Stadium Wi-Fi

Designing and deploying Wi-Fi in high capacity, high interference venues

BelAir Networks Wi-Fi is deployed in some of the busiest places in the world, including Times Square in New York City. At huge festivals like Lollapalooza and South by Southwest, BelAir Networks Wi-Fi addresses the demands of tens of thousands of smartphone- toting, social networking attendees per day. It also powers North America's largest Wi-Fi networks, serving customers in New York, New Jersey, Connecticut and Pennsylvania.

So, it's not a surprise that world-leading venues including Lincoln Center, Sun Life Stadium and Lincoln Financial Field also feature BelAir Networks world-leading Wi-Fi.

But, Wi-Fi networks for sports bowls and auditoriums are not simply a larger version of a busy Wi-Fi enabled office, nor are they the same as public Wi-Fi in busy downtown cores. Even solutions that can be applied to music festivals and other large events are not entirely applicable to stadium and auditorium deployments. To achieve the multiplication of basic Wi-Fi capacity necessary to support large venues it is necessary to implement intelligent software features and to examine the physical layer as well as the underpinnings of 802.11 standards. The physical layer has to enable the capability of multiple simultaneous transmissions and creatively optimize the performance of the CSMA protocol that governs 802.11 operation, while maintaining full compatibility with client devices.

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The BelAirOS operating system includes a feature set known as VHCI – Very High Capacity and Interference mode. VHCI encompasses software features – such as modulation control, adaptive cell size control and AP load balancing – as well as network planning guidelines, and monitoring and management features that deliver high throughput while minimizing interference and its effects.

BelAir management and aggregation solutions, such as BelView NMS and the BelAir4000 Hot Zone Controller, further enhance BelAirOS performance and integration in stadium environments. BelView NMS enables real-time remote insights and provisioning controls, while the HZ4000 locally offloads policy and accounting features. These capabilities, designed in close coordination with our service provider customer base, enable carrier-grade insights into these challenging and high visibility deployments.

This document will review the standards-driven and environmental issues impacting Wi-Fi and outline techniques and features used by BelAir Networks to maximize performance of Wi-Fi in large venues, specifically stadiums and auditoriums.

Understanding Wi-Fi Capacity

While 5 GHz Wi-Fi popularity (802.11an) is rising, the dominant band supported on handhelds is still 2.4 GHz (802.11bgn). That band, for most of the world, provides 11 channels of 5 MHz width. Since WiFi channels are typically 20 MHz, this only leaves 3 non-overlapping channels 1, 6, and 11. In a clean RF environment it obviously makes sense to avoid overlap, but this should not be a blind mantra. While the 3 non-overlapping channels are a good planning and design guideline, environments may dictate use of a less conventional channel plan to achieve optimal throughput.

Indoor vs. Outdoor and Large Environments

In indoor environments, an 802.11n access point (AP) using 20 MHz channels communicating with 802.11n compliant client devices and assuming channel conditions that support MIMO, the maximum useful capacity is in the range of 100 Mbps for Transmission Control Protocol (TCP) traffic. So, with 3 non-overlapping channels in a simple environment, up to 300 Mbps can be reasonably expected.

In outdoor and large environments, an 802.11n AP using 20 MHz channels communicating with 802.11n compliant client devices, the nominal useful capacity is in the range of 50 Mbps for TCP traffic. The reduction relative to the small indoor space is driven by the fact that channel conditions required to support multiple streams of traffic do not generally exist in an outdoor setting. So, with 3 non-overlapping channels in a simple environment, up to 150 Mbps may be reasonably expected.

While the 3 non-overlapping channels are a good planning and design guideline, environments may dictate use of a less conventional channel plan to achieve optimal throughput.

Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)

CSMA-CA is the access protocol used by 802.11 to allow multiple client devices to connect to an 802.11 AP. This is best described as a “listen before talk” arrangement. Before transmitting, any device (whether AP or client) wishing to access the channel has to determine that the channel is clear before sending its packet over the air interface. In an basic defined case, two devices on the same channel will each get 1⁄2 of the channel capacity. Three devices would get 1/3 each and so on. So a channel that has ten APs and 90 clients that all want to transmit at the same time would provide 1/100 of the available channel capacity to each device.

It is important to note that CSMA-CA does not preclude two devices transmitting at the same time. In simple cases, the resulting signal to interference ratio causes the desired packets to be irresolvable and a collision results. The receiving device will not send an acknowledgement of the packet so the sending device will have to re-transmit the same data again. If this happens several times in a row (due to collisions or other noise effects) the modulation rate will be adapted down and the process will start again.

The Impact of Beacons and Probe Responses

When designing large Wi-Fi networks, it is important to understand the impact of beacons and probe responses that are sent out by APs. Beacons are a necessary part of 802.11 operation as they announce the presence of an AP to client devices. Clients use these beacons to determine when they should roam to a higher power device, and the beacons advertise the compatibilities of an AP to support the service options/modulation rates of Wi-Fi.

