iBwave

**WHITE PAPER**

# HOW TO DESIGN BETTER WIRELESS NETWORKS FOR STADIUMS

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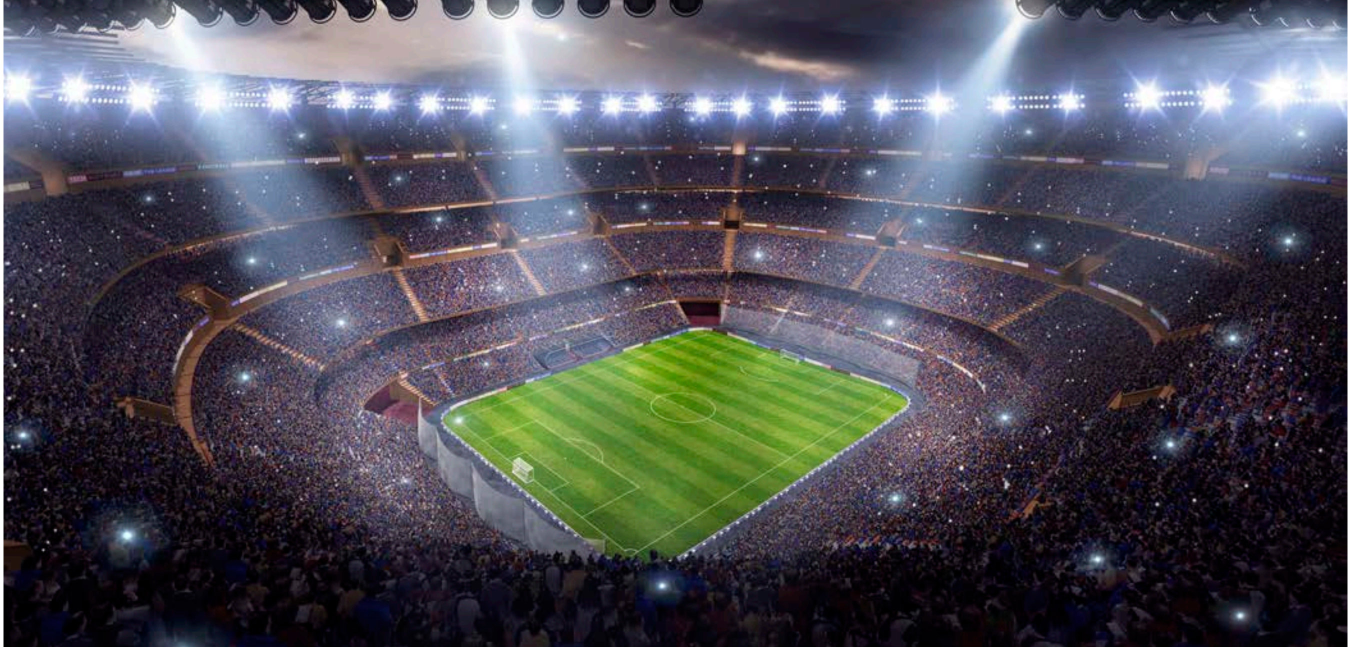


## 01. INTRODUCTION

A stadium is a venue which consists of a field/track surrounded by a bowl-shaped seating area. The largest stadium in the world is in Pyongyang, North Korea, with a capacity of 150,000 spectators. The second biggest is in Kolkata, India with 120,000 spectators. There are only a handful of stadiums with more than 100,000 seats.

As of 2014, 934 stadiums worldwide have 30,000 or more seats: 228 in North America; 129 in Central and South America; 243 in Europe; 98 in Middle East and Africa; and 236 in the APAC region. The USA alone has 217 stadiums with 30,000 seats or more, and about two thirds of these are used primarily for American Football. See Figure 1 for a worldwide high-capacity stadium breakdown [1].

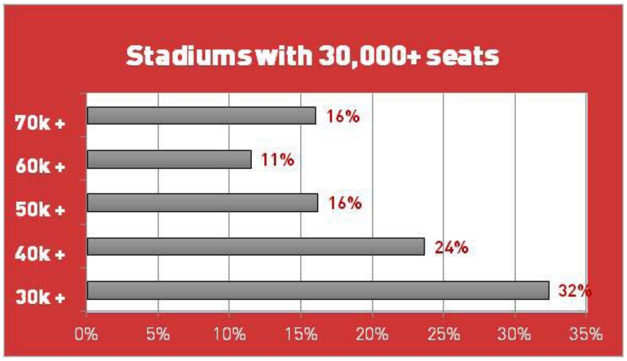



Figure 1: Worldwide High-Capacity Stadium Breakdown

Although the size and configuration of stadiums vary widely, there are design and deployment considerations common to all stadiums. These are the subject of this paper.

## 02. PROBLEM

The venue has a capacity of 60,000 seats with five different seating levels as shown in Figure 2. General public retail shops and concession stands are located on the first level, between the stadium entrance and the entry points to the seating bowl. On the same level, but not accessible to the general public are conference rooms. One level below is ground level where the press rooms and team dressing rooms are located.

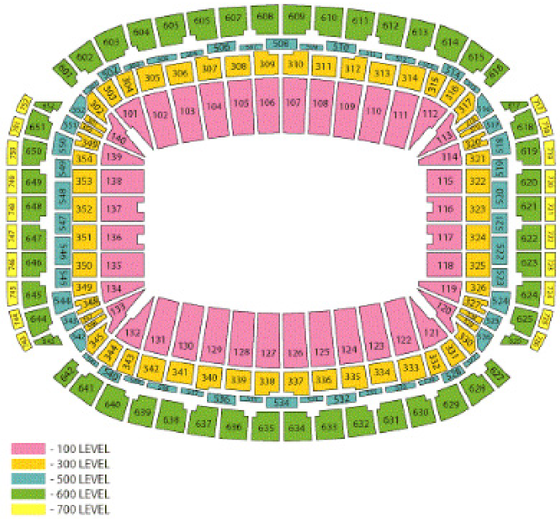



Figure 2: 2D Stadium Seating Plan

The existing RF coverage coming from surrounding macro sites is fair to good in the bowl, but poor below it, in back offices, in conference rooms, and in concession areas. The macro sites that cover the stadium report high call blocking during venue events, as illustrated in Figure 3. For this example, note that blocking peak of 60% is reported in the busy-hour peak (that is, during event)

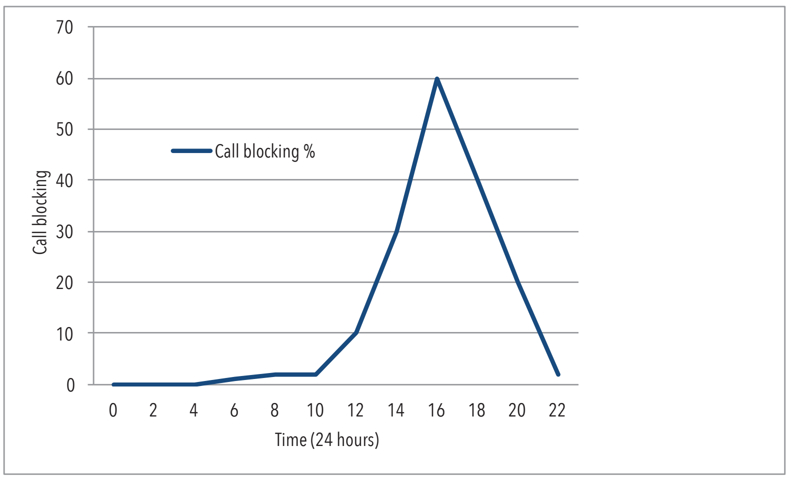



Figure 3: Typical Call-Blocking Statistics on the Day of a Stadium Event

The call-blocking problem is not restricted only to the stadium building, but also occurs in surrounding areas where spectators congregate before and after events. These transit areas include parking lots, train stations, pedestrian walkways (above or below ground), etc. Examples of such transit areas are shown in Figure 4.

