WHITE PAPER

BUSINESS CAMPUS: CONNECTING THE CORPORATE HQ

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01. INTRODUCTION

Office buildings are very diverse venues. These buildings vary in layout, size, and number of floors. Office buildings are often grouped together in a business campus. A typical business campus has a cluster of multi-level office buildings located off public streets. Very often a business campus has a single tenant that uses the campus as its corporate headquarters. An example of a business campus with two buildings is shown in Figure 1.

Figure 1: A major business campus with two office buildings

Business campuses that have multiple tenants are less common. In a multi-tenant campus, the in-building network is most often built piecewise for each tenant or building instead of all at once across the whole campus. This is not a preferred way to deploy a network because it is time-consuming and therefore more costly.

02. PROBLEM

In our specific paper, the business campus consists of two buildings. The larger building has an 80 meter by 20 meter rectangular cross section and ten floors. The smaller building has a 60 meter by 17 meter rectangular cross section and six floors. Each floor is 3 meters high. The buildings are 30 meters apart and directly across from each other. A three-dimensional representation of the venue is shown in Figure 2.

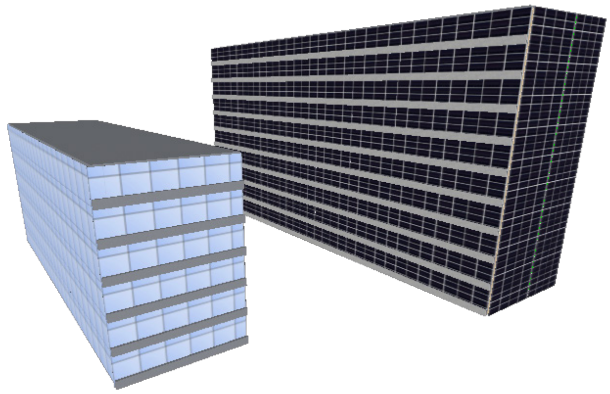

Figure 2: Three-Dimensional Representation of the White Paper Business Campus

The two buildings have a single tenant who requires good voice and data coverage throughout both buildings. As the company has adopted a "bring your own device to work" policy, the employees use their own smart phones for business, for which they are reimbursed, monthly, by the company. In order to provide good coverage for everybody, all major wireless service providers (WSP) must be included in the network.

03. DESIGN REQUIREMENTS

Specific design requirements for the venue are as follows:

3.1 RF Coverage

- RF Coverage should be provided for the following technologies:
  - UMTS
  - LTE
  - Trunked Radio (Public Safety)
- The coverage should include stairs and four elevators ("cars") in two elevator shafts.
- In-Building Wireless (IBW) target signal level should be 5 to 7 dB greater than the residual macro signal for all WSPs; this is to ensure that the IBW predominates throughout both buildings.
- It is preferable to measure residual macro coverage on all floors. However, if it is not feasible to do a detailed RF survey on all floors, the coverage may be approximated by adding 1 to 2 dB per floor [1]. This approximation applies only to floors that are lower than the height of neighboring macro sites. For floors above the height of neighboring macro sites, residual macro coverage does not significantly increase with floor height.
- Minimum signal strength is UMTS CPICH = -85 dBm, LTE RSRP = -95 dBm and Trunked Radio Rx = -95 dBm, and may be adjusted depending on the residual macro coverage .

3.2 Handoff Management

- Establish a clear handoff area between the macro network and the in building network in the areas where most of the traffic occurs (entrance lobby, parking area entrance, etc.).
- Once a user hands off from the macro network, he should remain on the in-building network throughout the duration of his stay in the building.

- The number of handoffs from one in-building sector to another should be minimized. If sectors are designed horizontally, the only areas where a handoff can occur are in a stairwell area or inside an elevator. Handoffs in stairwell areas are allowed because the users are moving at pedestrian speed, thus allowing plenty of time for a handoff to complete. Allowing handoffs to occur in a moving elevator is undesirable because elevators generally move too fast for handoffs to complete. Figure 3 shows a cross section of the taller building showing the two elevator shafts, the directional antennas (red triangles), and three in-building sectors, each represented by a different color.

