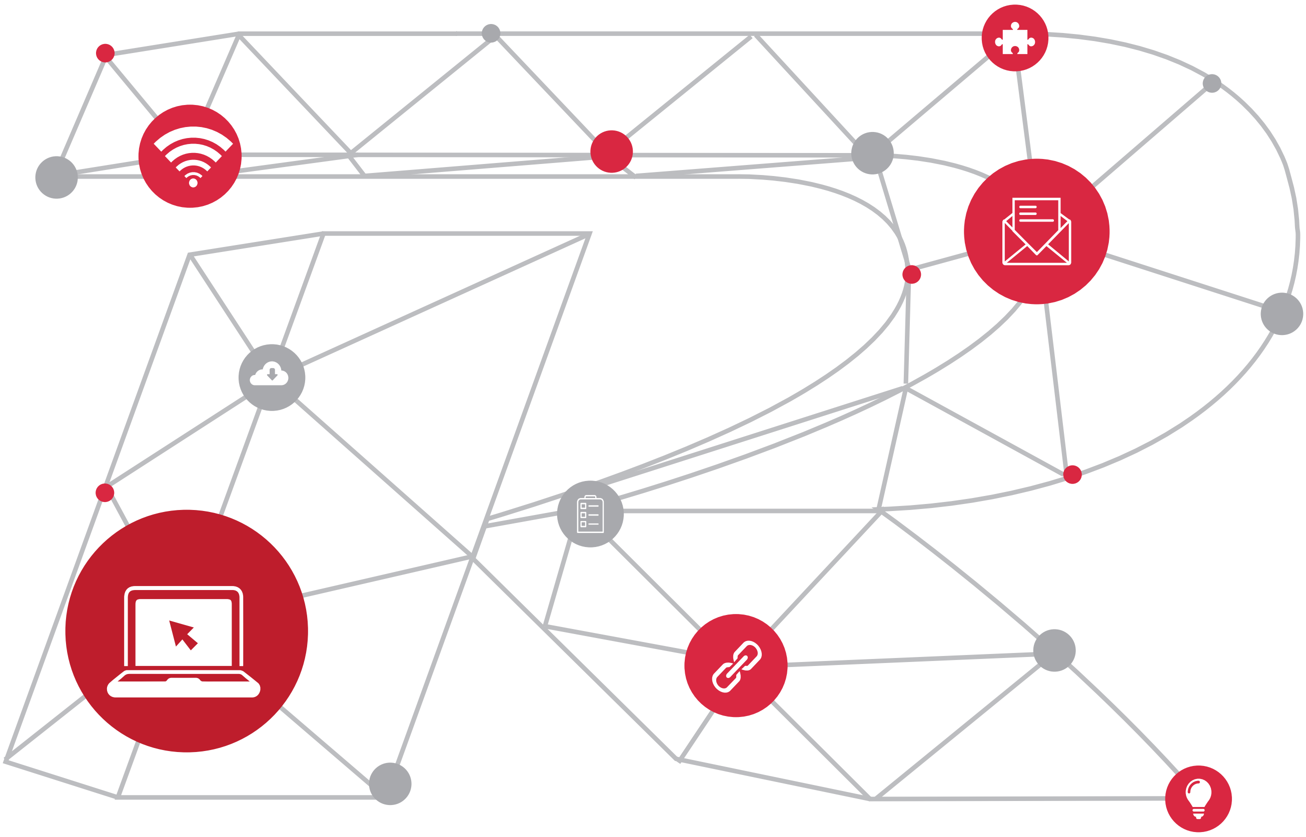
Ruijie High-density Networking

White Paper



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Introduction

The following requirements must be met to ensure good experience for a station (STA) in a high-density network:

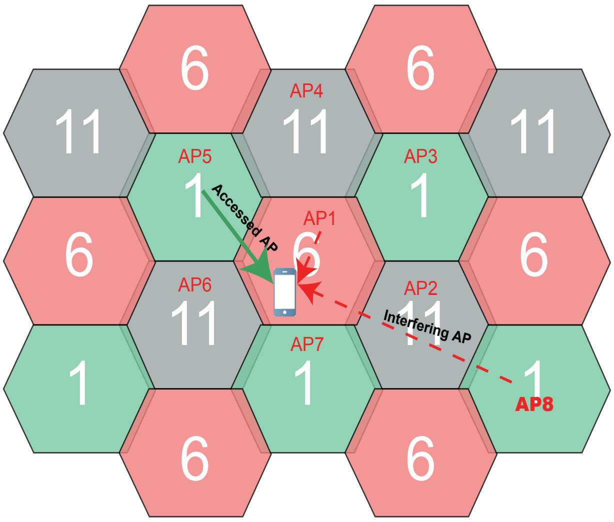
- The STA accesses the closest access point (AP) with support for load balancing.
- The network protects against interferences to enable highly concurrent information transmission.
- APs balance the load of concurrent access by multiple STAs.

Experience will be affected if any of the three requirements cannot be met. The following describes Ruijie techniques designed to address these requirements.

• Remote Access in High-density Network

In a high-density network with closely spaced APs, an STA may not try the nearest AP for access due to reasons such as environmental fluctuations and vendor differentiation. In the following figure, the STA associates with AP 5 instead of AP 1.

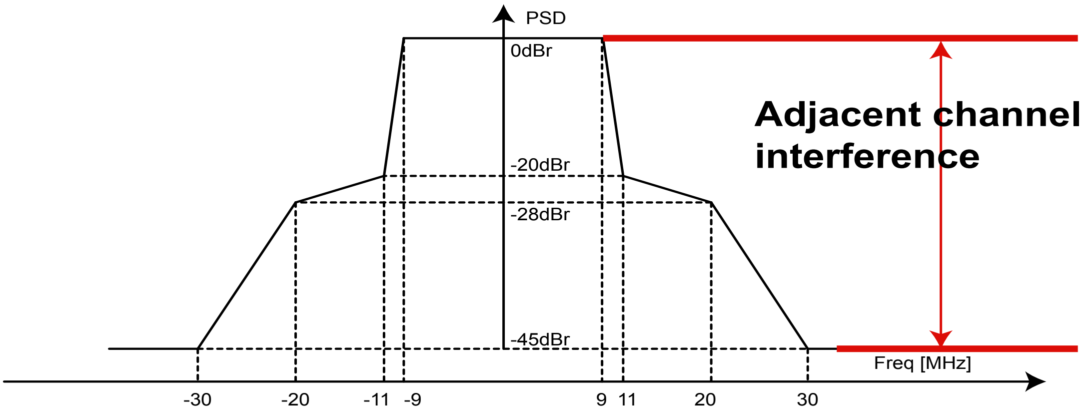
Figure 1



Failure to associate with the nearest AP may also result from the high received signal strength indication (RSSI) value in the upstream direction. This misleads many network optimization engineers to consider that the STA still has good experience. In the actual condition, however, the STA encounters adjacent channel interference and co-channel interference.

