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Solution Paper:
Contention Slots in PMP 450

CN PMP 450 CS 03052014

This solution paper describes how Contention Slots are used in a PMP 450 wireless broadband access network system, and provides guidance on how to select the number of Contention Slots with a given sector configuration.

In the PMP 450 user interface, the contention slots parameter is referred to as control slots.

Frame Structure and Contention Slots in the PMP 450

In the PMP 450 system, contention slots are symbols at the end of the uplink subframe that are reserved for random access (network entry and bandwidth requests), and cannot be used for data transmission. These symbols form the contention space.

The PMP 450 frame is 2.5 ms long, and is divided into a downlink subframe comprised of data transmitted from the Access Point (AP) to the Subscriber Module (SM), and an uplink subframe (data transmitted from the SM to the AP).

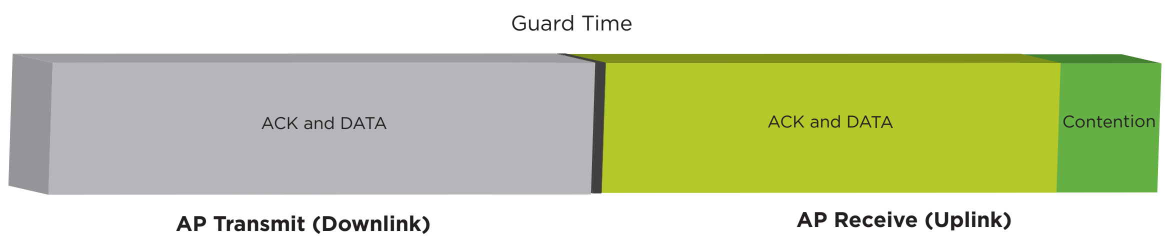

Figure 1 – PMP 450 frame structure

The symbols in the uplink subframe can be either scheduled or unscheduled. All scheduled symbols come before all unscheduled symbols. The number of scheduled and unscheduled symbols changes frame by frame depending on the amount of uplink requests received by the AP.

The contention slots number is selected by the operator and indicates the number of symbols that are reserved in the unscheduled portion of the uplink. The total number of unscheduled symbols in each frame is the sum of the contention slots and any additional symbol that was not used in uplink data transmission. This means that the unscheduled portion of the uplink can be as small as the number of contention slots, or as big as the entire uplink portion. This allows SMs in sectors with a small number of contention slots configured to still successfully transmit bandwidth requests using unassigned data slots.

Random Access

When an SM needs to send an unscheduled message (for network entry or a bandwidth request), it randomly selects one symbol out of the unscheduled portion of the uplink subframe, and uses that symbol for transmission. The higher the number of unscheduled symbols, the lower the probability two or more SMs will select the same symbol for transmission which would cause their messages to collide. When two messages collide at the AP receiver, most likely neither will be decoded correctly, and both SMs will need to restart the random access process. If this collision happens frequently, the overall latency of the system increases.

A higher number of contention slots give higher probability that an SM's bandwidth request will be correctly received when the system is heavily loaded, but the tradeoff is that sector capacity is reduced, so there will be less capacity to handle the request. The sector capacity reduction is about 200 kbps for each contention slot configured in a 20 MHz channel at QPSK SISO modulation. The reduction in sector capacity is proportionally higher at MIMO modulations, as shown in Table 1.

Modulation mode	Throughput penalty for each additional contention slot
QPSK SISO (1X)	200 kbps
QPSK MIMO (2X)	400 kbps
16QAM MIMO (4X)	800 kbps
64QAM MIMO (6X)	1.2 Mbps
256QAM MIMO (8X)	1.6 Mbps

Table 1 - Throughput Penalty Per Modulation

Table 1 shows that the throughput penalty for each additional contention slot increases with modulation mode. The reason for this is that at higher modulation modes more fragments can be transmitted in a symbol. If additional symbols are reserved for random access, the number of fragments that cannot be sent in these symbols is higher at higher modulations, and therefore the throughput penalty is higher. However, the penalty expressed as a percentage of the throughput is the same for each modulation mode. For example, if a frame has 80 total symbols, each additional symbol reserved for random access reduces the sector throughput by 1.25%, regardless of the modulation mode.

Selection of Contention Slots Parameter

The number of contention slots has to be selected according to the specific deployment parameters in each sector. If the number of contention slots is too small, then latency increases in high traffic periods. If the number of contention slots is too high, then the maximum capacity is unnecessarily reduced.

The two main contributing factors to the selection of the number of contention slots are the number of Virtual Circuits (VC) in a sector, and the type of traffic in the sector.

Number of VCs in a sector

If the number of VCs in a sector is large, it is recommended to increase the number of contention slots, in order to reduce the probability of two or more requests colliding. The suggested contention slot settings as a function of the number of active VCs in the sector are shown in Table 2.

Number of VCs	Suggested number of Contention slots
1 to 10	3
11 to 50	4
51 to 150	6
>150	8

Table 2 - PMP 450 AP Contention Slot Settings

Note that each SM uses one or two VCs. All SMs have a Low Priority Channel that uses one VC; if the High Priority Channel is also enabled for the SM, then the SM uses a second VC. Therefore the number of active VCs in a sector is greater than or equal to the number of SMs registered to the AP in the sector. For example, a network of 40 SMs includes 20 SMs with High Priority Channel disabled and another 20 SMs with High Priority Channel enabled has 60 active VCs and may be configured with 6 contention slots.

Type of traffic in a sector

Besides the number of VCs, the other main factor in contention slots selection is the type of traffic. If the sector experiences a lot of uplink traffic composed of small packets, for example in a sector that serves several VoIP streams, the average number of bandwidth requests transmitted by each individual SM is high. Another scenario with constant uplink traffic is video surveillance, which also generate a large number of uplink bandwidth requests.