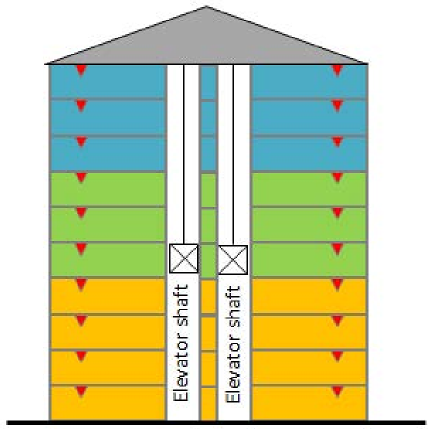

Figure 3: Cross Section of the Taller Building with Two Elevator Shafts

- Each elevator shaft holds two elevator cars (marked with an "X"). Only one elevator car per shaft is visible in Figure 3 because the elevators are side by side in the elevator shaft. The slim area between the shafts is the elevator bank area. The signal at elevator banks is not strong enough to penetrate into the shafts, and that lack of coverage is represented by the white background color in the shafts. The problem of providing coverage in elevators is discussed further in section 5.2.

3.3 Interference Management

- To minimize interference between the macro and in-building network, many WSPs mandate that IBW signal level must drop to a specified value at a specified distance outside of the building. This is called 'signal leakage'. An example of signal leakage outside a building is shown in Figure 4.

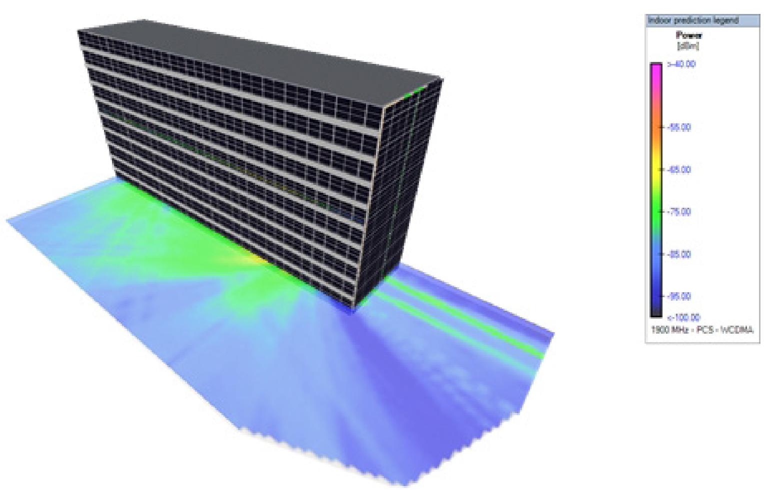

Figure 4: An Example of Signal Leakage from Antennas on the Ground Floor

- Many office buildings have large panoramic windows that have low (less than 5 dB) penetration loss, making it a challenge to meet the above requirement.
- In-building signal containment is especially important in a campus environment because buildings may be close to each other. Overlapping coverage from one building to another may cause excessive interference, lower capacity, and reduced data rate.
- For this particular project, UMTS CPICH at a distance of 30 meters from the exterior of each building must be -90 dBm or less, LTE RSRP must be -100 dBm or less, and Trunked Radio Rx must be -100 dBm or less.

In following sections we discuss how to design an IBW network to meet the common requirements. We also identify some common design mistakes.

04. SOLUTION

As neutral host small cells are not commercially viable yet, the best solution is a Distributed Antenna System (DAS). In the shorter building, the DAS is fed by one trunked radio sector, one UMTS sector, and two LTE sectors. The taller building has one trunked radio sector, two UMTS sectors, and three LTE sectors. Details of capacity calculations are omitted for the sake of brevity.

Public safety (PS) has additional technological, regulatory and jurisdictional requirements summarized in [2]. PS and WSPs may be deployed in a converged DAS, or two separate DAS may be built, one for PS 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.

05. BEST PRACTICES

5.1 Interference Control

In-building DAS antennas are most commonly omnidirectional antennas. A very popular choice is the Andrew Cell-Max™ O-25 which has 0.85 dBd gain and a V plane beamwidth of 40 degrees. As with all omnidirectional antennas, H-plane beamwidth is 360 degrees and front-to-back ratio is 0 dB. The use of this antenna produces the RF coverage shown in Figure 5.