Adjacent channel interference: The following figure shows a 20 MHz spectrum graph. The x-coordinate indicates the deviation from the center frequency, and the y-coordinate indicates the difference from the maximum power. 0 dBr indicates that the power at the frequency is the same as the maximum transmit power of the device. The mean power reduces by –35 dBr to –40 dBr when the deviation from the center frequency is 15–35 MHz. For example, the transmit power of Channel 6 (2.4 GHz) is 23 dBm and the center frequency is 2437 MHz. Channel 11 deviates from the center frequency by 15–35 MHz on the right, indicating that this channel also sends –17 dBm interfering signal. Channel 1 deviates from the center frequency by 15–35 MHz on the left, indicating that this channel also sends –17 dBm interfering signal. If an STA accesses Channel 6 of AP 1 (nearest AP), because the power received from Channel 6 of AP 1 is higher than that from Channel 1 of AP 5, the former power is 35–40 dB higher than the interfering signal of Channel 6 that leaks from Channel 1 of AP 5. This does not cause communication problem. If the STA accesses Channel 1 of AP 5, because the power received from Channel 6 of AP 1 is higher than that from Channel 1 of AP 5, the latter power is only slightly different from the interfering signal of Channel 1 that leaks from Channel 6 of AP 1. This affects the transmission of signals with a high modulation and coding scheme (MCS) index. The 802.11 defines adjacent channel suppression as follows: common STA chip < 10 dB with MCS = 7, indicating that signals with MCS = 7 cannot be transmitted when RSSI is great and the power received from the adjacent channel is more than 10 dB higher than the power of the local channel. This results in adjacent channel interference otherwise not existing in remote association, and experience is affected.

Figure 2



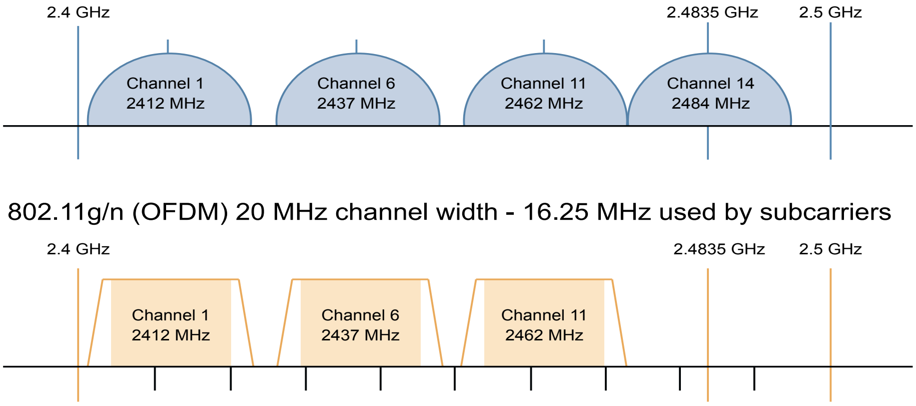
Co-channel interference: This type of interference is more serious for STAs accessing remote APs than adjacent channel interference. Assume that only co-channel interference is considered here without consideration of adjacent channel interference. The valid signal to interference plus noise ratio (SINR) of the accessing STA is equal to the power received from the associated AP minus the power received from the APs in the same channel that form a hidden node with the associated AP. The transmission rate is directly proportional to SINR. When the STA associates with a remote AP, the power received from the associated AP reduces whereas the power received from other interfering APs increases. As the difference between the two powers significantly narrows, the transmission rate reduces sharply and packets are lost.

CorrectLink is developed to address the remote association issue during access.

• Interference in High-density Network

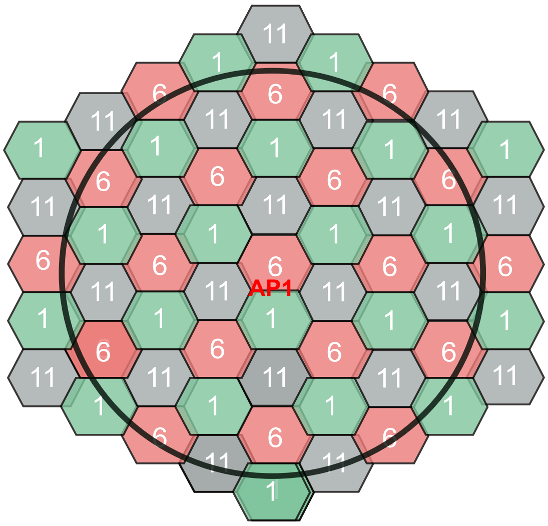
Wireless local area networks (WLANs) operate in the Industrial, Scientific, and Medical (ISM) band, which includes the 2.4 GHz and 5 GHz frequency bands. Devices that operate at the same frequency will interfere with each other. Generally, three non-overlapping channels (Channel 1, Channel 6, and Channel 11) exist in the 2.4 GHz frequency band.