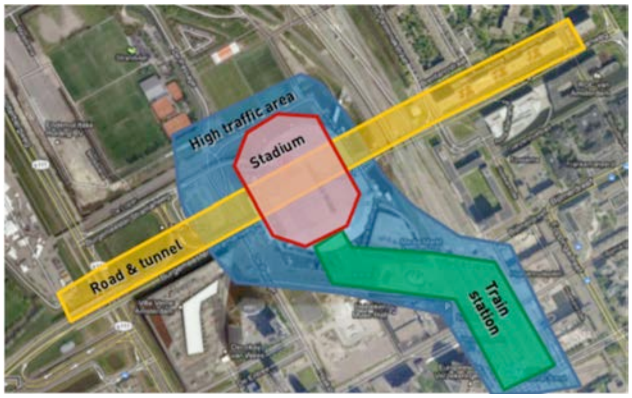


Figure 4: Bird's-Eye View of Transit Areas Outside the Stadium

The stadium network needs to provide coverage and capacity both to the stadium and to nearby transit areas. The network should be able to support traffic when the stadium is at full capacity during an event, and also the traffic near the venue before and after an event.

## 03. SOLUTION

Although there is some residual macro RF coverage in the seating area, the main problem is lack of capacity from the surrounding macro sites. The stadium therefore needs its own RF network to satisfy demand during events. All commercial wireless service providers (WSPs) want to be included in the stadium network. The network must also include public safety and the venue operations trunked radios. An IEEE 802.11 (Wi-Fi) network needs to be included as well.

As the in-building system has to include multiple WSPs and the Emergency Service (ES) network, an optimum solution is the use of a neutral host Distributed Antenna System (DAS), capable of providing high-power signal to the serving antennas, critical at large venues where the distances between subscribers and antennas are large. ES and WSPs may be deployed in a converged DAS, or two separate DAS may be built, one for ES and one for all WSPs. The decision whether to deploy the converged or the discrete DAS architecture should be based on EIRP, spectrum bands and technologies that are being deployed.

Although transit areas outside the stadium have good coverage, they suffer from inadequate capacity before and after events. The DAS therefore has to be extended to those areas as well. The DAS signal has to be stronger than the residual macro signal to guarantee that subscribers connect to the stadium network rather than to the surrounding macro network.

## 04. DESIGN REQUIREMENTS

The design requirements for this 60,000-seat venue are as follows:

### 4.1 RF Coverage

- The stadium network signal must be dominant throughout the venue, even if there are areas where the existing macro coverage gives a "five-bar" reading on a phone.
- To achieve this dominant signal requirement, the RF design should provide signal that is everywhere 5 to 7 dB stronger than the residual macro signal. This requirement applies to the nearby transit areas as well (see Figure 4, above).

### 4.2 CAPACITY

- The stadium network should be designed to address all service types, from voice to streaming video.
- The pattern of voice and data calls may be different at the stadium than at typical macro networks: voice calls may be shorter due to stadium crowd noise; there may be far more file uploads to social media than usual; and some venues may limit streaming video or, as was the case at the 2014 Super Bowl, ban it completely.

### 4.3 HANDOFF MANAGEMENT

- Establish clear handoff areas between the macro network and the stadium network in the transit areas outside the stadium.
- Once a subscriber hands off from the macro network, he should remain with the stadium network throughout the duration of his visit to the venue.
- Handoff traffic is handled by control channels. Extensive handoff traffic may use up control channel capacity and result in call blocking even if sufficient physical resources are available to carry voice and data traffic.

### 4.4 INTERFERENCE MANAGEMENT

- Non-serving sectors are a source of interfering signal. Interference can be internal, from non-serving DAS sectors, and external, from the macro network.
- Minimizing interference improves both network capacity and maximum achievable data rate (MADR).

## 05. BEST PRACTICES

When designing a network, certain rules need to be followed to achieve an optimum design. These include the following:

### 5.1 SITE SURVEY

During the initial site visit, information about the physical structure, architecture and the different morphologies within the venue is gathered. A lot of information is captured in the form of photos, videos, measurements from data collection tools, voice memos and text annotation. Potential locations at which to mount antennas, run cables and install equipment are also scouted.

During the survey the existing macro radio coverage at the venue should be recorded for all wireless carriers that are to be included in the network, and at all frequency bands of interest. This is an important part of the survey because the actual stadium network has to overcome the residual macro coverage by a comfortable margin. Otherwise, spectators' User Equipment (UE) may be registered with the macro network while at the venue, a highly undesirable situation because an important requirement is to offload the macro networks. Figure 5 shows a field engineer collecting RF and other venue data.

During the site survey, in addition to RF data, the engineer needs to identify spots where antennas may be mounted, to identify a room big enough to house the headend for the in-building network, and to identify potential cable paths between the headend and the antennas.

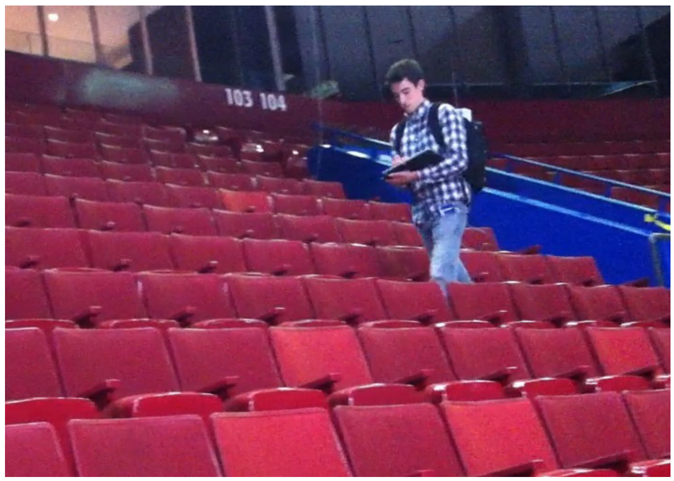
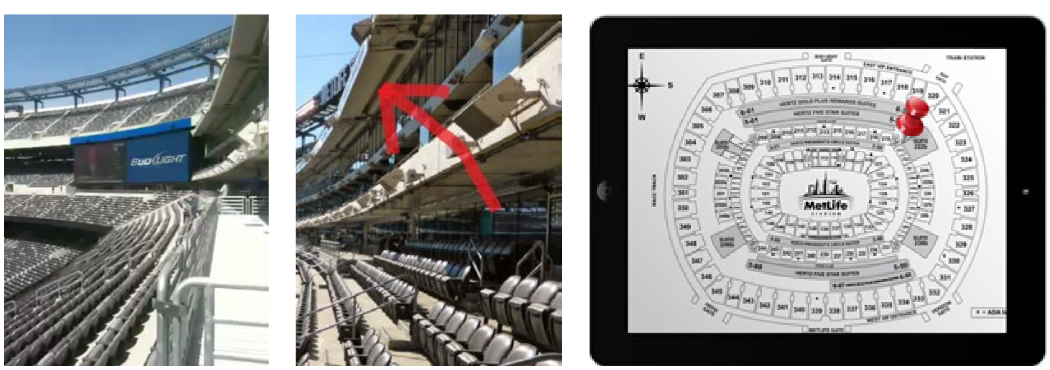