An alternate and more common approach to network discovery is active scanning. Active scanning is triggered when a client generates a broadcast/wildcard probe request. Conventional behavior in Wi-Fi necessitates immediate probe response from all listening APs. Because the probe response is typically considered a station management feature, this mechanism inadvertently benefits from the higher internal system priority given to such traffic. The combination of this makes active scanning especially useful and popular in low power and handheld devices. By scanning for a short, triggered interval the device is able to detect networks and return to sleep faster than passive approaches allow.

The downside of beacons and probe responses is that they are normally sent at low data rates to ensure that all users in the coverage area have a high probability of reception. An AP set up in a nominal operational mode for 802.11bgn support in 2.4 GHz will have a beacon that consumes 2% of the available air time. And depending on topology and visible APs, active scanning can occupy an even greater share of the air through probe response flooding.

If the beacon and probe response setup is not modified, it is clear that a modest number of AP devices can consume a substantial portion of the available airtime. The manner in which beacons and probe responses can be modified is limited, as client operation depends on the successful reception of transmitted beacons and probe responses.

A common solution is to force the beacons and probe responses to be sent on a higher modulation rate. This approach is suitable as long as the most remote user in an AP coverage area can successfully receive the beacon at the higher modulation rate.

Cellular Offload

While close 3G/4G and Wi-Fi integration is out of scope for this document, no discussion of Wi-Fi in stadiums is complete without acknowledging the important and sometimes delicate interplay of Wi-Fi and cellular/mobile data.

A key driver of Wi-Fi deployments in stadiums continues to be exceedingly exhausted 3G/4G data networks, many of which are engineered directly into major venues. For this reason a Wi-Fi network must be especially licensed band resistant, and mobile data quality aware. Full carrier-grade user experience is only possible through coordination and continual quality tracking of each access network technology.

BelAir implements a variety of tools and features that enable intelligent load balancing and accurate throughput testing. These features are being integrated into policy solutions for mobile operators seeking to implement client-less ANDSF architectures and other tight coordination offload designs.

User Managed Data Offload

User managed data offload is a user configured method for Wi-Fi enabled devices like smartphones and tablets to gain access to Wi-Fi networks as an alternative connection to 3G data connection for internet access. Figure 1 depicts an overview of the user managed data offload approach. This effectively provides data offload from 3G networks, however, it bypasses service provider involvement in the service for any value added capabilities. This offload method is being utilized today and will continue as an offload solution in some circumstances even when service provider offload solutions are offered. This offload method requires the user to configure the SSIDs to be recognized and configure any authentication information required to access the SSID. The benefits of this approach for the user are: higher performance data connection, lower cost data usage than 3G data (often free), and user control of data connectivity. This bypass of the service provider 3G core network for data represents a loss of revenue opportunity and a loss of user experience control. The benefits for the service provider is this 3G offload capacity is provided by a home or business and does not require any service provider resources.

BelAir Networks VHCI Software Feature Set

As is the case with all Ethernet and IP based networks, good design doesn't solve problems, it avoids them. BelAir's VHCI features are specifically designed to accommodate high-scale networks and as a collection are absolutely critical to any effective deployment.

Eliminating Unnecessary Packets

While this may seem like an obvious area of improvement, most existing Wi-Fi solutions simply forward all packets that they receive on the wired side over the air interface. There are a number of processes on laptop and handheld devices that will generate broadcast messages. This is then further aggravated as these messages reach other client devices and they, in turn, respond to many of these messages.

In a home network with four or five devices this is acceptable overhead. But, in public systems with hundreds or thousands of users this can quickly bring a Wi-Fi network to its knees. Let's look at some of the ways that unnecessary packets can be eliminated.

Peer to Peer Traffic Control

Controlling traffic between end users in a public Wi-Fi solution is a critical feature. This secures end users from malicious scanning and allows the service provider to ensure that all traffic is passing through the core and eligible for lawful intercept or DPI for advanced traffic classification. Another benefit of suppressing peer to peer traffic is that broadcasts remain unacknowledged and chatty discovery-oriented applications begin to settle and sleep. In BelAir radio solutions, the suppression occurs at all levels of the network. At the AP, across the mesh, and across the switching fabric. This functionality is applied on a per-SSID basis so that select trusted networks can enable peer to peer communications, while allowing public networks to remain protected.

Broadcast and Multicast Filtering

The nature of BYOD (bring your own device) networks is that DHCP behavior drives very large subnets for mobility. While some shy away from large subnets using antiquated "broadcast domain" sizing assumptions, intelligent broadcast and multicast controls can enable sophisticated subscriber-centric IP topologies that don't tax existing transport infrastructure.

The core-facing functionality in this area is provided using group address filters. These filters block all unnecessary upstream broadcast and multicast traffic from clients, allowing near limitless scaling of a single subnet. Enabled on a per-SSID basis, this feature can be disabled for networks requiring multicast video without sacrificing scale. Alternative architectures using BelAir VLAN pools can be used to support such applications with some added complexity.

