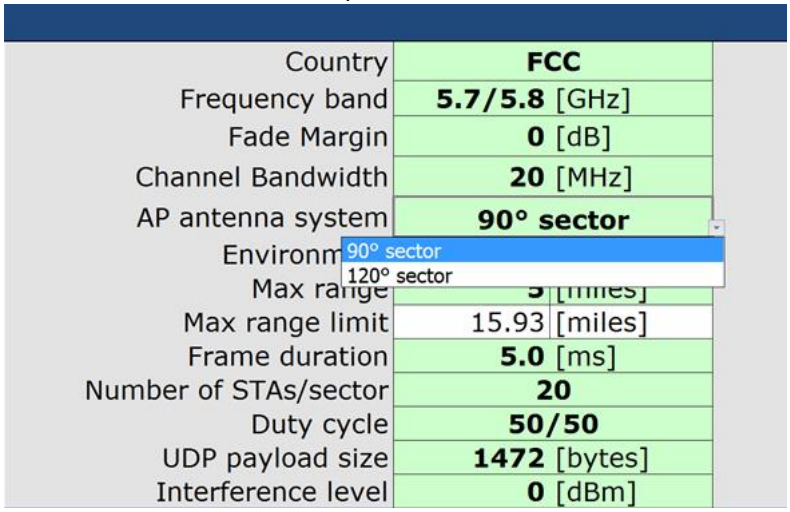


Fade Margin: setting of the margin on signal fading that the user wants to introduce in order to obtain a particular link availability.

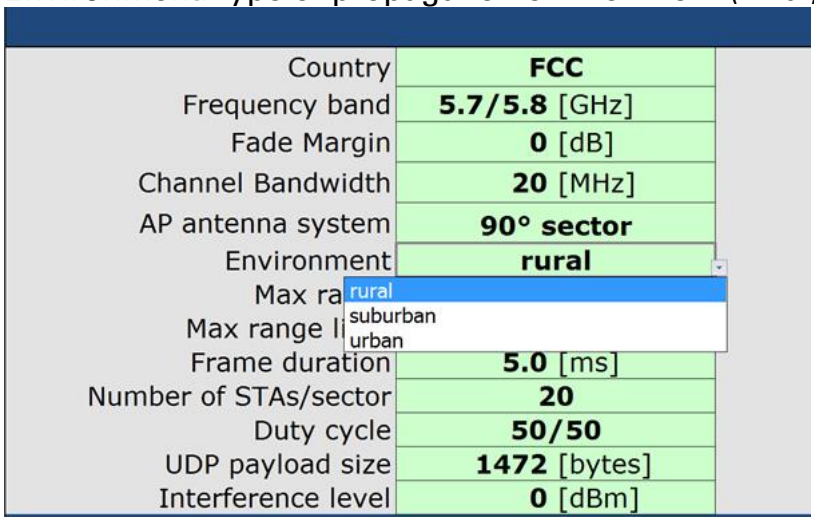
Channel Bandwidth: selection of the width of the operating channel (20MHz or 40MHz).



AP antenna system: selection of the antenna used for the AP module (90° sector antenna or 120° sector antenna).

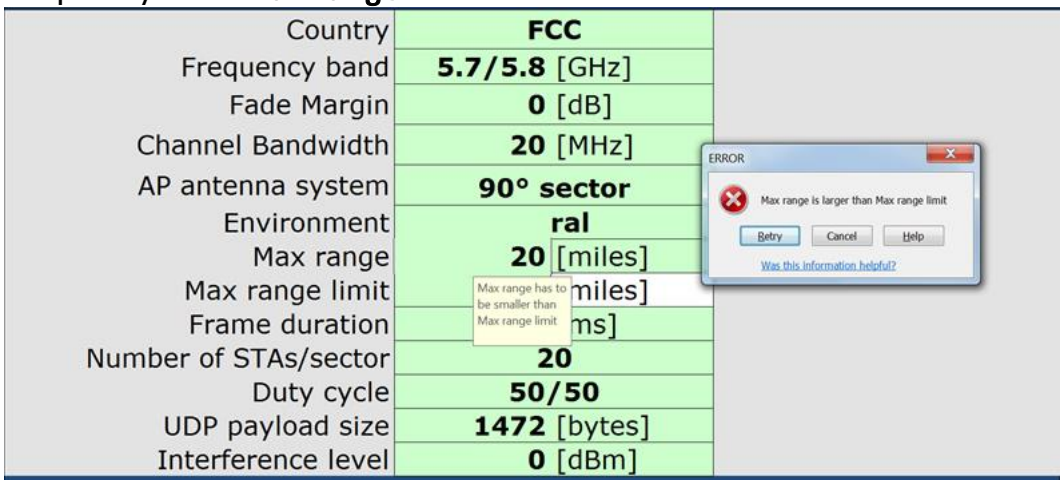


Environment: type of propagation environment (rural, suburban or urban)