Figure 5: Site Survey Engineer Collecting RF and Other Venue Data

Recording the information directly onto a floor plan saves time and facilitates information exchange with other departments and stakeholders. Plenty of information is captured and making sense of it is of crucial importance to reducing deployment timelines and costs. It is also important to identify several locations at which to mount candidate antennas so that different alternatives to control radio signals and provide capacity can be considered during the detailed RF coverage design phase later on.

Figure 6 shows an example of data collected by an engineer during a site survey. Figure 6a is a photograph of a general area of a potential antenna location in the seating area. Figure 6b zooms in on the location, marked with a red arrow. The location needs to be identified on a layout plan as well so that the RF design engineers can know where they can put DAS antennas. This is illustrated by Figure 6c which shows the venue layout displayed on a tablet; a red pushpin indicates the antenna location.




(a) (b) (c)

Figure 6: (a) General Area of an Antenna Location; (b) Red Arrow Marks the Location (C) Red Pushpin Indicates the Location on a Site Layout

### 5.2 DETAILED 3D MODELING

Stadiums are multilevel structures that contain a wide variety of RF propagation environments. The most significant is the seating bowl, which is modeled as an inclined surface so as to take into account the difference in elevation between rows of seats. UE in this area will have a clear Line of Sight (LOS) to the serving antennas, positioned above the seats. An example of a 3D model of a seating bowl is shown in Figure 7.

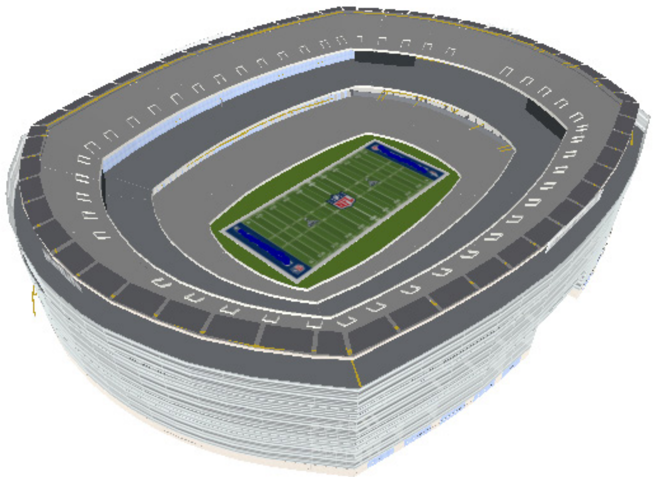


Figure 7: 3D Model of a Stadium Seating Bowl

Capacity hotspots outside the bowl area need to be included in the design. Corporate and news media boxes, retail shops, and concession stands are examples of capacity hotspots. Capacity hotspots that are not accessible to the general public such as conference rooms, press rooms, and team locker rooms also need to be included. Capacity hotspot examples are shown in Figure 8.

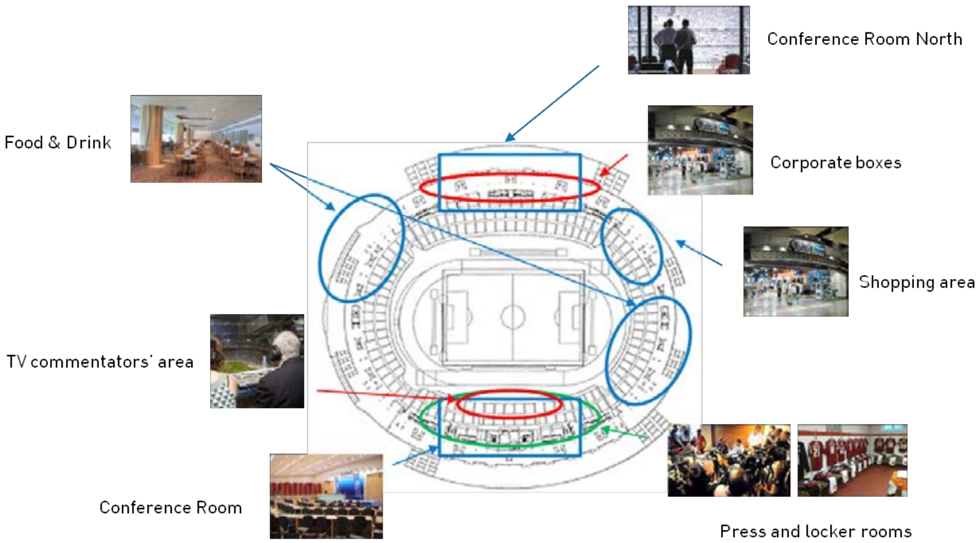



Figure 8: Stadium Hotspots Outside the Seating Bowl

These areas are generally well isolated from the seating bowl so they need their own antennas for coverage. RF propagation characteristics in stadium hotspots vary considerably. Inside the bowl, signal from the DAS is clearly in LOS with UE. Underneath the bowl, in the retail area, LOS is prevalent but there are numerous reflected signals due to the bowl's concrete walls. In the back-of-the-house areas, where the conference and locker rooms are located, wall density is much higher so there is significant signal diffraction and non-line-of-site (NLOS) propagation.

As propagation characteristics at hotspots differ from those in the seating area, it is necessary to properly model the hotspots in 3D as well. Figure 9 shows the retail area immediately below the seating. (The seating is marked in red.)