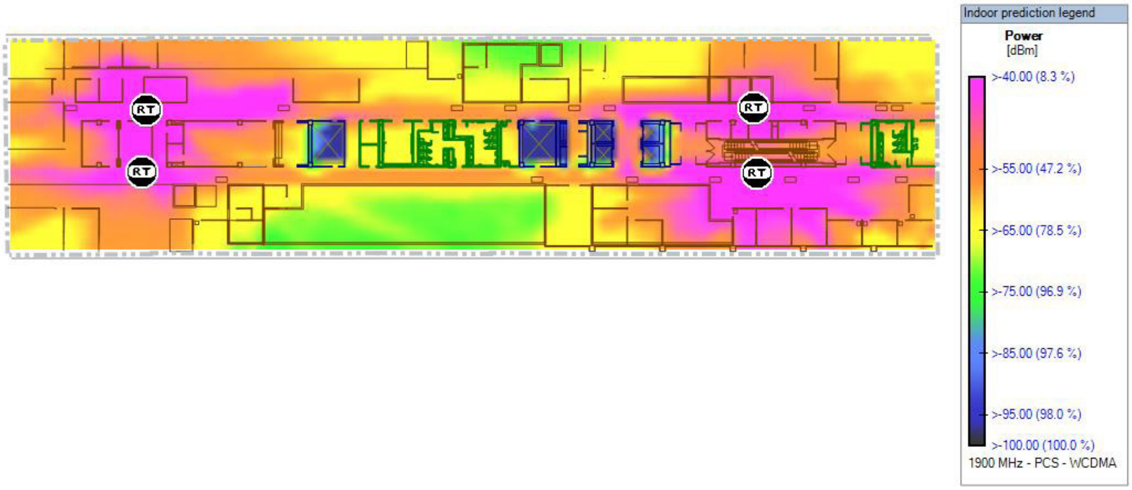

Figure 5: In-Building RF Coverage Using Omnidirectional Small Cells

Signal level is greater than -85 dBm over 97.6% of the floor plan. This coverage may seem acceptable at first. However, the RF coverage requirement also includes the signal leakage outside the buildings. Let us examine the RF leakage when omnidirectional antennas are used (Figure 6). The ground-floor antenna locations are indicated by the red arrows.

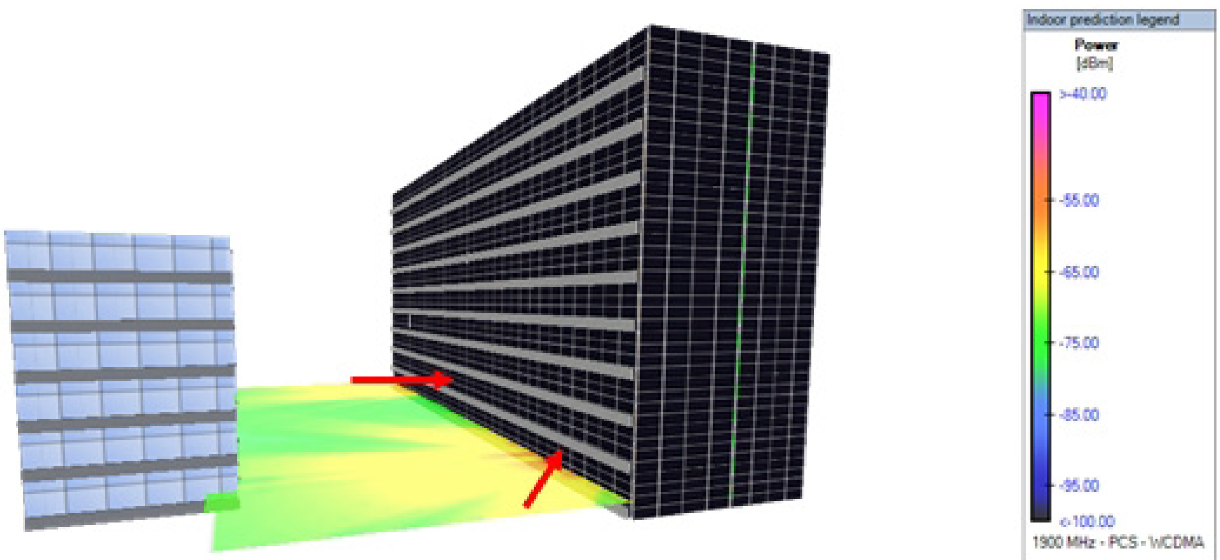

Figure 6: In-Building RF Leakage from Two Ground-Floor Antennas (Red Arrows)

The RF signal is not well contained inside the building; the UMTS signal level just outside the smaller building is around -75 dBm. As the two buildings are 30 meters apart, it is clear that the requirement for the leaked signal to be limited to -90 dBm is not satisfied.