Figure 3



In a large and high-density network, many overlapping APs that operate in the same channel will result in mutual interference.

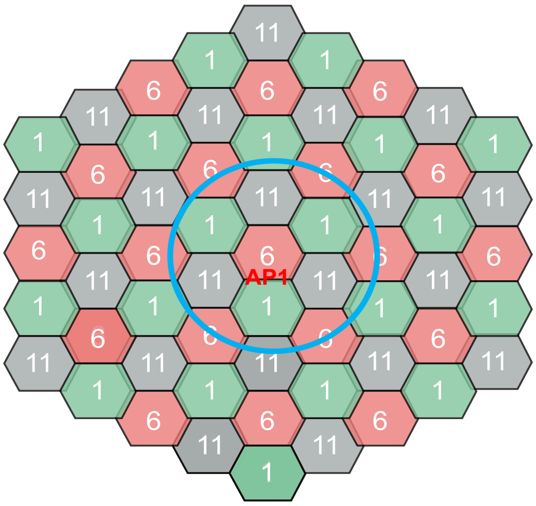
Figure 4



In the preceding figure, non-overlapping channels are deployed in dense mode. The distance between APs is 10 m. Signals emitted by APs cannot attenuate to 0 within a distance of 30 m. AP 1 is co-located with other 18 APs in the same channel within the coverage area of AP 1. According to the carrier-sense multiple access with collision avoidance (CSMA/CA) mechanism, the 18 APs share air interface resources with AP 1. When all these APs are in the running state, AP 1 occupies only one-nineteenth of air interface resources, resulting in significant reduction of network performance.

This issue can be addressed by reducing the AP coverage area. In the following figure, after the coverage area of AP 1 is reduced, AP 1 shares air interface resources with only seven other APs in the same channel, improving the average AP performance by 170%.

Figure 5



Pre-ax adopts dynamic clear channel assessment (DCCA) and dynamic transmit power control (DTPC) to improve channel multiplexing and network performance.

• Load Balancing in High-density Network

Each AP generally associates with N STAs. Experience will be affected if packets sent by some STAs are not scheduled.

For example, 40 to 60 STAs are tested simultaneously for e-Schoolbag. Load balancing is particularly important when courseware, files, and pictures are downloaded in unicast mode. The time that each STA spends in receiving files must be almost the same to ensure good experience. If it takes a long time for some STAs to receive files, the experience of e-Schoolbag and the class progress will be affected. The impact is more pronounced when e-Schoolbag is demonstrated to leaders from the bureau of education.

For example, if the productivity of some employees in an office network is affected by bad experience, they will request network optimization or appeal to the quality control department. A load balancing algorithm is required to reduce the impact of service imbalance on business reputation.

Related Techniques

• CorrectLink

Before accessing a network, an STA broadcasts a Probe Request packet to each channel, and all APs can receive this packet. Received packets can be summarized on the access controller (AC) to create a global view for each STA and thus select the set of APs most suitable for this STA. The following table shows the view that can be created for each STA.

	Signal Strength	STA Quantity
AP 1	RSSI 1	N 1
AP 2	RSSI 2	N 2

The set of APs most suitable for this STA is selected based on the RSSI view. Considering RSSI measurement accuracy and tolerable environmental interference (for example, 10 dB adjacent channel interference), the first set of APs includes not only the AP with the greatest RSSI value but also other APs compliant with specific requirements. This set of APs ensures the air interface experience of the STA after access. All STAs compete for channel resources in time division multiplexing (TDM) mode (adopted by 802.11) because different APs connect to different numbers of STAs. As an AP connects to more STAs, the bandwidth allocated to each STA reduces. Therefore, the load status of APs from the first set is checked based on STA access requests to obtain the final set of APs used for STA access in accordance with the load balancing principle.