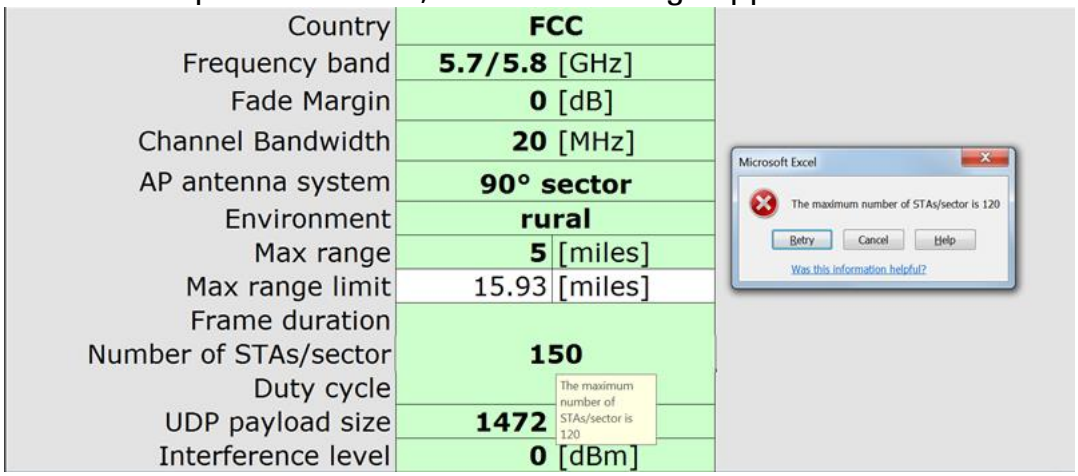
Maximum range: distance (in miles) between the AP and the location of the farther SM the user wants to serve with the AP. The potential maximum cell size is calculated using other link budget parameters selected in the green cells and is shown as the **Max range limit** (also in miles). If the **Maximum range** input is larger than the **Max range limit**, the **Maximum range cell** becomes red and an error message appears.

With a smaller cell size, a larger percentage of users can use higher order modulation, and the sector capacity is higher. On the other hand, with smaller cells network planning becomes very important, in order to limit interference between sectors using the same frequency. The **Max range limit** is a reference value and cannot be changed.

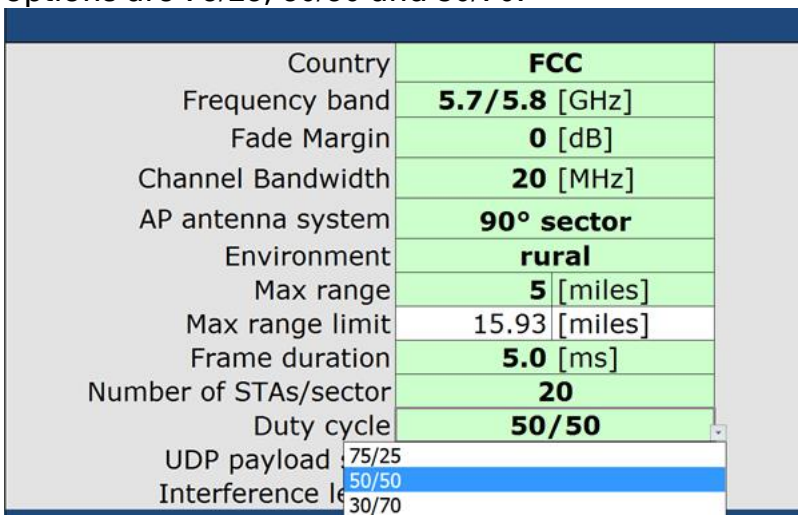


Frame duration: duration (in ms) of the TDD cycle. The first release supports the 5 ms selection only.