The solution is to use directional antennas. A very popular choice is the V polarized Andrew Cell-Max™ D-25 directional antenna that has a 4.85 dBd gain, H plane beamwidth of 70 dB, V plane beamwidth of 60 dB, and front-to-back ratio of 20 dB. This antenna can be mounted vertically against a wall or column. Figure 7 shows the resultant

RF coverage, with an arrow pointing in the direction of the main lobe of each antenna.

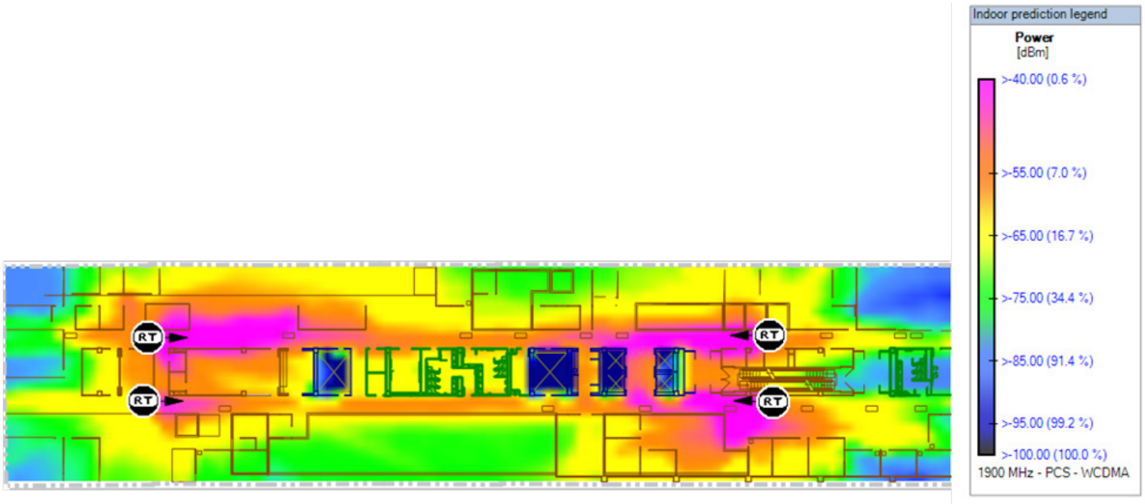

Figure 7: RF Coverage using Andrew Cell-Max™ D-25 Directional Antennas

Using directional antennas has reduced the RF coverage to 91.4%. However, coverage at the edges is also reduced, which helps suppress RF leakage. Most of the energy is directed toward the middle, the direction in which the antennas are aimed. Good front-to-back ratio ensures that energy coming from side lobes is low, which further reduces leakage.

Figure 8 shows a three-dimensional view of coverage between the buildings.