Equally important in stadium applications is the management of received broadcast traffic destined for the air interface. BelAir inplements automatic secure port detection, whereby the only traffic allowed to reach a client originates from a set of auto-discovered hosts using a series of simulated client exchanges at the AP and or controller.

VLAN Pooling

VLAN pooling enables multiple VLANs to be assigned to a single SSID. This essential functionality allows scaling of mobility capable architecture while retaining some legacy broadcast domain features that are leveraged in multicast video distribution.

Pooling is done by hashing the last 3 bits of the MAC address and then assigning them to one of up to 8 custom-defined VLANs. This mechanism has the benefit or deterministic selection and works consistently across any number of access points.

DHCP Filtering and Advanced Management

BelAirOS implements 4 distinct features to improve DHCP performance and eliminate superfluous traffic/ network load.

The first feature converts broadcast DHCP responses from the network into unicast frames before sending to the client. In busy air environments the conversion significantly improves performance by enabling reliable unicast delivery to a client instead of best effort in the broadcast case.

Another DHCP enhancement is the ability to statefully reset broadcast flag on client-originated packets without impacting interoperability. Conditioning packets to ensure unicast response through a transport network is often advisable; unfortunately some operating systems fail to implement unicast response handling properly. To ensure minimal failures, and consequent retries, the AP readjusts client responses to broadcast in cases where the client specifically requested such response.

While the network-facing DHCP conditioning using a transparent proxy mechanism resolves many issues, it is unable to address the case of the authoritative server and a misbehaving client. Many mobile operating system vendors have resorted to an unconventional interpretation of DHCP RFCs and now “test” multiple old and expired addresses through a series of renewals to shortcut their way on the network. While such an approach has merits in the local example, it fails to work well in public environments with centralized DHCP. For these environments BelAirOS provides DHCP relay from the AP. This ensures delivery of a fast DHCP NAK without increasing network load from broadcasts. All alternative architectures fail to address the NAK use case effectively.

While network load management is extremely important, the underlying value of intelligent network design is a more pleasant user experience. DHCP whitelisting allows the acceleration of DHCP NAKing by locally sourcing the NAK when an RFC1918 address is presented by the client for renewal outside the supported IP range on the sanctioned network. This edge acceleration simulates the fast NAK in the decentralized network model assumed by the mobile operating system, but does not require decentralization of the DHCP itself.

Non-Attached ARP Blocking

VHCI includes a feature that prevents forwarding of ARP requests for IP addresses that are not in use by an attached client. Transmitting an ARP over the air when it is already known that no client will respond is a waste of bandwidth.

Improved Clear Channel Assessment

With VHCI, BelAir has optimized the clear channel assessment algorithm to identify transmit opportunities much more aggressively.

Client Access Control

Managing Modulation Rates

One of the realities of Wi-Fi systems is that they can be prone to a lowest common denominator effect. Having users that connect right at the edge of the operating range, as depicted in Figure 1, can reduce the experience of all users. Clients at low modulation rates consume a larger portion of the available air time to send the same amount of data. VHCI provides features designed to address this issue, improving network performance and overall experience.

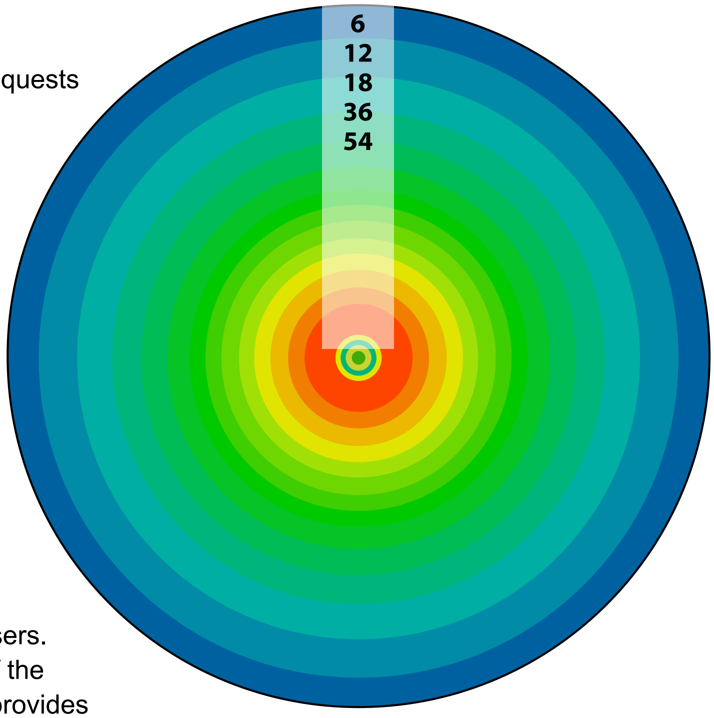

Figure 1: Modulation rates decline as users move away from the Wi-Fi AP

First, VHCI enables the balancing of time slices that users get rather than simply metering the number of frames each user gets. VHCI also includes features enabling control of the effective cell edge. In a Wi-Fi system optimized for user experience rather than absolute range, total system throughput is greatly augmented if the APs preclude a user from connecting at very low power. Through VHCI, BelAir Networks APs can limit user connection by both the power necessary to associate to the AP initially and, in the case of an established session, the power necessary to maintain that connection.