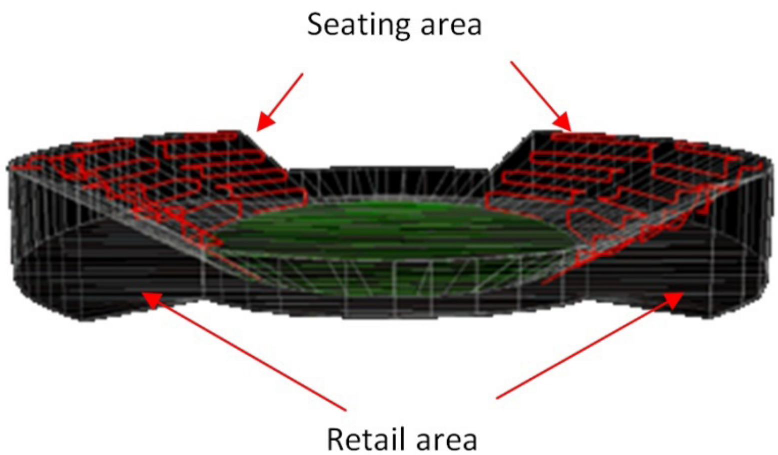



Figure 9: 3D "Wire-Mesh" Model of the Stadium

Making a 3D model of a venue can take anywhere from five hours for smaller venues, to 20 hours for larger, more complex venues. Availability of the drawings in electronic form (CAD), rather than in the form of paper drawings, also affects the time to complete the 3D model. Often we design the system for a building under construction; hence the need to work using a 3D model as we cannot access the venue. Proper modeling of the venue is important not only for propagation analysis, but also for good Bill of Materials estimates, such as for lengths of coax or fiber.

### 5.3 SECTORIZATION

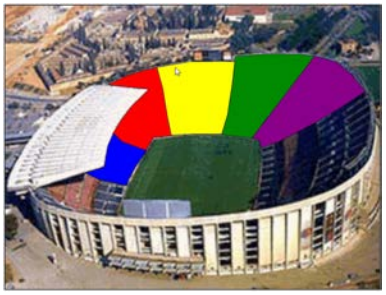
Sectorization has a dual purpose in the design of a radio network. First and foremost, it increases network capacity because each sector has its own channel cards capable of carrying voice and data traffic. Sectors are assigned a specific area to cover and serve a specific number of subscribers. The actual area to be covered and the actual number of the subscribers that a sector should serve are a part of capacity sizing, where parameters such as number of channels per sector, data rates, and the type and duration of calls and data connections are taken into account.

The second purpose of sectorization is to minimize the number of signals present in the area by limiting sector coverage. Limiting the coverage also limits interference from non-serving sectors, which improves capacity, signal-to-interference-plus-noise ratio (SINR) and maximum achievable data rate (MADR). In LOS areas like the seating bowl, sector overlap minimization is achieved by using highly directional antennas.

There are a few common sectorization types. Horizontal (ring) or vertical (wedge) sectorization are used most commonly where the number of sectors is not very high. Examples of such sectorization schemes are shown in

Figure 10. The advantage of these methods is that horizontal or vertical movements by spectators do not result in extensive UE handover.

(a)



(b)

Figure 10: Examples of (a) Ring and (b) Wedge Stadium Sectorization

If, however, a significant number of sectors are required, then hybrid ring-and-wedge sectorization is the best option. An example of mixed sectorization with 24 sectors is shown in Figure 11.

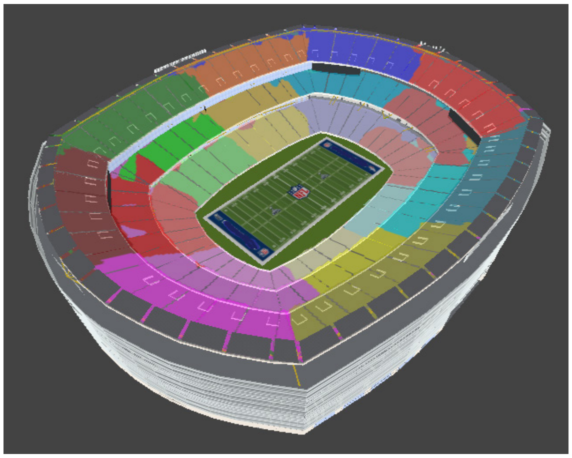


Figure 11: Mixed Sectorization Example with 24 Sectors

### 5.4 MACRO COVERAGE MANAGEMENT

Early on in macro network deployments, WSPs recognized the revenue potential of venues with high subscriber density, like stadiums. At first they tried to provide good stadium coverage ("five-bar") by pointing sectors of nearby macro sites toward the venue. However, as networks became more data-centric, the data traffic became more congested and capacity at the venue became the primary concern. Nowadays many stadiums have good coverage in the seating bowl, but need a dedicated stadium network to direct the traffic away from the neighboring cell sites that would otherwise be overloaded during stadium events.

When designing stadium network coverage, a common practice is to design so that DAS signal will be stronger than the residual macro signal by at least 5 to 7 dB. If the residual macro signal is already strong, a DAS may need many antennas to achieve this goal which may make the cost of deploying the DAS prohibitive. The most effective way to reduce the residual macro coverage is to down-tilt antennas at nearby sectors that point towards the venue, as shown in Figure 12.

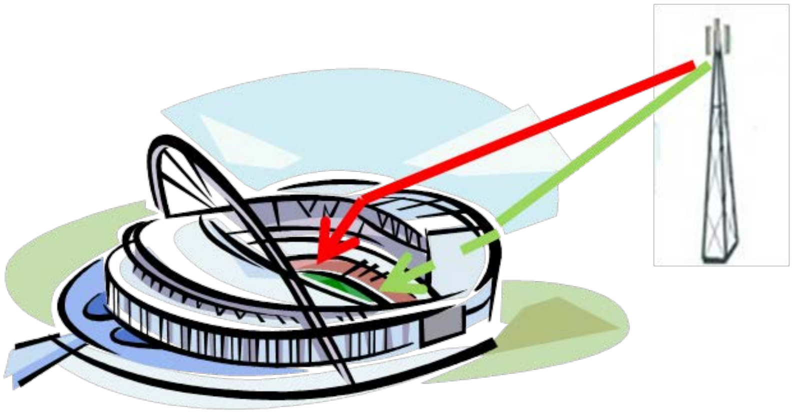


Figure 12: Down-Tilting of Sector Antennas

The red line in Figure 12 shows the RF signal path with the initial antenna down-tilt. The signal is diffracted from the stadium roof which causes little attenuation, thus providing strong signal in the bowl. When the sector is down-tilted further, the signal path shown in green penetrates the concrete wall. This is often preferable because the concrete wall significantly attenuates the signal before it reaches the bowl.

### 5.5 PASSIVE INTERMODULATION (PIM) MANAGEMENT

Neutral-host networks with high transmit power are susceptible to Passive Intermodulation (PIM) noise generation. If the PIM noise level is sufficiently high, it can reduce coverage, slow the network, cause dropped calls, and reduce battery life. LTE networks are especially susceptible to PIM noise because SINR is referenced to Physical Resource Block (PRB), which is 180 kHz wide. Thermal noise referenced to 180 kHz is -121 dBm and, for an LTE network to function properly, maximum PIM noise must be -127 dBm or lower. To ensure that PIM noise is kept in check, the following steps should be undertaken during the design stage [2]:

- Combiners near the power amplifier should have a PIM specification of -162 dBc @ 2x35 dBm to achieve the required PIM noise.
- Braided coaxial cables and N type connectors are a known source of PIM noise and should not be used.
- Silver-plated 7/16 DIN connectors should be used as they have a low PIM rating (165 dBc)
- Consider only antenna locations that are away from metal objects, as metal near antennas generates PIM.
- Do not use equipment for which the manufacturer does not specify a PIM rating.
- Perform on-site PIM testing prior to antenna installation, using an antenna on a pole.