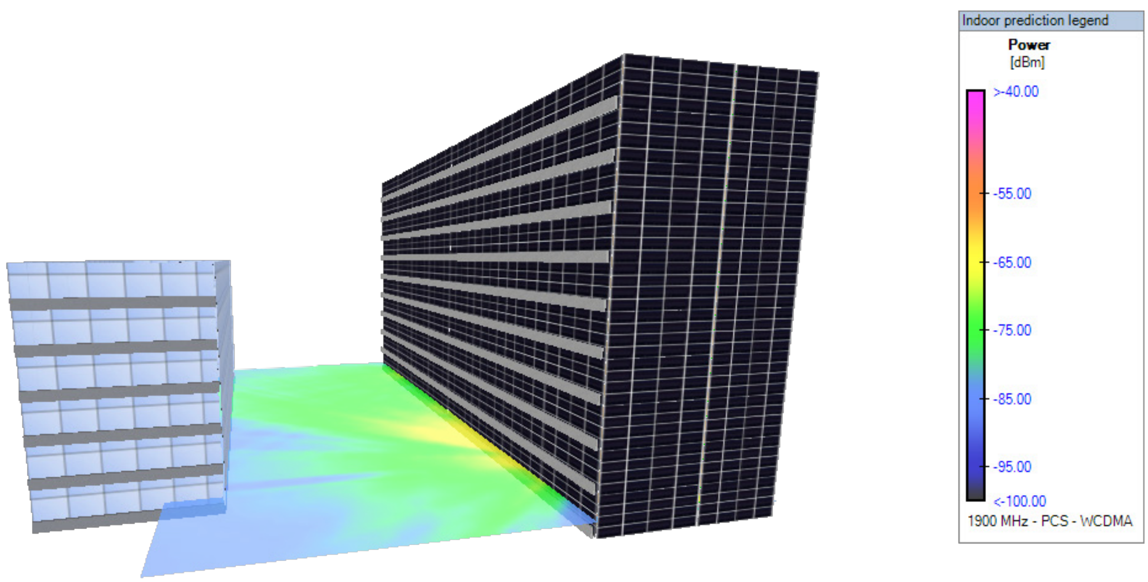

Figure 8: In-Building RF Coverage Leakage with Directional Antennas

The leaked RF coverage is 10 to 15 dB lower than with the omnidirectional antennas. This is a significant reduction and shows that directional antennas can help with interference control.

5.2 Elevator Coverage

Another important aspect of the design is the provision of coverage inside the elevators. As can be seen from the in-building RF coverage in Figure 5 and Figure 7, there is no RF coverage in the elevator shafts due to the high penetration loss of the elevator doors. A much simplified vertical cross section of the building showing a three-sector in-building RF coverage with two elevator shafts with no coverage is shown in Figure 3.

The simplest solution to provide the required coverage may seem to be to simply add omnidirectional antennas on each floor at the elevator banks. Doing so would extend each sector's coverage into the shaft as shown in Figure 9 in which omnidirectional antennas are represented with red dots. However, applying this solution would increase the risk of dropped calls in moving elevators. A handoff takes 2 to 3 seconds to complete, and User Equipment (UE) that goes from sector 1 (lower floors) straight to sector 3 (upper floors) would not have enough time to execute the handoff from sector 1 (yellow) to sector 2 (green) and then to sector 3 (blue); calls would be dropped.

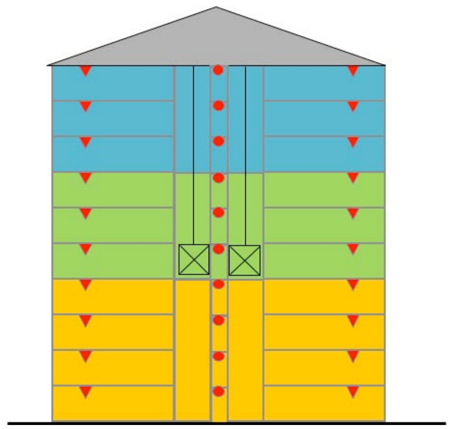

Figure 9: Elevator Coverage Using Omnidirectional Antennas at Elevator Banks

An alternative solution is to place RF equipment inside the elevators and/or the elevator shafts. A clear advantage of this approach is that the coverage does not rely on signal penetration through the metal doors. A disadvantage is that some municipalities in North America do not allow any electronic equipment inside elevator shafts due to the fire hazard. There are a few types of coverage solution with electronics inside the shaft. One, as shown in Figure 10, is to place an indoor antenna inside the elevator, connected to a DAS by means of a cable. Here, the handoff can occur only when the elevator is stopped and passengers are entering or leaving it, greatly reducing the possibility of a dropped call. However, the antenna needs to be connected to a DAS remote unit via a cable which makes this type of solution impractical in buildings with many floors.

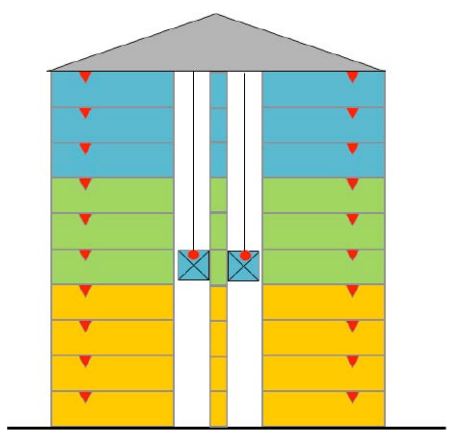

Figure 10: Elevator Coverage Solution: Wired Antenna Inside Each Elevator

Another solution, shown in Figure 11, is to put a directional DAS antenna at the top of the elevator shaft, pointing down the shaft. A donor directional antenna is located on the top of each elevator, pointed upward at the DAS antenna. The donor antenna is connected via a jumper cable to an omnidirectional serving antenna located inside the elevator. The antenna pair used at each elevator is a purely passive repeater system.