Number of Users Per AP and Load Sharing

Another key aspect of client control is ensuring that in a large system a single AP does not end up being overloaded. Some Wi-Fi solutions try to accomplish this by manipulating the beacon transmit power from the AP. Unfortunately, this approach can result in a negative user perception since the “number of bars” on a client device is strongly related to beacon RSSI.

With VHCI, the BelAir approach is to actively manage the number of connections. Assuming that the user has met the other connection criteria, BelAir APs have the ability to hard or soft limit the number of client devices per AP. A hard limit is consistent with environments where the user has an alternate connection path, as would be the case with a Wi-Fi network designed for cellular offload. With a limit of M users the M+1st user is refused a connection by the AP. This will force the client device to look for an adjacent Wi-Fi connection or revert back to the cellular system. The soft limit operates in a similar fashion with the difference being that if a client returns to the same AP three times in a specified period the AP will then allow the connection on the presumption that the client device has no other place to go.

Use of 5 GHz

In outdoor/public networks the issues that client devices may experience using 5 GHz in a home setting are largely not present. Outdoor/public systems do not generally deploy APs in a way that requires penetrating many walls and other obstructions. As a result, the use of 5 GHz provides a simple means to significantly increase the deployed bandwidth in a system.

While it is true that 5 GHz has seen slow adoption in smart phones, this is changing. The iPad and virtually all of the competing tablets are supporting 5 GHz operation out of the gate and there is increasing recognition by carriers that 5 GHz must be in smart phones to maximize the opportunities for data offload from the carrier networks. Ultimately, it is very difficult to ignore the 100’s of MHz available in the 5 GHz range.
Two approaches for getting users onto 5 GHz are recommended.

Band Steering

Devices that are both 2.4 and 5 GHz capable are generally defaulted to allow connections to both bands. With many of the current drivers there is a bias towards using the 2.4 GHz band first. This propensity can be overcome with band steering.

Essentially, the access point keeps track of probe requests from clients on both 2.4 GHz and 5 GHz. If the noise floor, number of clients, and signal strength look favorable for a client on 5 GHz, the AP will suppress probes and migrate the client over the 5 GHz radio.

Adding a 5 GHz Specific SSID

Though manual options are generally not preferred, adding a second SSID at 5 GHz can allow demanding users, who are usually more tech savvy, to manually connect to the 5 GHz interface. And more importantly, in emerging EAP-AKA applications, where supplicant use is frequent, a suppressed SSID specific to a 5 GHz radio might make sense, especially if the device and application are targeted to video or voice.

On BelAir Networks APs, this SSID can coexist with the automated connection SSID previously discussed and both traffic groups can be mapped on to the same network infrastructure. This is accomplished by mapping both SSIDs to the same user traffic VLAN.

Operating Environments

There are many distinct environments in which Wi-Fi operates. These vary in relative user group size, usage patterns, interference environment, and deployment complexity. Stadiums can represent the most challenging environment for Wi-Fi. On the plus side, stadiums tend to be radio islands. Unlike general public hotspots/hotzones, stadium deployments can be engineered without having to be overly concerned about 3rd party Wi-Fi devices. Most facilities of this type control the radio devices that can be deployed, where they can be deployed, and at what power level they can operate.

To better understand stadium Wi-Fi, it's important to review how we get from small networks of a few APs up to massive facilities with hundreds of Wi-Fi access points.

Simple/Small Environment

As noted earlier, assuming channel conditions that support MIMO, in indoor environments an 802.11n access point (AP) using 20 MHz channels communicating with 802.11n compliant client devices, the maximum useful capacity is in the range of 100 Mbps for TCP traffic. With 3 non overlapping channels, up to 300 Mbps is therefore reasonable in a simple environment.

Medium Environment

As the space size and the number of client devices increase, the usual approach is to use multiple APs and maintain the use of the 1,6,11 frequency plan. It is important to note, though, that in a single room where all of the APs can "see" each other, adding APs does not add incremental capacity. In these cases, the design objective is to ensure that all users are connected at the maximum possible data rate. CSMA (Carrier Sense Multiple Access) will force the APs and clients to wait for an opportunity to transmit when the channel is clear. All of the APs and all of the client devices using the same channel will share the channel capacity.

The use of multiple APs on the same channel incurs some overhead due to the time required for multiple beacons to be sent out. If an unmodified AP is used and it is transmitting beacons at a 1 Mbps on air rate, each beacon can consume up to two percent of the available airtime on a particular channel.