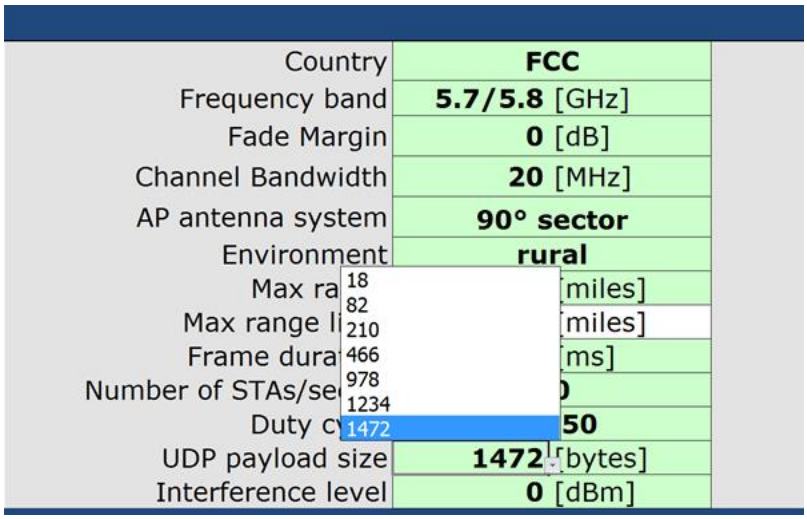
Number of STAs/sector: Number of STAs connected to one AP in one sector. The number of STAs affects the throughput that can be achieved in a sector, and also the scheduling latency within the AP.
The maximum number of STAs that can be connected in one sector is 120. If a larger number is input in this field, an error message appears.



Duty cycle: Percentage of frame time dedicated to downlink (AP to STA) transmission. The options are 75/25, 50/50 and 30/70.



UDP payload size: Number of bytes in the UPD payload. Options are: 18, 82, 210, 466, 978, 1234 and 1472. A larger payload size means a smaller overhead for transmitting packet headers.



Interference level: Value (in dBm) of the interference measured in the channel currently used (co-channel). A value of 0 in this field indicates no interference.

In the **DOWNLINK AND UPLINK BUDGET** part of the user interface the settings of all the parameters included in the link budget calculation are listed in two columns: one for the downlink direction (from AP to STA) and one for the uplink direction (from STA to AP). This section also shows the Carrier-to-Interference-and-Noise-Ratio (CINR) values both for the DL and the UL.

Both the sensitivity and CINR values are listed for all the MCS levels supported (MCS15 to MCS 9, in addition to MCS1). The modulation and coding rate corresponding to each MCS level is also shown in this section.

The table includes a note highlighting the eventual amount of imbalance of the System Gains that can be useful to reconfigure the system.

DOWNLINK BUDGET (AP to STA)			UPLINK BUDGET (STA to AP)		
AP Tx Power per chain	**20** [dBm]	0.100 [Watts]	STA Tx Power per chain	**20** [dBm]	0.100 [Watts]
Cable Loss	**1.0** [dB]	0.001 [Watts]			
AP Antenna Gain	**15** [dBi]	90° sector	STA Antenna Gain	**13** [dBi]	Internal SM antenna
AP EIRP	**34** [dBm]	2.512 [Watts]	STA EIRP	**33** [dBm]	2.0 [Watts]
STA Rx Sensitivity	**-68** [dBm]	64QAM 5/6 MCS15	AP Rx Sensitivity	**-70** [dBm]	64QAM 5/6 MCS15
	-70 [dBm]	64QAM 3/4 MCS14		**-71** [dBm]	64QAM 3/4 MCS14
	-73 [dBm]	64QAM 2/3 MCS13		**-73** [dBm]	64QAM 2/3 MCS13
	-77 [dBm]	16QAM 3/4 MCS12		**-78** [dBm]	16QAM 3/4 MCS12
	-82 [dBm]	16QAM 1/2 MCS11		**-81** [dBm]	16QAM 1/2 MCS11
	-83 [dBm]	QPSK 3/4 MCS10		**-84** [dBm]	QPSK 3/4 MCS10
	-87 [dBm]	QPSK 1/2 MCS9		**-86** [dBm]	QPSK 1/2 MCS9
	-90 [dBm]	QPSK 1/2 SS MCS1		**-89** [dBm]	QPSK 1/2 SS MCS1
STA CINR	**28** [dB]	64QAM 5/6 MCS15	AP CINR	**30** [dB]	64QAM 5/6 MCS15
	27 [dB]	64QAM 3/4 MCS14		**28** [dB]	64QAM 3/4 MCS14
	25 [dB]	64QAM 2/3 MCS13		**25** [dB]	64QAM 2/3 MCS13
	20 [dB]	16QAM 3/4 MCS12		**21** [dB]	16QAM 3/4 MCS12
	17 [dB]	16QAM 1/2 MCS11		**16** [dB]	16QAM 1/2 MCS11
	14 [dB]	QPSK 3/4 MCS10		**15** [dB]	QPSK 3/4 MCS10
	12 [dB]	QPSK 1/2 MCS9		**11** [dB]	QPSK 1/2 MCS9
	9 [dB]	QPSK 1/2 SS MCS1		**8** [dB]	QPSK 1/2 SS MCS1
STA Antenna Gain	**13** [dBi]	Internal SM antenna	Cable Loss	**1.0** [dB]	0.001 [Watts]
			AP Antenna Gain	**15** [dBi]	90° sector
The link is **uplink** limited by **1 dB**					