• Pre-ax

DCCA

CSMA/CA has two CCA thresholds used to determine whether a channel is busy:

1. CCA-signal detection (SD): Considering Wi-Fi interference, many synchronized preamble signals are Wi-Fi signals in the same channel. This leads CCA-SD to be equal to receiver sensitivity in many cases, because co-channel packets that exceed receiver sensitivity are easily demodulated by APs.
2. CCA-energy detection (ED): Many preamble signals that cannot be synchronized are Wi-Fi signals in different channels. STAs will encounter a reception error when inter-channel Wi-Fi signals are sufficiently strong. This phenomenon is called adjacent channel suppression. In this case, CCA-ED is used to determine whether a channel is idle.

In Figure 6, CCA-ED is 20 dB higher than CCA-SD.

A high CCA-ED value greatly reduces the probability of AP backoff when APs in different channels consider the channels of other APs to be busy. The CCA-SD is relatively low and reaches –90 dBm when MCS is 0. The physical-layer packet header of 802.11n is modulated with MCS = 0 because the packet header carries the profile of subsequent information, such as modulation mode and length. After an AP sends a packet, other APs easily demodulate the packet header and trigger backoff.

In Figure 7, AP 1 has a low receiver sensitivity, which reaches –90 dBm when MCS is 0. When AP 1 transmits data to STA 1, AP 2 easily detects the data and then drops the data communication with STA 2. This affects the downstream throughput of AP 2. In the actual condition, AP 2 is closer to STA 2, and the SINR of STA 2 is great enough for data transmission. In this case, transmission efficiency is wasted.

Figure 6

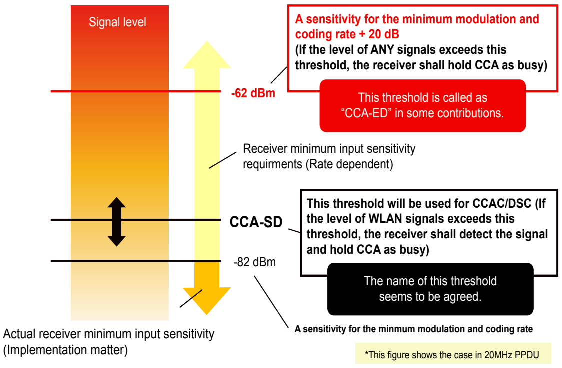
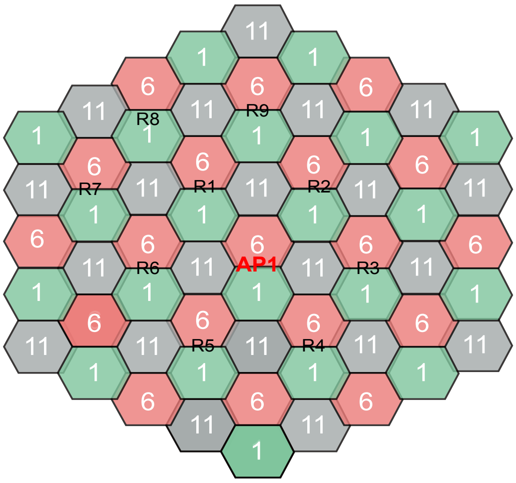


Figure 7

To address this issue, CCA-SD is dynamically adjusted to reduce the number of mutually interfering APs for performance improvement.

Figure 8



The DCCA algorithm periodically detects the RSSI values of beacon frames transmitted by intra-frequency neighboring APs and calculates the optimal CCA-SD by using the TopK algorithm. In the preceding figure, the coverage area of AP 1 is reduced to seven intra-frequency APs to improve the AP performance and network concurrency.