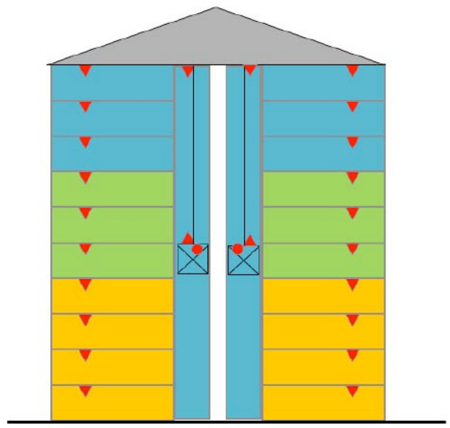

Figure 11: Elevator Coverage Solution: Passive Repeater at Each Elevator

If the DAS antenna has a CPICH EIRP of 20 dBm, and if the target signal inside each elevator is -85 dBm one meter away from the serving antenna, the maximum path loss is 20+85=105 dB. Typical antenna gain is 7 dBi for directional antennas and 3 dBi for omnidirectional, while 1 dB loss is typical for a 1 meter RF jumper cable. It is of interest to calculate the maximum distance between antenna on the top of the shaft and the elevator. Some simple free space path loss calculations at 2.1 GHz, also taking into account the 8 dB gain due to the waveguide effect inside the shaft [3], show the maximum distance to be approximately 115 meters.

If the shaft is longer than 115 meters, another DAS antenna may be mounted at the bottom of the shaft, pointing upwards. This antenna sends a signal that is captured by another directional donor antenna located at the bottom of the elevator, pointing down the shaft. This donor antenna at the bottom of each elevator is connected to the same serving antenna inside the elevator. To ensure a proper handoff, RF coverage overlap between the two DAS antennas in the shaft must be accounted for. Typically, 10-15% of the antenna range is given to overlap, so with 15% coverage overlap the maximum distance between the top and bottom DAS antennas is (2 x 115) - (2 x 15) = 200 meters.

Another possible solution is to install radiating cable along the length of the shaft. This approach provides more uniform coverage than using a DAS directional antenna. Depending on shaft length and cable attenuation per meter, the signal may be strong enough to penetrate the elevator, making the passive repeater unnecessary. This solution is illustrated in Figure 12, where the radiating cable is shown as a solid black line between the elevator and the elevator bank.

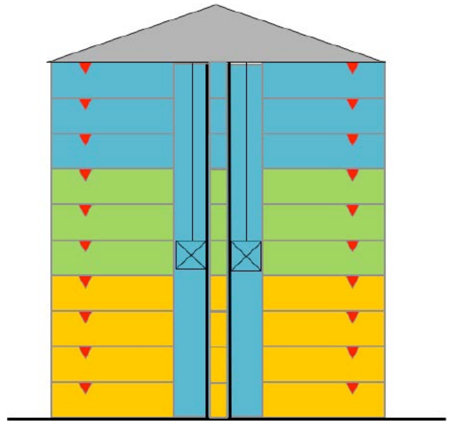

Figure 12: Elevator Coverage Solution: Radiating Cable in Shaft

06. DETAILED RF COVERAGE DESIGN

To properly represent RF coverage at the venue, the coverage leakage from both buildings into the area between the buildings must be included in the analysis of the ground-floor level coverage. An example of ground-floor level LTE RSRP coverage is shown in Figure 13 and Figure 14.