When the system experiences interference and a value not equal to 0 is set in the **Interference level** field in the **SYSTEM CONFIGURATION** section, the noise floor of the system increases according to the interference levels, and the DL/UL receive sensitivities for all MCS levels change. With higher interference levels a stronger signal is needed at the receiver to achieve the same MCS level.

The effect of co-channel interference is a reduction of the potential range for each MCS level as shown in the **COVERAGE AND CAPACITY** section. This results in a number of STAs not being able to connect if the maximum range was set as equal to the maximum potential range, or in the average capacity decreasing because fewer STAs can use higher MCS levels.

In the **COVERAGE AND CAPACITY** part of the user interface the results of the link budget calculation are shown.

COVERAGE AND CAPACITY															
Modulation		System Gain		Potential Range				Max DL Throughput		Max UL Throughput		Max Total Throughput		Capacity (Mbps)	
64QAM 5/6	MCS15	**115.0**	dB	**1.42**	mi	**2.28**	km	**39.6**	Mbps	**30.4**	Mbps	**70.0**	Mbps	**DL**	**21.8**
64QAM 3/4	MCS14	**117.0**	dB	**1.79**	mi	**2.88**	km	**36.0**	Mbps	**26.2**	Mbps	**62.2**	Mbps	**UL**	**16.6**
64QAM 2/3	MCS13	**120.0**	dB	**2.52**	mi	**4.06**	km	**32.4**	Mbps	**24.2**	Mbps	**56.6**	Mbps	**Total**	**38.3**
16QAM 3/4	MCS12	**124.0**	dB	**4.00**	mi	**6.44**	km	**23.4**	Mbps	**18.2**	Mbps	**41.6**	Mbps		
16QAM 1/2	MCS11	**128.0**	dB	**6.34**	mi	**10.20**	km	**16.2**	Mbps	**12.2**	Mbps	**28.4**	Mbps	**Scheduling latency (ms)**	
QPSK 3/4	MCS10	**130.0**	dB	**7.98**	mi	**12.85**	km	**12.6**	Mbps	**8.0**	Mbps	**20.6**	Mbps	**DL**	**17.5**
QPSK 1/2	MCS9	**133.0**	dB	**11.27**	mi	**18.14**	km	**7.2**	Mbps	**6.0**	Mbps	**13.2**	Mbps	**UL**	**16.1**
QPSK 1/2 SS	MCS1	**136.0**	dB	**15.93**	mi	**25.63**	km	**3.6**	Mbps	**2.0**	Mbps	**5.6**	Mbps	**Total**	**33.6**

The System Gain is reported for every modulation scheme and it is relative to the more stringent of the two directions.

The range is expressed both in miles and in kilometers and represents for each modulation scheme the maximum distance at which the radio link can operate with the selected configuration and fade margin. Values of range in red indicate that the potential range is larger than the maximum range set in the **Max range** field in the **SYSTEM CONFIGURATION** section.

The DL/UL/Total Max Throughput is the Downlink/Uplink/aggregate capacity of the sector assuming all the registered SMs are operating at that modulation.

The DL/UL/Total Capacity is the Downlink/Uplink/aggregate capacity of the sector, taking into account the percentage of users using each modulation, under tha assumption that the users are evenly distributed in the covered area and and they all generate the same amount of traffic.

The covered area is limited by in the **Max range** field set in the **SYSTEM CONFIGURATION** section.

The DL/UL/Total scheduling latency (in ms) shows the time needed at the AP to schedule all the STAs connected in the sector, and it depends on the number of STAs set in the **SYSTEM CONFIGURATION** section.