In these environments important features include the ability to keep individual APs/channels from getting overloaded. Some Wi-Fi solutions do this by simply reducing the power level from an overloaded AP which encourages client devices to roam to a higher power AP. This can result in some client devices that don't roam, for a variety of reasons, operating at a lower modulation rate, which in turn consumes more time per packet and ultimately reduces the supported capacity on a channel.

As discussed earlier, BelAir's approach in these cases is to set a limit on the number of users that can connect to a particular AP by the use of hard or soft limits. For example, setting an AP to a 60 user hard limit would result in the 61st connection being rejected. The user device would then attempt a connection on another AP within range. In the case of a soft limit, the 61st user would initially be rejected, but could be allowed to connect, for example, after three attempts within a defined time window. The rationale is that the user has no other connection available. These hard and soft limit features balance the users across the available Wi-Fi radios without compromising the network's ability to support maximum data rates.

Large to Very Large Sports Bowls and Auditoriums

To scale beyond environments where everything possible is already being done to maximize the operation of the baseline capacity of 802.11n, the solution set needs to change to creatively adapt the CSMA protocol in order to multiply bandwidth, while maintaining standards based client interoperability.

To do this, the radio operation and antenna subsystems have to allow for parallel operation of both client devices and APs. Normally CSMA-CA operates to prohibit this. With simple omni or low directionality antennas, APs can "see" each other from all parts of the bowl.

To understand the dynamics, we will look at the four types of interaction, depicted in Figure 2, that occur in these facilities:

1. AP to AP
2. AP to non served client devices on the same channel
3. Client device to non serving APs on the same channel
4. Client device to client device

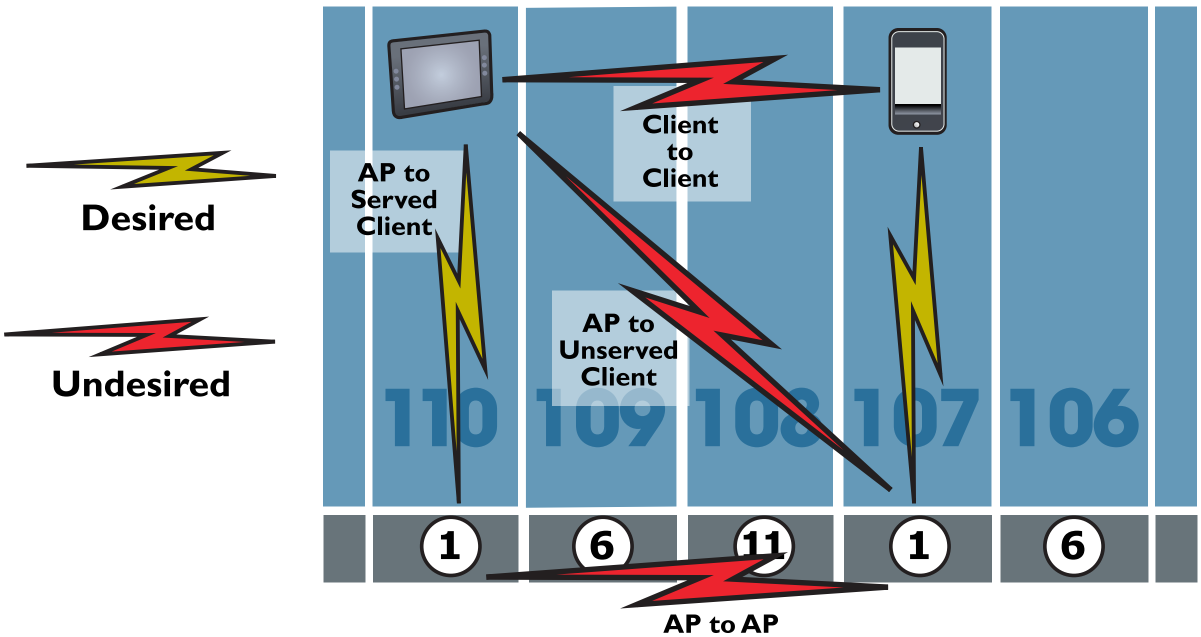

Figure 2. CSMA interactions in a stadium

1. AP to AP

Problem Statement: With conventional enterprise APs the antenna subsystems are generally comprised of simple low gain/low directionality antennas, either small omnis or low gain directionals. In either case the result is that most, if not all, APs operating on the same channel can "see" each other. In a facility with 100+ APs in the bowl area, the coupling of all of these access devices can result in the system spending much of its time simply listening to beacons from other APs, as depicted in Figure 3.