## 06. DETAILED RF DESIGN

### 6.1 CAPACITY SIZING

In order to properly size stadium networks it is necessary to determine the number of sectors required to support each carrier's capacity requirements. The number of sectors per carrier depends on the number of seats, the carrier's subscriber penetration rate (the percentage of that carrier's subscribers as a proportion of the general population), and the carrier's mobile traffic profile. For our white paper, the stadium has 60,000 seats and the stadium network needs to carry three WSPs, public safety, stadium operations network, and Wi-Fi. The characteristics of the three WSPs are as follows:

**WSP A:**

- Cellular band (850 MHz), 2 UMTS channels
- AWS band (2100 MHz), 2 UMTS channels
- 700 MHz band (700 MHz), 10 MHz LTE-FDD channel
- 40% subscriber penetration rate (24,000 subscribers)
    - 75% LTE subscribers, (18,000)
    - 25% HSPA subscribers (6,000)
    - Voice on 3G network

**WSP B:**

- PCS band (1900 MHz), 2 UMTS channels
- 2.5 GHz band, 10 MHz LTE-TDD channel
- 10% subscriber penetration rate (6,000)
    - 50% LTE (3,000)
    - 50% HSPA (3,000)
    - Voice on 3G network

**WSP C:**

- AWS band (1900 MHz), 2 UMTS channels
- PCS band, 5 MHz LTE-FDD channel
- 20% subscriber penetration rate (12,000)
    - 75% LTE subscribers (9,000)
    - 25% UMTS subscribers (3,000)
    - Voice calls on 3G network

Let us define HSPA and LTE traffic distribution per user at the stadium as shown in Table 1 which lists, for each service type, the duration of the network connection during busy hour expressed in milliErlangs (mE) per subscriber and the fixed data rate in kbps. It is important to note that a subscriber is not limited to one service type attempt per busy hour; rather he is expected to use, or attempt to use, all of the service types listed.

| Service type | mE/User | kbps |
|---|---|---|
| Email | 50 | 100 |
| Browsing | 100 | 200 |
| Video conf | 5 | 600 |
| Data Download | 150 | 1000 |
| Video Streaming | 1 | 2000 |

Table 1: Data Traffic Distribution at the Stadium during Busy Hour by Service Type: Duration (milliErlangs per user), Data Rate (kbps).

The average duration of a video streaming session per subscriber (10 mE) is shorter than at other venues because fewer customers use this service due to crowd noise. Most stadiums ban video streaming outright due to high bandwidth required for support; as some technical savvy subscribers may find a way to circumvent this ban, we specify a very short connection time (1 mE) per subscriber. Most of the traffic at the venue is internet browsing and data downloading, with some email.

It is assumed that voice traffic is carried over WCDMA (R99) protocol, while data is carried over HSPA and LTE protocols. When defining the subscriber profile for R99, we take into account that data traffic would switch to R99 data only if both HSPA and LTE are unavailable. Therefore, R99 data call duration is very short. as shown in Table 2.

| Service type | mErl/User | kbps |
|---|---|---|
| Voice | 33 | 12.2 |
| Emails | 3 | 64 |
| Browsing | 3 | 128 |
| Data download | 3 | 384 |

Table 2: R99 Traffic Distribution at the Stadium during Busy Hour by Service Type: Duration (milliErlangs per user), and Data Rate (kbps)

For HSPA and LTE, SINR coverage in the seating area is calculated and broken down into SINR intervals based on the modulation scheme that can be achieved in each SINR interval. The example in Table 3 shows that, in a region where LTE PDSCH SINR is 20 dB or more, 64-QAM modulation with coding rate R=0.93 is possible, and gives a spectral efficiency of 5.5 bit/s/Hz. With SINR between 15 and 20 dB, spectral efficiency is 3.9 bit/s/Hz; with SINR between 9 and 15 dB, the efficiency is 2.4 bit/s/Hz, etc.

| Modulation | MCS efficiency | SINR |
|---|---|---|
| QPSK | 1.18 | 3 |
| 16 QAM | 2.40 | 9 |
| 64 QAM | 3.90 | 15 |
| 64 QAM | 5.55 | 20 |

Table 3: LTE Example Showing the Relationship between Modulation Scheme, MCS Efficiency (bit/s/Hz) and SINR (dB)

The relationship between SINR versus spectral efficiency in Table 3 is taken from research paper [3], but it can also be obtained directly from vendors. Knowing the relationship between the signal modulation scheme, spectral efficiency, and SINR allows us to calculate the number of resources needed to support each service type listed in Table 1 and 2.. These "resources" are different for different technologies: LTE resources are Physical Resource Blocks (PRB); UMTS resources are HSPA orthogonal codes; etc. As spectral efficiency varies with SINR, so does the number of resources needed to support a certain service type in each SINR zone. For example, if SINR is high, a single PRB may be sufficient to support email but, if SINR is low, more than one PRB may be required.

#### 6.1.1 DATA CAPACITY SIZING EXAMPLE

For LTE capacity dimensioning, a downlink LTE SINR coverage map must be calculated. As sector overlap affects SINR, an assumption must be made about the number of sectors in the network. Let us assume that propagation analysis with 24 sectors has produced an SINR coverage map of the stadium bowl that can be split into four SINR ranges, as shown in Figure 13. Each SINR range has a specific modulation scheme with a specific spectral efficiency value, as seen in Table 3. The dependence of spectral efficiency on SINR is important because spectral efficiency ultimately determines the maximum achievable data rate (MADR) for each SINR range. A uniform distribution of spectators within the bowl is considered a reasonable assumption so, for example, as SINR Range 1 covers 30% of the seating bowl, 30% of the spectators are assumed to be in SINR Range 1.

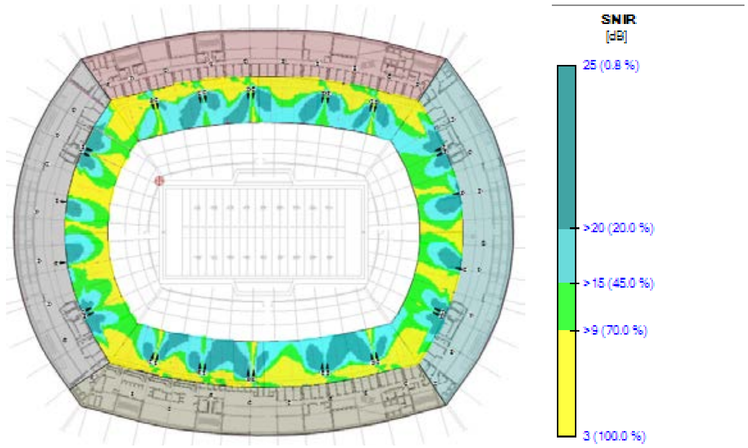



Figure 13: LTE PDSCH SINR Coverage Used for Data Sizing Example

As we see from Figure 13 (above), LTE SINR Range 1, (3 ↖ SINR↖ 9), covers 30% of the area. SINR Range 2 (9 ↖ SINR ↖ 15) covers 25% of the area. SINR Range 3 (15 ↖ SINR ↖ 20) covers 25% of the area, and SINR Range 4 (SINR → 20) covers 20% of the area. Assuming a uniform distribution of spectators, the percentage of LTE users within particular SINR range is the same as the SINR coverage percentage for that range. For the sake of brevity, repeating this exercise with HSPA SINR is omitted; calculating the HSPA SINR distribution yields 30% HSPA users in HSPA SINR Range 1, 25% in Range 2, 15% in Range 3, and 20% in Range 4.