DTPC

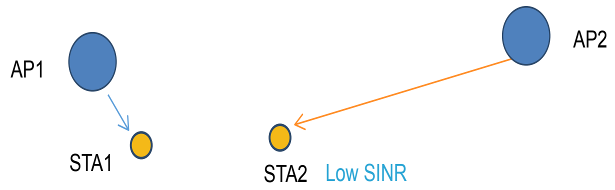
The following table lists the signal-to-noise ratio (SNR) required for each modulation mode. Demodulation is implemented when the required SNR is reached. When the maximum MCS value is reached, throughput can no longer be improved as SNR increases with power, but more serious interference results.

MCS		1	2	3	4	5	6	7	8	9
SNR (dB)	.2	7.0	9.6	11.8	15.5	18.8	20.4	21.9	25.0	27

STAs within the coverage area of an AP are at different locations. When a unified value of transmit power is applied, increased interference will result from higher power, or reduced throughput of edge STAs will result from lower power. Different powers can be applied to different STAs at different locations in the network for throughput balancing. This is the power control solution used to balance the SINR values of STAs.

In the following figure, STA 1 is closer to AP 1, so the RSSI value is greater; STA 2 is far from AP 2, so the RSSI value is relatively small.

Figure 9



When AP 1 and AP 2 are configured with the same power, the SINR of STA 2 is low, resulting in low throughput.

Assume that the power of AP 1 is P1 and that of AP 2 is P2; Γ_1 and Γ_2 are the SINR values required by demodulation on STA 1 and STA 2. If SINR must be greater than 22 dB when MCS is equal to 7, then the following calculation method is acquired, where g_{ii} is the spatial attenuation of AP 2 relative to STA i.

$$\begin{bmatrix} P_1 \\ P_2 \end{bmatrix} > \begin{bmatrix} \Gamma_1 & 0 \\ 0 & \Gamma_2 \end{bmatrix} \begin{bmatrix} 0 & g_{12}/g_{11} \\ g_{21}/g_{22} & 0 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} + \begin{bmatrix} \sigma^2\Gamma_1/g_{11} \\ \sigma^2\Gamma_2/g_{22} \end{bmatrix}$$

$$\Rightarrow P > \Gamma GP + N$$

The value of $\rho(\Gamma G)$ must be smaller than 1 to obtain the power solution required to make this inequation valid. The smaller the value of g_{ij}/g_{ii}, the easier to meet this inequation.

The following conclusions are derived from the preceding deduction:

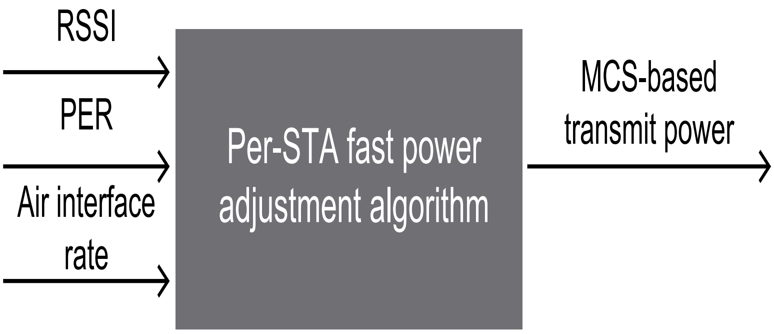
1. When the value of $\rho(\Gamma G)$ is smaller than 1, the valid power solution is obtained so that the packets of each STA are successfully demodulated.

2. When the value of $\rho(\Gamma G)$ is greater than 1, no valid solution exists. In this case, the value of P is sufficiently great to result in CSMA/CA-based backoff of AP 1 and AP 2. STA 1 and STA 2 use air interface resources in time division mode. This avoids the issue of low throughput on edge STAs. The following power control method is derived from the preceding deduction:

$$P_i^{t+1} = \frac{\Gamma_{ii}\left(\sum_{j \neq i} P_j^t g_{ij}\right)}{g_{ii}}$$

This is a power control algorithm for classic cellular mobile communication. Because $\left(\sum_{j\neq i} P_j^t g_{ij}\right)$ is complex to obtain in WLANs, the power update method described in the following can be based on packet error rate (PER) statistics, which achieves the same effect. The DTPC algorithm collects the RSSI and PER information of STAs and applies different powers to different STAs. A balance is stricken between throughput and power to improve network throughput and STA experience.