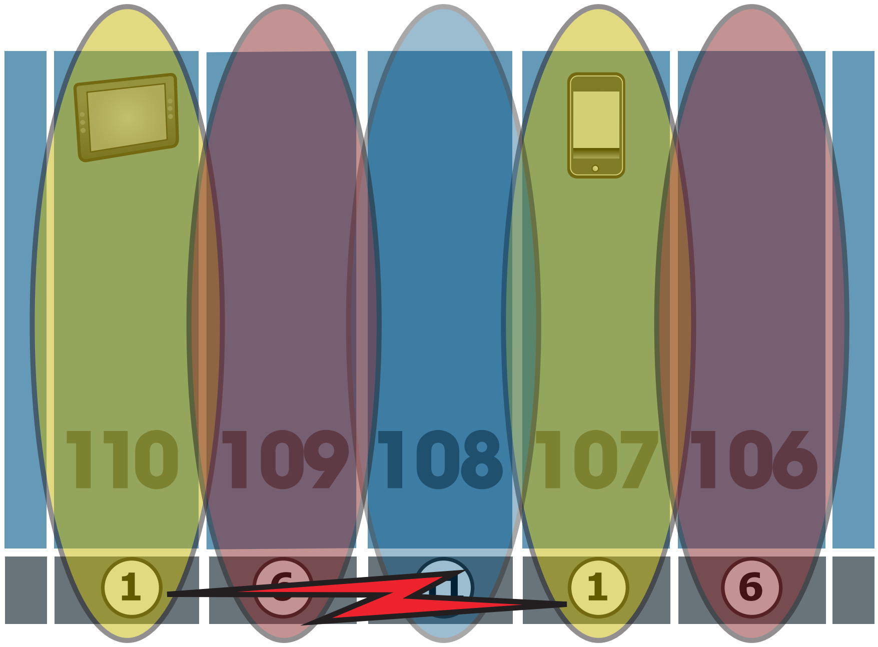

Figure 3. AP to AP interactions

Remediation: A number of actions can help alleviate the issue of AP to AP coupling: reducing AP power levels, controlling the antenna patterns to reduce emissions in the direction of other APs on the same channel (both along the seating area and across the field), and controlling the transmit power. Additionally, taking advantage of a BelAir feature that allows the AP to ignore low power packets on the same channel means that BelAir radios can transmit more often (thus multiplying the available capacity that is available with 3 channels) by allowing multiple APs to transmit in parallel.

2. AP to non served client devices on the same channel

Problem Statement: Transmission from an AP that is on the same channel but not serving a particular client, as depicted in Figure 4, will cause the CSMA algorithm in the client devices to engage and the client will not transmit until the channel clears.

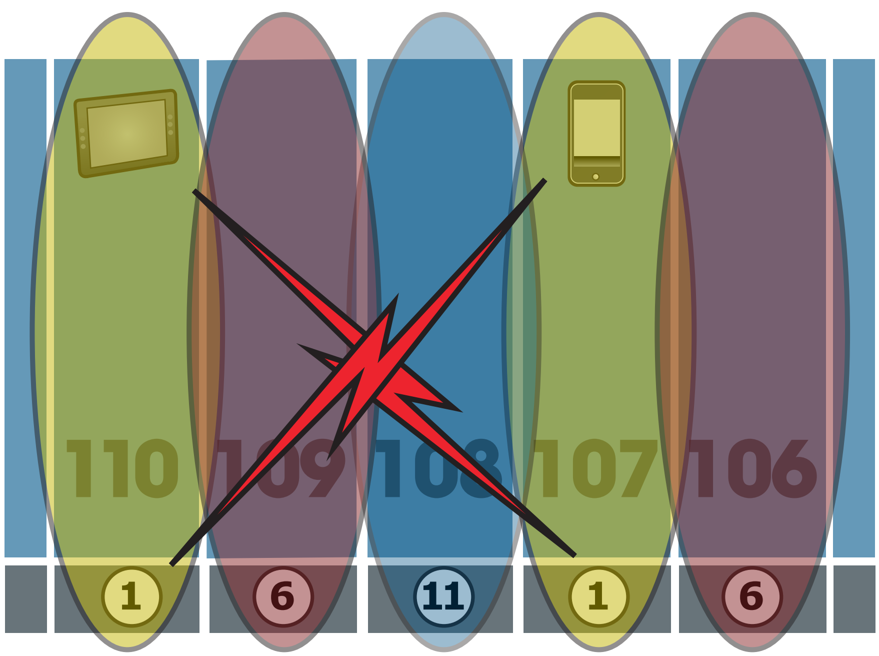

Figure 4. AP to non served client devices or client device to non serving AP interactions

Remediation: In the "along bowl" direction the use of directional antennas on the APs means that the signal is attenuated by the antenna pattern. The isolation provided by the antennas allows the serving and the non serving AP to transmit at the same time and the packet will arrive at the client with sufficient signal to interference to allow the packet to be successfully received.

The presence of fans also helps in this situation. The body loss of the people between the non-serving AP and the client device can have the effect of completely isolating the client from the non serving AP in such a way that the client does not trigger the CSMA algorithm. This effect becomes more pronounced as the distance increases. The "across bowl" direction is managed by the vertical antenna pattern of the selected AP. Managing the transmit power of the APs can also assist in this regard.