Let us assume that there are 1,000 subscribers in a sector. According to subscriber breakdown for WSP A in Section 6.1, of those 1,000 subscribers 750 are LTE and 250 are HSPA. . We then calculate HSPA and LTE busy-hour traffic (in Erlangs) based on the number of subscribers in each SINR range, and busy-hour traffic per subscriber as given in Table 1. The results are shown in Table 4.

| Metrics | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| SNIR | 5 | 11 | 22 | 24 |
| Percentage coverage | 30.0% | 25.0% | 25.0% | 20.0% |
| Subscribers | 75 | 63 | 63 | 50 |
| Emails | 3.75 | 3.13 | 3.13 | 2.50 |
| Web Browsing | 7.50 | 6.25 | 6.25 | 5.00 |
| Video Conferencing | 0.75 | 0.63 | 0.63 | 0.50 |
| Data Download | 11.25 | 9.38 | 9.38 | 7.50 |
| Video Streaming | 0.08 | 0.06 | 0.06 | 0.05 |

Table 4a: HSPA Users and Busy-Hour Traffic (Erlangs) by Service Type and SINR Range

| Metrics | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| SNIR | 3 | 9 | 15 | 20 |
| Distribution | 30.0% | 25.0% | 25.0% | 20.0% |
| subscribers | 225 | 188 | 188 | 150 |
| emails | 11.3 | 9.4 | 9.4 | 7.5 |
| browsing | 22.5 | 18.8 | 18.8 | 15.0 |
| video conf | 1.1 | 0.9 | 0.9 | 0.8 |
| data download | 33.8 | 28.1 | 28.1 | 22.5 |
| video streaming | 0.2 | 0.2 | 0.2 | 0.2 |

Table 4b: LTE Users and Busy-Hour Traffic (Erlangs) by Service Type and SINR Range

The number of resources needed to support the service types across the ranges is calculated next. Table 5 shows the distribution of resources by SINR Range for HSPA and LTE networks for this example.

| NUMBER OF HSPA CODES PER CONNECTION | | | | |
|---|---|---|---|---|
| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
| Emails | 3 | 1 | 1 | 1 |
| Web Browsing | 6 | 3 | 1 | 1 |
| Video Conferencing | 19 | 8 | 1 | 1 |
| Data Download | 31 | 13 | 2 | 1 |
| Video Streaming | 63 | 25 | 4 | 2 |

Table 5a: HSPA Resources by Service type and by SINR Range

| NUMBER OF PRIMARY RESOURCE BLOCKS PER CONNECTION | | | | |
|---|---|---|---|---|
| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
| Emails | 1 | 1 | 1 | 1 |
| Web Browsing | 2 | 1 | 1 | 1 |
| Video Conferencing | 4 | 2 | 2 | 1 |
| Data Download | 6 | 3 | 2 | 2 |
| Video Streaming | 12 | 6 | 4 | 3 |

Table 5b: LTE Resources by Service type and by SINR Range

Based on Tables 4 and 5, and given the total number of HSPA and LTE resources in a sector, the blocking probability for each service type may be calculated. Blocking rate is defined as the percentage of attempted network connections that are denied due to insufficient network resources. The blocking rate formula for multiple services used for this the calculation is taken from the ITU-R recommendation [4]. The resultant blocking rates for HSPA and LTE technologies, by service type and SINR range, are as shown in Table 6.

| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Emails | 11.5% | 4.0% | 4.0% | 4.0% |
| Browsing | 21.8% | 11.5% | 4.0% | 4.0% |
| Video conferencing | 55.3% | 28.1% | 4.0% | 4.0% |
| Data Download | 74.2% | 41.9% | 7.8% | 4.0% |
| Video Streaming | 95.0% | 65.9% | 15.1% | 7.8% |

Table 6a: HSPA Blocking Rate By Service Type and SINR Range

| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Emails | 3.2% | 3.2% | 3.2% | 3.2% |
| Browsing | 6.4% | 3.2% | 3.2% | 3.2% |
| Video conf | 12.6% | 6.4% | 6.4% | 3.2% |
| Data Download | 18.5% | 9.5% | 6.4% | 6.4% |
| Video Streaming | 34.8% | 18.5% | 12.6% | 9.5% |

Table 6b: LTE Blocking Rate By Service Type and SINR Range

Table 6 is the key for sizing the network because it shows the blocking rate for each service type throughout the seating area (SINR Ranges 1 to 4). From Table 6b we see that 9.5% of the attempts to stream video using LTE from the area where LTE SINR exceeds 20 dB (range 4) are blocked due to insufficient LTE resources. Similarly, 7.8% attempts to stream video from Range 4 areas are blocked due to insufficient HSPA resources. . While blocking rates for both technologies are similar in the areas where SINR is good (Range 3 and 4), in the areas where SINR is low (Range 1 and 2) LTE has consistently lower blocking rates, even though it has 750 subscribers and occupies 10 MHz of spectrum compared to 250 HSPA subscribers served by 4 HSPA channels (20 MHz).

If the calculated blocking rates shown in Table 6 are not acceptable, the number of sectors should be increased (to reduce the number of subscribers per sector), the SINR map recalculated, and the capacity calculations repeated. This is an iterative process that is continued until acceptable blocking rates are found.

Carried busy-hour traffic is calculated based on offered traffic (Table 4) and blocking rate (Table 6) for each service type. Results are shown in Table 7.

| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Emails | 3.32 | 3.00 | 3.00 | 2.40 |
| Browsing | 5.86 | 5.53 | 6.00 | 4.80 |
| Video conf | 0.34 | 0.45 | 0.60 | 0.48 |
| Data Download | 2.90 | 5.45 | 8.64 | 7.20 |
| Video Streaming | 0.00 | 0.02 | 0.05 | 0.05 |

Table 7a: Carried HSPA Busy-Hour Traffic by Service Type and SINR Range

| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Emails | 10.9 | 9.1 | 9.1 | 7.3 |
| Browsing | 21.1 | 18.1 | 18.1 | 14.5 |
| Video conf | 1.0 | 0.9 | 0.9 | 0.7 |
| Data Download | 27.5 | 25.4 | 26.3 | 21.1 |
| Video Streaming | 0.1 | 0.2 | 0.2 | 0.1 |

Table 7b: Carried LTE Busy-Hour Traffic by Service Type and SINR Range

To determine offered busy-hour traffic, the entries in Tables 4a and 4b are summed. Offered traffic is 77.8 Erlangs for HSPA and 229.5 Erlangs for LTE. To determine carried busy-hour traffic, the entries in Tables 7a and 7b are summed. Carried HSPA traffic is 60.1 Erlangs, and carried LTE traffic is 212.5 Erlangs. The composite call blocking rate (BR) is calculated as:

Composite blocking rate is 22.7% for HSPA, and 7.4 % for LTE. Clearly, LTE technology has better call blocking statistics than HSPA, even though it supports 3 times the number of subscribers than HSPA, in only half of the spectrum.