In these cases the probability of two or more SMs transmitting a request in the same symbol is high. When this happens, the latency of the system increases, and it is recommended to increase the number of contention slots from the number in Table 2. If an AP is experiencing latency issues or a SM is experiencing servicing issues, increasing the number of contention slots may increase system performance, depending on traffic mix over time.

Recommendation on Contention Slots number selection

1- Calculate the number of active VCs in the sector (one VC per SM for SMs with Low Priority VC enabled only; two VCs per SM for SMs with High Priority VC enabled)

2- Evaluate the traffic mix that is expected in the sector, more specifically the expected percentage of real-time traffic (ex. VoIP, gaming, video conferencing, and video surveillance).

3- If the expected amount of real-time traffic is small, select the number of contention slots according to Table 2.

4- If the expected amount of real-time traffic is large, select a number of contention slots larger than the number in Table 2.

5- Monitor latency in your system. If the percentage of real-time traffic increases and the sector experiences increasing latency and SM-servicing issues, increase the number of contention slots from the current setting.

This is the reason why the maximum number of contention slots is 15, even if Table 2 shows 8 contention slots for more than 150 VCs. If the number of VCs is more than 150 and a significant portion of the traffic is real-time, the frequency with which bandwidth request messages are transmitted requires a higher number of contention slots, potentially as high as 15. A sector with a high number of video surveillance cameras would also require a larger number of contention slots to reduce the probability of collision between requests.

Cluster of APs

It is recommended to use care when changing the contention slots configuration of only some APs in a cluster, because changes affect the effective downlink/uplink ratio and can cause co-location issues.

In a typical cluster, each AP should be configured with the same number of contention slots to assure proper timing in the send and receive cycles. The number of contention slots is used by the frame calculator to define the downlink and uplink times, which should not overlap from one AP to another. However, if the traffic experienced by two APs in the same cluster is different (for example, one supports significantly more VoIP traffic), the number of contention slots selected for each AP may not be the same. For APs in a cluster of mismatched contention slots setting, it is recommended to use the frame calculator to verify that send and receive times do not overlap (see the “Frame calculator for co-location” section).

Note: Change contention slot configuration in an operating, stable system cautiously and with a back-out plan. After changing a contention slot configuration, monitor the system closely for problems as well as improvements in system performance.

Frame calculator for co-location

The frame calculator is a tool that calculates the length of the transmit and receive times, together with the number of downlink and uplink symbols, for a given set of configuration parameters. The frame calculator can be used to verify that co-location of APs using different contention slots settings does not create overlapping transmit and receive times.

Basic rules

For co-location of AP1 and AP2, we want to ensure that AP1 stops transmitting before AP2 starts receiving, and that AP2 stops transmitting before AP1 starts receiving.

These are the rules that have to be satisfied for a correct co-location of the two APs:

AP1 Receive Start > AP2 Transmit End

AP2 Receive Start > AP1 Transmit End

Steps for co-location

Let us assume that in a cluster of multiple APs with all the same settings, one AP's settings are modified with a different number of contention slots.

1. Obtain all configuration settings for the APs that do not change parameters (duty cycle, contention slots, max distance)
2. Input these configuration parameters into the OFDM Frame Calculator tool found in the system user interface under "Tools".
3. Click "Calculate"
4. Note the following values from the results:

   Downlink Transmit End = ______________________

   Uplink Data Rcv Start = ______________________

   These values will be named AP1 Transmit End and AP1 Receive Start respectively.
5. Access the AP that needs to have a different contention slots setting and use the frame calculator tool found under "Tools"
6. Input the configuration parameters for this AP (same duty cycle and max distance as the other APs, different contention slots)
7. Click "Calculate"

8. Note the following values from the results:

   Downlink Transmit End = ______________________

   Uplink Data Rcv Start = ______________________

   These values will be named AP2 Transmit End and AP2 Receive Start respectively.

9. Check that the two following equations are both true:

   AP1 Receive Start > AP2 Transmit End

   AP2 Receive Start > AP1 Transmit End

10. If one or both equations are not true, adjust the duty cycle until they become true (or the max distance if possible).

Example

Let us assume that all APs in a cluster have the following configuration parameters:

- Duty cycle: 75%
- Max range: 2 miles
- Contention slots: 3

Running the frame calculator as explained in the "Steps for co-location" section, the AP1 Transmit End and Receive start times are:

AP1 Transmit End = 17022

AP1 Receive Start = 17386

The settings in one of the APs in the cluster are now modified by changing the number of contention slots from 3 to 6, for example because this sector is constantly experiencing a higher volume of VoIP traffic.

Running the frame calculator again, the AP2 Transmit End and Receive start times are:

AP2 Transmit End = 16536

AP2 Receive Start = 16900

The two equations above have to be checked for correct co-location:

AP1 Receive Start > AP2 Transmit End → 17386 >16536 OK

AP2 Receive Start > AP1 Transmit End → 16900 >17022 NOT OK

The second of the two equations is not true. AP1 is still transmitting when AP2 has already started receiving. This creates interference at the AP2 receiver.

In order to avoid this interference scenario, the duty cycle of AP2 can be changed. For example, changing the duty cycle of AP2 from 75% to 77% changes the AP2 Transmit End and Receive start times as follows:

AP2 Transmit End = 16779

AP2 Receive Start = 17143

The two equations have to be checked again for co-location:

AP1 Receive Start > AP2 Transmit End → 17386 >16779 OK

AP2 Receive Start > AP1 Transmit End → 17143 >17022 OK

Now both equations are true and the APs can be co-located.

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