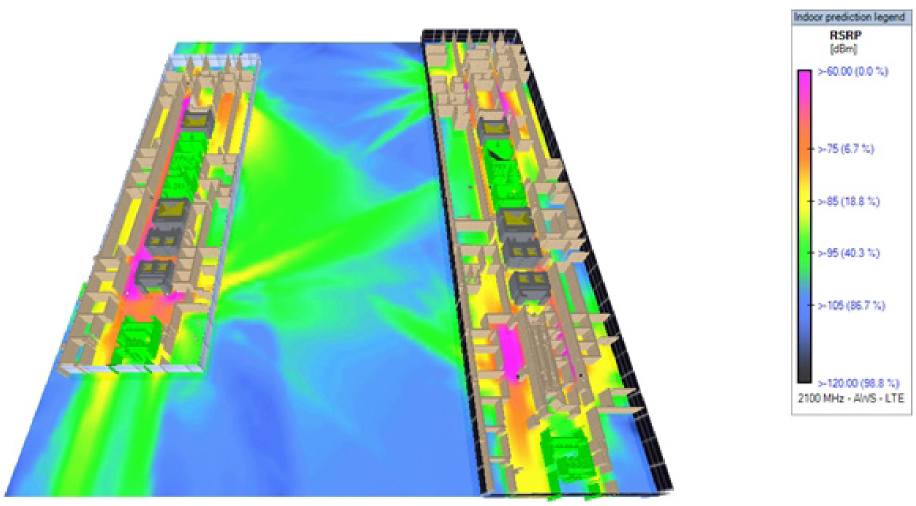

Figure 13: LTE RSRP Coverage Inside and Between the Buildings

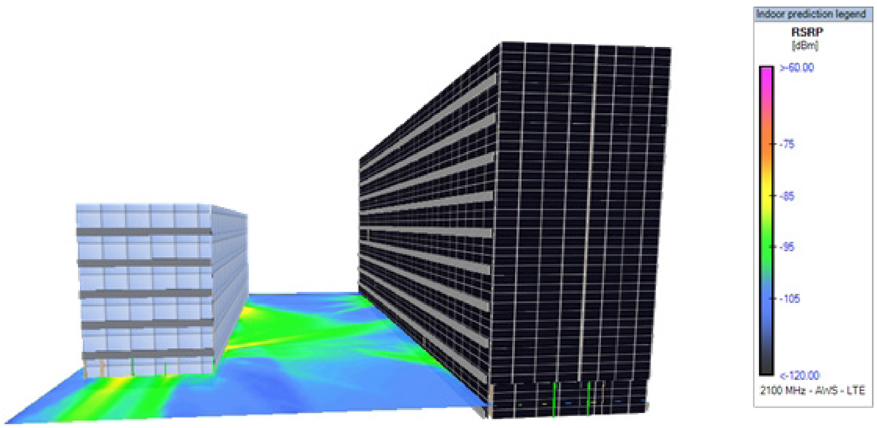

Figure 14: Full 3D Representation of LTE RSRP Coverage Between the Buildings

For UMTS, pilot signal (CPICH) coverage and Ec/Io coverage are of interest. As the signal from the same sector is multicast on the same floor, Ec/Io is very uniform as there is no inter-sector interference. The signal from the other building does interfere because it belongs to a different sector. The result is shown in Figure 15.

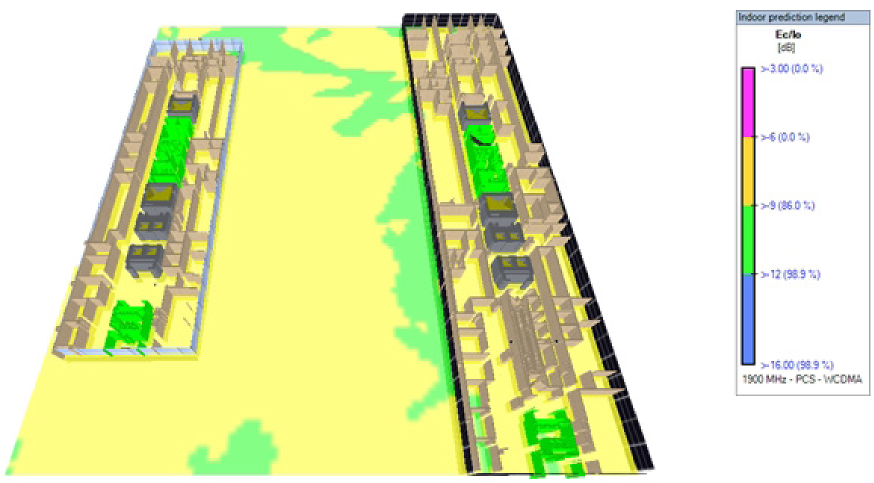

Figure 15: UMTS Ec/Io Coverage Inside and Between the Buildings

SINR and Maximum Achievable Data Rate (MADR) coverage are also of interest. As is the case with UMTS Ec/Io , antenna simulcast eliminates interference between antennas on the same floor, which causes high SINR. However, the signal from the other building does interfere, and causes poor SINR between the buildings as shown in Figure 16.