Duty cycle is defined as the ratio of carried traffic to theoretical maximum traffic when all resources are used for the full hour. It is 20% for HSPA and 42.5% for LTE. HSPA data usage is 13.1 Gigabytes in a busy hour, while LTE data usage is 51 Gigabytes. These values are for one sector, and since WSP A has 24 sectors, the traffic and data usage numbers need to be multiplied by 24 to get the total WSP A traffic for the whole stadium. Total traffic at the stadium for WSP A is 314.4 GB for HSPA and 1,224 GB for LTE.

Similar calculations can be done for WSP B and WSP C. Assuming that WSP A capacity statistics are acceptable, we can use this information to calculate the required number of sectors for WSP B and WSP C. The WSP A capacity calculation showed that 250 HSPA subscribers can be supported with 4 HSPA channels, which amounts to approximately 63 HSPA subscribers per channel. Also, 750 LTE subscribers can be supported in 10 MHz LTE-FDD channel, which equals to 375 subscribers in a 5 MHz LTE FDD channel, which is used by WSP C. The same number of LTE subscribers (375) can be supported in 10 MHz LTE-TDD channel used by WSP B, if the channel is configured symmetrically in uplink and downlink. Taking into account subscriber breakdown by technology as per Section 6.1, we come up with the following sector configuration at the stadium::

- WSP A: 24 UMTS, 24 LTE
- WSP B: 24 UMTS, 8 LTE
- WSP C: 24 UMTS, 24 LTE

### 6.1.2 VOICE CAPACITY SIZING

Voice capacity is sized through the WCDMA portion of the UMTS signal.

As we did for the data capacity calculations, we first determine Eb/N0 coverage (Eb/N0 is the ratio of energy per bit to noise power spectral density), separate the coverage into four different Eb/N0 ranges, and identify service types that can be used in each range. The Eb/N0 map for one stadium level is shown in Figure 14.

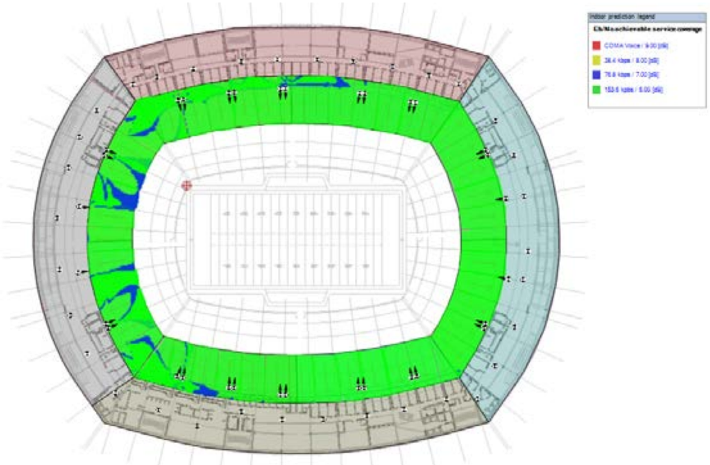


Figure 14: Eb/N0 Coverage Map Used for Voice Sizing Example

Assuming a uniform subscriber distribution, the percentage of subscribers connecting to the service in a particular Eb/N0 range is the same as the percentage of coverage for that range.  The resulting user distribution by Eb/N0 range and R99 traffic in each range (in Erlangs) is shown in Table 8.

| Metrics | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Eb/No | 9 | 8 | 7 | 6 |
| Distribution | 1.0% | 1.0% | 9.0% | 90.0% |
| Users | 10 | 10 | 90 | 900 |
| Voice | 0.3 | 0.3 | 3.0 | 29.7 |
| Emails | - | 0.0 | 0.3 | 2.7 |
| Browsing | - | - | 0.3 | 2.7 |
| Data download | - | - | - | 2.7 |

Table 8:    R99 Busy-Hour Data Traffic (in Erlangs), by Service Type, in each Eb/N0 Range

Only OVSF codes with spreading factor up to SF128 are used for the service types shown in Table 8.  The required number of OVSF codes per service type and Eb/N0 range is as shown in Table 9.

| Service type | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Voice | 1 | 1 | 1 | 1 |
| Emails | - | 4 | 4 | 4 |
| Browsing | - | - | 8 | 8 |
| Data download | - | - | - | 16 |

Table 9: OVSF Codes, by Service Type, in each Eb/N0 Range

As was the case with HSPA and LTE technologies, call blocking rates are calculated as per [4] and are as shown in Table 10.

| Service Type | Range 1 | Range 2 | Range 3 | Range 4 |
|---|---|---|---|---|
| Voice | 1.6% | 1.6% | 1.6% | 1.6% |
| Emails | - | 6.5% | 6.5% | 6.5% |
| Browsing | - | - | 13.4% | 13.4% |
| Data download | - | - | - | 28.0% |

Table 10: R99 Blocking Rates, by Service Type, in each Eb/N0 Range

For a sector with 1,000 subscribers, the R99 voice blocking rate is 1.6% throughout the bowl seating area. Most macro UMTS networks use a busy-hour call blocking rate target between 1% and 2%. Other R99 service types have higher blocking rates, but this is not of much concern because they are supported with better rates in 3G and 4G networks. The conclusion is that the call blocking rate for R99 traffic is acceptable and therefore the 24 sector configuration is sufficient to support voice traffic for 3G and 4G subscribers for WSP A.

### 6.2 RF COVERAGE DESIGN

For the RF signal to be dominant at the venue, it has to be slightly stronger than the residual signal coming from surrounding macro cell sites. As most stadiums are open-air, the residual macro signal itself is usually fairly strong; in our example we assume that macro LTE Reference Signal receive power (RSRP) is between -80 and -85 dBm throughout the seating area. Deploying highly directional high-gain antennas we can get RSRP of -75 dBm (or higher) over 90% of the area, as shown in Figure 15. .