3. Client device to non serving APs on the same channel

Problem Statement: Again shown in Figure 4, this problem is effectively the reverse of the issue discussed regarding AP to non-served client devices on the same channel. Transmission from a client device that is on the same channel but attached to a different AP can activate the CSMA algorithm in the AP until the channel clears. Remediation: In the "along bowl" direction, the use of directional antennas on the APs means that the signal is attenuated by the antenna pattern. The isolation provided by the antennas allows client devices in reuse areas to transmit at the same time and still be successfully received at their respective APs.

Again, the presence of fans helps in this situation. The body loss of the people between the client device and the non-serving AP can completely isolate the client from the non serving AP so that the client does not trigger the CSMA algorithm. This effect becomes more pronounced as the distance increases. In this direction the previously mentioned feature whereby an AP is able to ignore packets below a given threshold is beneficial here as well. The "across bowl" direction is managed by the vertical antenna pattern of the selected AP.

4. Client device to client device

Problem Statement: As depicted in Figure 5, in this case we are concerned with the CSMA interaction between client devices on the same channel. For clients on the same side of the bowl, i.e., along bowl, the body loss effect almost completely eliminates this issue. However, dealing with this problem for clients on opposite sides, i.e., cross bowl, is the issue that makes stadium Wi-Fi network design unique from other high capacity settings. The sloping sides of the bowl mean that there are no obstructions between client devices on the same channel on opposite sides of the bowl.

Remediation: As noted, in the along bowl direction the body loss of the fans has been proven to offset this problem entirely. In the across bowl direction, the clients' interactions will result in the CSMA algorithm being engaged. In the case where the client is receiving a packet from its serving AP and a packet arrives from across the bowl the signal to interference ratio is sufficient to allow the packet from the serving AP to be successfully received.

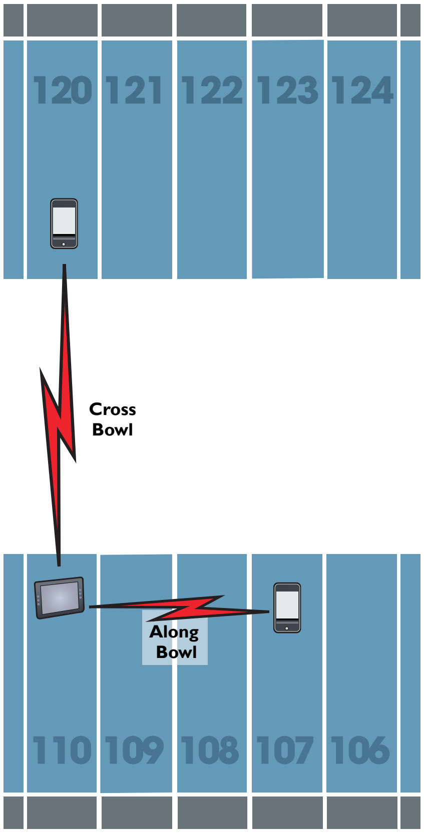

Figure 5. Client to client interactions along and across the stadium bowl

Alternate Frequency Planning

Alternate frequency planning is another approach for defeating the carrier-sense induced limitations in the stadium bowl, particularly the client-to-client interactions.

Using channel plans that utilize all 11 channels available breaks the clients into 11 groups rather than the usual 3. Clients that are on overlapping channels appear as noise rather than valid 802.11 packets.

Modern chipsets are especially adept at handling overlapped channel conditions. Adaptive receive sensitivity and clear channel thresholds enable the AP to operate in very noisy environments with little to no degradation of performance, especially in power-bounded deployments with limited link distance.

Alternate frequency planning should only be applied to engineered environments like a stadium bowl where advanced antenna solutions can be brought to bear. The design problem becomes one of managing signal to interference ratio. This is achieved using the same antenna techniques discussed previously. The alternate channel plan derives its most significant benefit from the reduction of the client-to-client interaction.

Sample Design

The following is a working example of a 73,000 seat stadium.

Restrictions

As with all stadiums the selection of mounting locations is key. The sight lines from seats and suites cannot be obstructed. Ideal mounting sites allow the antennas to be positioned to maximize the down-tilt while minimizing the cross bowl AP to AP interactions. Mounting locations must be selected such that fans cannot reach or interfere with the radio equipment. A natural outcome of frequency and radio planning is that the network design should maintain good symmetry. This keeps the radio interactions normalized and predictable.

Capacity and Load

In this sample design, as in all cases for large venues, the Wi-Fi network may be part of a larger system. In those cases, the Wi-Fi network should be designed to augment the cellular data system, not replace it. Results from live networks in high capacity environments reflect mobile data capacity improvements of 100% or more.

The target user experience is for the client device to have access to a virtual 700 kbps bearer capacity when it accesses the system. It's also important to consider that according to industry statistics from the cellular industry, up to 50% of attendees at a public venue will have a data enabled device.

Compounding the design challenge is the fact that Internet access at sports events tends to be very bursty. The cultural phenomenon of fantasy sports results in users accessing sites regularly for updates at every interruption in play. This is where capacity multiplication becomes critical. Traditional enterprise Wi-Fi cannot handle this load.