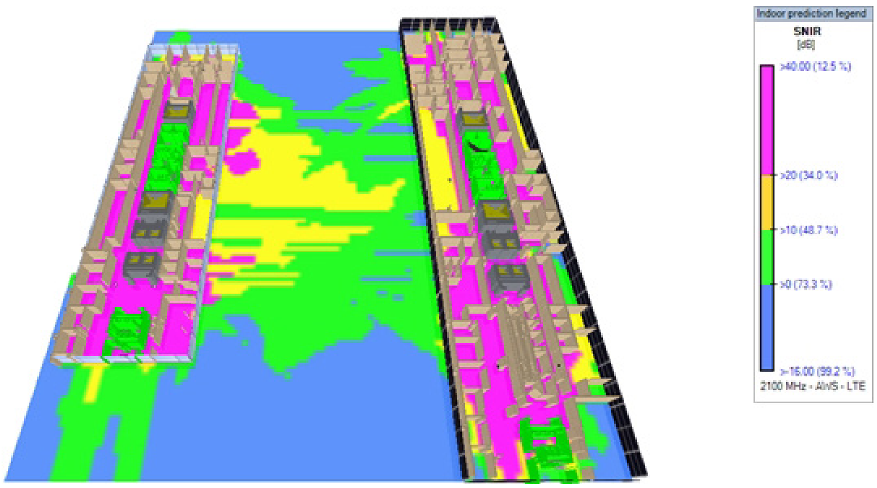

Figure 16: LTE SINR Coverage Inside and Between the Buildings

Good SINR coverage also means that MADR is very high inside buildings. MADR for a 10 MHz LTE SISO is shown in Figure 17.

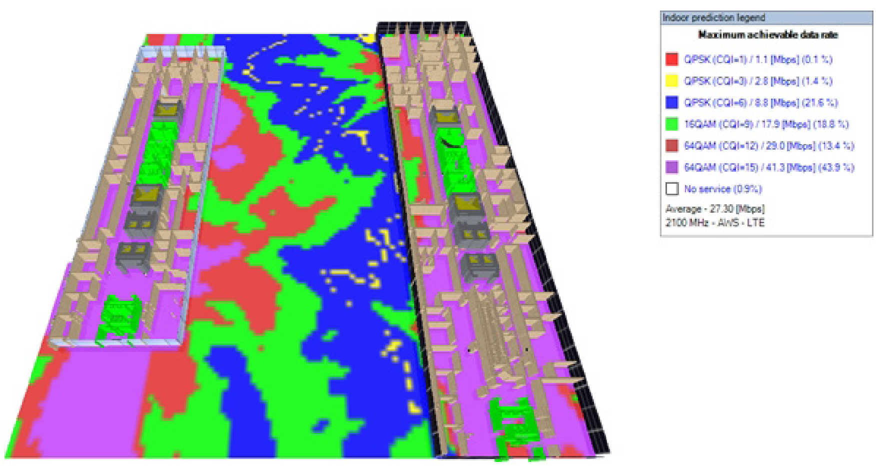

Figure 17: LTE MADR Coverage Inside and Between the Buildings

07. CONCLUSION

In-building coverage is required in a business campus with a single tenant who occupies two buildings. The tenant has adopted a "bring your own device to work" policy, so all major WSPs need to be included in the system. First responders (public safety) also need to be included. Based on the requirements that multiple technologies and multiple frequency bands need to be included, a neutral-host DAS is chosen. To properly model the coverage, three-dimensional modeling of the venue is essential. Due to the close proximity of the buildings, the overlapping in-building coverage from one building to the other must be taken into account. During the design process, care must be taken to contain the RF signal within the buildings as much as possible. This is most efficiently done by choosing directional antennas rather than omnidirectional. Coverage often needs to be provided in stairwells and elevators. Elevators are especially challenging in municipalities that prohibit electronic equipment inside elevator shafts due to the fire hazard. Where such equipment is permitted, the most effective solution is radiating cable or a combination of a DAS antenna in each shaft and a passive repeater in each elevator.

REFERENCES

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