Figure 10



• AirReorder

AirRecorder allocates an air interface time slice to each user based on their requirements to ensure air interface bandwidth.

In normal networking, STAs differ greatly from each other in the following aspects:

1. Different types of STAs co-exist. For example, some STAs are compatible with 802.11n whereas some others with 802.11ac.

2. Some STAs support single stream transmission whereas others support double stream transmission.

3. STAs have varying capabilities of air interface competition, such as varying degrees of Wi-Fi Multimedia (WMM) support. Due to these differences, the air interface time and rate allocated to each STA is different.

General scheduling without consideration for STA differences may result in the following issues:

1. Low-speed STAs occupy a large amount of air interface time. As a result, packets of other high-speed STAs are dropped due to congestion.

2. STAs with a strong capability of air interface competition always occupy air interface resources. As a result, packets of other STAs are dropped due to congestion.

AirRecorder introduces the following mechanisms to address the preceding issues:

1. Time slice allocation: AirRecorder allocates a time slice to each STA. The time slice indicates the time during which the STA can send packets over the air interface. This prevents low-speed STAs and STAs with a strong capability of air interface competition from occupying the air interface for a long time while enabling other STAs to send packets normally without congestion.

2. Underlying air interface time calculation: Accurate air interface time calculation is key to implementing time slice allocation as a scheduling policy. Each time a packet is sent at the bottom layer, AirRecorder calculates the time taken for the packet to be successfully sent over the air interface and subtracts the calculated time from the allocated time slice. This enables time slice calculation to be tightly coupled with the air interface and ensures time slice accuracy.

3. Time slice borrowing: The service requirements of users change constantly. For example, a user may be transmitting web page data now but will switch to video transfer later. Therefore, fixed time slice allocation may result in waste of air interface resources in the actual condition. AirRecorder calculates the usage of allocated time slices during each scheduling cycle. When the time slice usage on an STA is low, a portion of this slice is borrowed by another STA with high usage. Borrowing does not change the original STA's ownership of the borrowed time slice. When this STA needs bandwidth, the borrowed time slice is recycled.

Technical Features

• CorrectLink

The process of STA access is classified into three phases:

1. The STA sends a Probe Request packet, and the AP that receives this packet returns a Probe Response packet.
2. The STA sends an Auth Request packet, and the AP returns an Auth Response packet.
3. The STA sends an Association Request packet, and the AP returns an Association Response packet.

Then the STA can access the network normally. If any of the preceding phases fails, in many cases STAs will continue to send a Probe Request packet.

The latest CorrectLink solution integrates three functions: 5G preference, remote access suppression, and load balancing.

A layered model is designed based on the actual test data from the access process to achieve the following purposes:

1. Improve the compatibility with existing STAs and extend the applicable scope of algorithms. The first layer is remote access suppression during the second phase when the Auth Request packet is sent. The second layer is 5G preference and load balancing during the third phase when the Association Request packet is sent. These two layers improve the guiding probability.

2. Effectively balance between the access time and guiding probability. Because STAs will continue to send a Probe Request packet when any of the three phases of access fails, the access time length may increase if remote suppression is implemented during the third phase. To address this issue, a layered model is designed to perform remote suppression during different phases based on requirements and allocate different times of suppression to different phases in order to effectively balance the access time and guiding probability.