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For illustrative purposes, let's assume that 1% of the smartphones in a stadium access the Internet at a break in play. Assuming a 1 MB (8 mbits) website size, this results in 3 Gbits of data being demanded from the entire data infrastructure in a burst demand event. Assuming that this is entirely carried by the Wi-Fi infrastructure, 100 APs would have to carry 30 Mbits of load each. Now, if we assume that the system, as designed, provides 5-10 Mbps per AP in the 2.4 GHz band (resulting in a venue capacity of 500 to 1000 Mbps on the example design) this would be delivered in 2-4 seconds. The cellular data infrastructure will of course carry some of this load but it's clear that without applying the techniques outlined earlier to drive capacity multiplication in the Wi-Fi network, the system would collapse and the time to complete the transaction would increase beyond the user tolerance.

On the assumption that the Wi-Fi and cellular networks are capable of handling the stated load use case, it will, of course, be critical for the transport, switching, and routing infrastructure to be dimensioned appropriately.

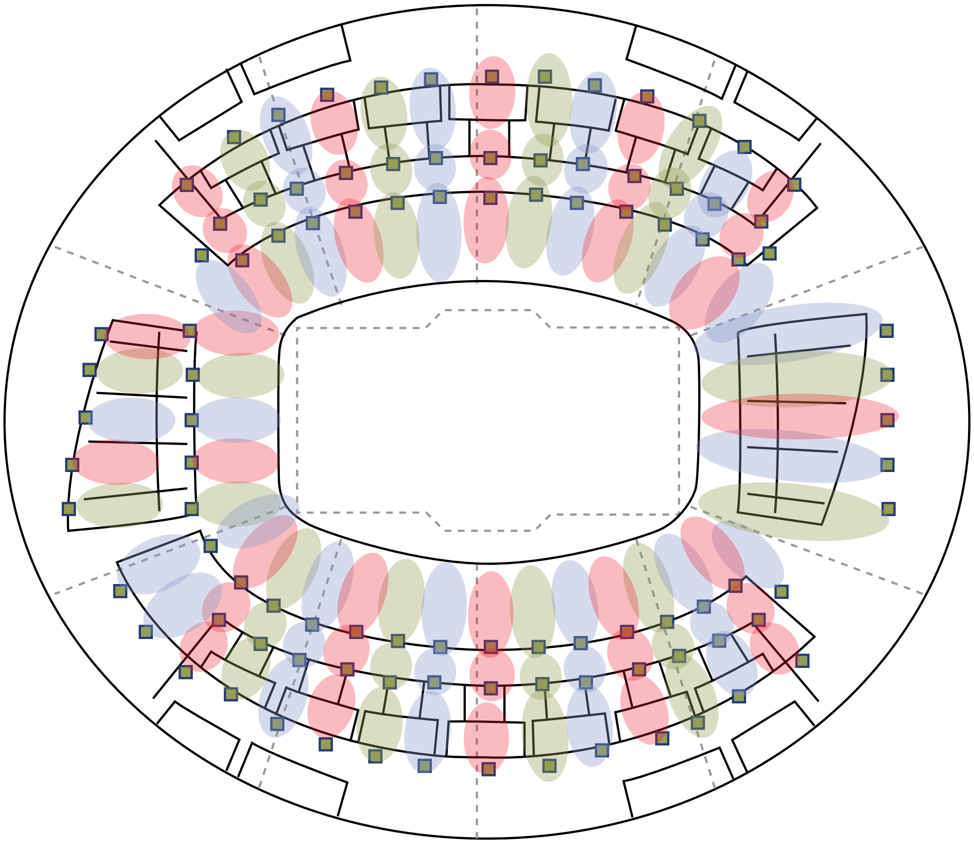

Figure 6. Sample stadium bowl Wi-Fi network design

Figure 6 indicates the deployment locations, three channel variants and associated coverage of the Wi-Fi APs in the sample stadium design. The antennas have a 20 degree horizontal beamwidth and are down tilted so that the beam peak in the vertical plane points at the first seat in each seating block. BelAir VHCI software features outlined earlier complement this physical implementation to maximize the user experience. Figure 6 indicates a 1, 6, 11 frequency plan, however an alternate frequency plan would use the same AP mounting locations but change the associated channel assignments.

Summing Up

Large public venues represent the extreme use case for any Wi-Fi solution.

The design approach and features outlined illustrate how 2.4 GHz Wi-Fi access networks can be constructed. The ability to also deliver concurrent 5 GHz Wi-Fi access provides additional room for growth as smartphones and tablets increasingly provide support for that band.

BelAir Networks fully understands the boundaries imposed by the 802.11 family of standards. To maximize capacity it's necessary to maximize the opportunity for multiple APs and clients to transmit at the same time. This provides the multiplication required to support higher capacities in large venues.

For more information, Please contact:
HT&T Communications Group
Thailand Business Partner

info@httcom.asia
sales@httcom.asia
www.httcom.asia

BDMC00120-B01