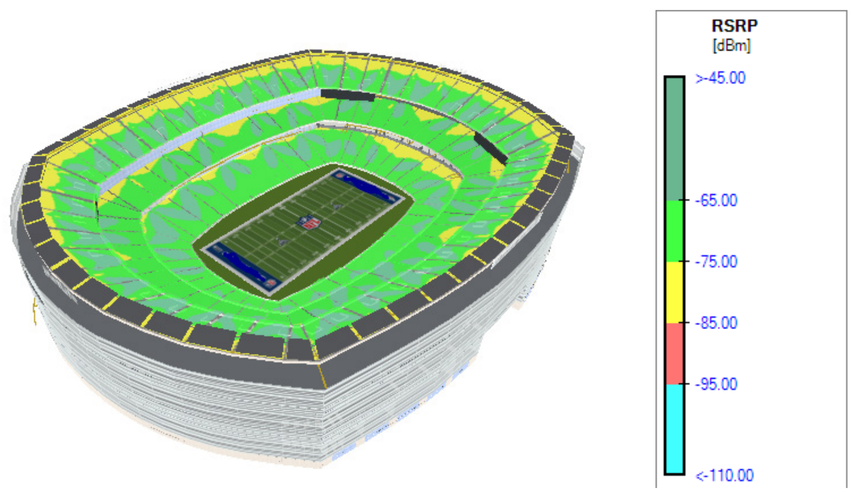



Figure 15: LTE RSRP Coverage at the Stadium

The modulation scheme used in LTE networks is directly related to PDSCH SINR, as high SINR makes possible high-order modulation such as 64-QAM. High-order modulation has high spectral efficiency, which allows for a high maximum achievable data rate (MADR) in the network. However, a large number of sectors also implies numerous sector overlaps which may cause interference and lower SINR. An example of a 24-sector LTE PDSCH SINR plot is shown in Figure 16.

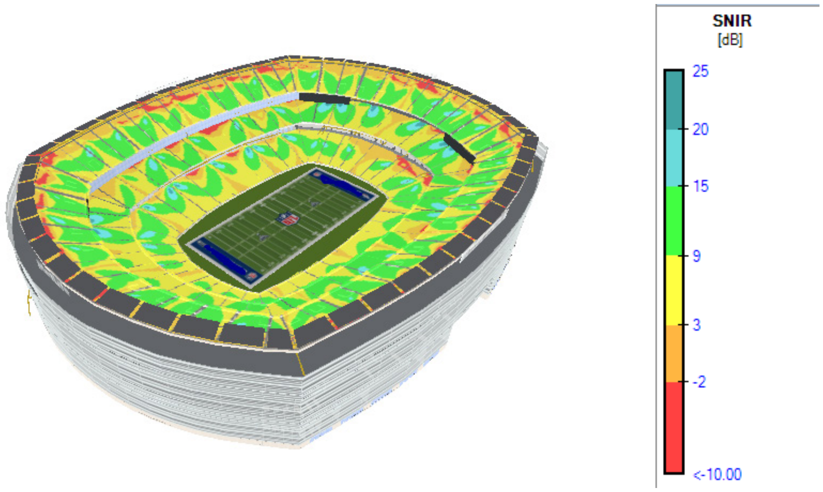



Figure 16: LTE PDSCH SINR Coverage at the Stadium

Based on the SINR coverage distribution, the downlink SISO MADR distribution across the stadium is then calculated as shown in Figure 17.

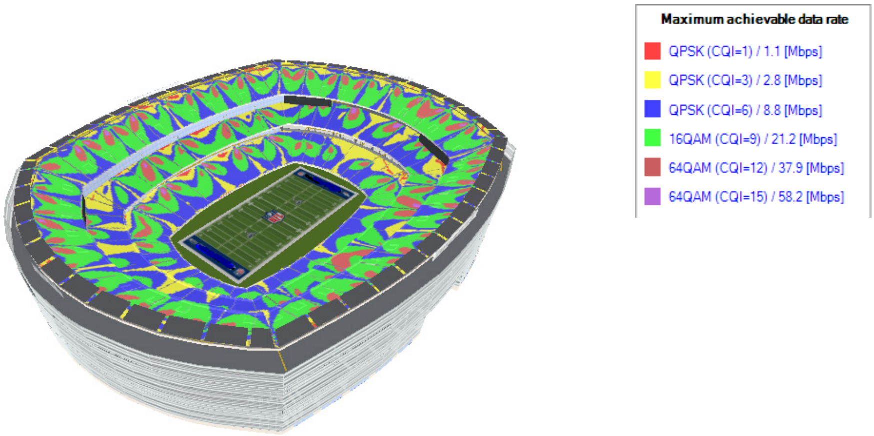



Figure 17: Downlink LTE MADR SISO Coverage at the Stadium

## 07. CONCLUSION

A neutral-host DAS solution is cost-effective for stadium networks in which multiple commercial and non-commercial networks must share infrastructure. Stadium networks are characterized by a very high density of users who need many sectors to satisfy their data needs. The high sectorization requirement is addressed by using highly directional DAS antennas which provide good spatial signal isolation. This also helps to control sector overlap and minimizes inter-sector interference.

The RF propagation environment differs vastly within the stadium, from pure LOS in the seating area, to LOS with a lot of reflections in retail areas underneath the bowl, to NLOS in locker rooms and conference rooms. To properly model the coverage, 3D modeling of the venue is essential. Most stadiums have open-air seating areas and therefore many have significant residual macro coverage in those areas. As the stadium network signal must be dominant everywhere inside the venue, it is essential to perform an RF survey to determine the residual signal strength prior to designing the DAS. Since spectators tend to spend time outside the venue before and after events, the design area should be extended to parking lots, side streets, and nearby bus and train stations.

Finally, neutral-host DAS networks with high-power amplifiers are susceptible to PIM generation, and PIM can severely impact the stadium network. LTE is particularly sensitive to PIM because it has low thermal noise power ( 121 dBm). Care must be taken at the design stage to avoid PIM generation by using equipment with a PIM rating of 162 dBc at 2x35 dBm. Silver-plated 7/16 DIN connectors should be used instead of N type connectors, as they have lower PIM rating. Also, antennas must not be placed near metallic structures because this tends to generate PIM as well.

### REFERENCES

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[2] Rogers Canada, PIM webinar

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[4] "Methodology for calculation of spectrum requirements for the terrestrial component of International Mobile Telecommunications", ITU-R M.1768-1, 2013-April
http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1768-1-201304-I!!PDF-E.pdf

## About iBwave

iBwave develops solutions to help wireless operators, system integrators and equipment manufacturers, essentially anyone who has a stake in the network, bring strong, reliable voice and data wireless communications indoors, profitably. Our customers are trying to bring the full value of voice and data networks indoors, for revenue generation and a satisfied subscriber base. Our software and professional services are used by nearly 700 global leading telecom operators, system integrators and equipment manufacturers in 83 countries worldwide. We help customers realize the full value of wireless voice and data networks, increasing competitiveness by improving the user experience, reducing churn and generating revenue through data applications to maintain ARPU. Our in-building design solutions optimize capital expenditure and let the network live up to its full potential. Our team is made up of seasoned radiofrequency engineers, business visionaries and technology gurus, plus a host of service professionals to guide and support you. Our leaders are in-building wireless technology veterans, whose vision is what drives the company to remain at the cutting edge in the field.