• Pre-ax

DCCA

The technical principle of the adaptive noise immunity (ANI) function of the QCA SDK used by some vendors is the same as that adopted by Ruijie, with the only difference that the ANI function periodically detects the PHY error rate and sets the CCA-SA threshold for dynamic and real-time adjustment based on the traffic condition of the live network. However, the adjustment takes some time and is only based on the traffic condition during one period. Fluctuations may occur in adjustment if the traffic between two periods varies greatly. Therefore, threshold design adopts the "slow increase but fast decrease" principle to prolong the time required to adjust to the stable level.

The implementation principle adopted by Ruijie is to periodically detect the RSSI values of beacon frames transmitted by intra-frequency neighboring APs to set the intra-frequency coverage range. Because the RSSI values of beacon frames are determined by physically relative locations and are quite stable, fluctuations do not occur in adjustment.

DTPC

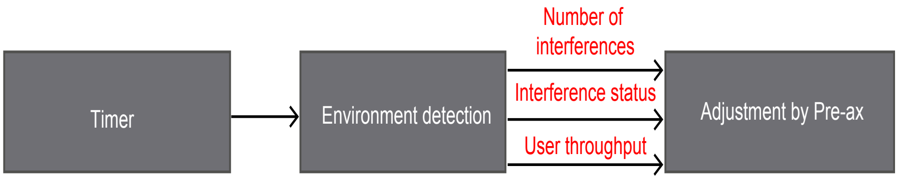
Some vendors use the transmit power control (TPC) function of the QCA SDK to control the packet transmit power in register based (rate-to-power mapping in PHY registers) and per-packet TPC (descriptor based) modes. Packets are transmitted at the predefined power despite varying transmission rates and levels. This is only a basic function.

Ruijie controls the transmit power on a per-packet basis in accordance with statistics on RSSI and PER to control existing air interface traffic and balance between STA performance and network interference, thus improving network performance.

Environment-based Automatic Adjustment

Currently, many network optimization algorithms require manual parameter setting. Pre-ax automates environmentally adaptable algorithms by means of environment detection. In the following figure, Pre-ax periodically detects the environment to obtain the interference status and network load status resulting from user throughput and sets parameters accordingly, delivering a robust capability of environmental adaptation.

Figure 11



• AirReorder

Each vendor develops a concept and principle of air interface time slice allocation.

Ruijie AirRecorder differs from general time slice allocation techniques in the following aspects:

1. Underlying air interface time calculation: Accurate air interface time calculation is key to implementing time slice allocation as a scheduling policy. Each time a packet is sent at the bottom layer, AirRecorder calculates the time taken for the packet to be successfully sent over the air interface and subtracts the calculated time from the allocated time slice. This enables time slice calculation to be tightly coupled with the air interface and ensures time slice accuracy.

2. Time slice borrowing: The service requirements of users change constantly. For example, a user may be transmitting web page data now but will switch to video transfer later. Therefore, fixed time slice allocation may result in waste of air interface resources in the actual condition. AirRecorder calculates the usage of allocated time slices during each scheduling cycle. When the time slice usage on an STA is low, a portion of this slice is borrowed by another STA with high usage. Borrowing does not change the original STA's ownership of the borrowed time slice. When this STA needs bandwidth, the borrowed time slice is recycled.

Typical Application

Typical application scenarios include high-density networks with closely spaced APs, for example, office networks, college dormitories, large conference rooms, and railway stations.

Limitations

The DTPC technique of Pre-ax is based on the statistics that LMAC collects on the downstream data (RSSI and PER) of STAs. The platform where LMAC runs must meet memory requirements. The available memory of some chips such as Offload Structure is not sufficient to support LMAC operation. In this case, Pre-ax is not supported.

Summary

The high-density networking technique provides solutions to STA access, interference prevention, and multi-STA load balancing. These three aspects affect each other. For example, an access error may result in failed interference prevention, or lack of effective interference prevention measures will cause multi-STA load balancing to fail.

These three aspects are considered during design to improve the concurrent throughput of high-density networks, reduce the delay on STAs, and improve STA experience.

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For further information,please visit our website **http://www.ruijienetworks.com**