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Stadium Coverage Using Directional Antennas for High Density Access Points Based on Narrow HPBW

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ABSTRACT

The existence of a Wi-Fi network in the stadium is an important issue because of the many requests for communication access from spectators. Implementation of HD-AP Wi-Fi using directional antennas is one solution to avoid severe interference. This study simulates the coverage of the AP installed on the roof of the tribune station. The simulator is designed using HPBW Elevations 20^0, 40^0, and 60^0. Testing also considers the use of the appropriate transmit power, to obtain the appropriate HPBW combination to avoid interference. The analysis is carried out by comparing the reception of the strongest signal with a reception at the sector border. The results of the study show that Antenna directional with HPBW Elevation 40^0 is more effective in serving users in three service sectors.

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1. INTRODUCTION

The demand for the existence of telecommunications networks is growing not only in academic or office environments but also in other mass meeting point zones. Some big events like football matches can gather a lot of people. A stadium as a meeting point area with a large capacity must be able to provide a telecommunications network to serve the needs of many spectators who are immersed in an atmosphere of high euphoria. This euphoria is generally channeled through various smartphone applications that require telecommunications as a mandatory supporting infrastructure. The application of Wi-Fi in mass conditions in a stadium environment is an example of implementing a High-Density Access Point (HD-AP) [1,2]. This condition is a trade-off between spectral efficiency, interference, and network capacity [3]. Even in everyday life environments where several types of wireless technologies using the same channel at the same time cause severe interference [4,5]. In other words, implementing WiFi in HD-AP conditions can also cause serious problems when the same channel is reused [6].

A solution by limiting the number of users and transmission power with the constrained water filling problem (CWFP) method has been proposed [7]. Although this method can reduce interference, this solution is not effective in HD-AP conditions, where WiFi transmitters are placed relatively close to each other with a large number of users, such as in a campus environment [8,9]. The use of frequency hopping strategy has also been studied in wireless sensor networks with data rates of up to 98% [10]. This solution is also less effective when the reuse method applies non-overlapping channels [11]. Other literature states that choosing the right antenna radiation pattern can reduce the interference that occurs when many sites are close together [12,13,14]. Wi-Fi network construction must be initialized with a coverage-oriented design idea [15,16]. Meanwhile, in the 5GHz frequency band, a new method has been proposed by dynamically manipulating channel boundaries (channel bonding) [17]. Although AP can provide better throughput, this concept has a relatively high complication rate compared to the previous standard methods.

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2. RESEARCH METHOD

In this study, directional antennas with narrow elevation of Half Beam Width are used to transmit coverage of the stands with uniformly distributed delopments. Coverage is generated based on collaborative deployment of rooftop antennas based on non-overlapping channels in wifi technology. Some details of placement models, antenna HPBW and other methods will be explained in the next section.

2.1. Layout and Sampling

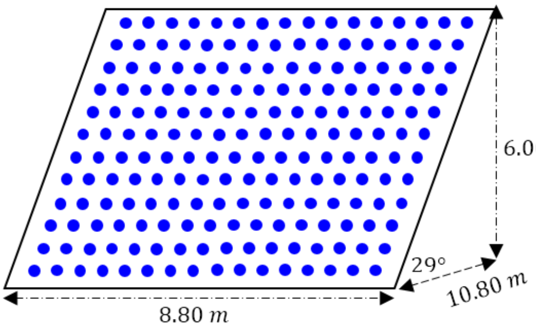

Figure 1. Simplified grandstand layout

The layout has a sloping floor defined by the width (*pm*) and the height of the stands (*tm*). If the layout is modeled in a horizontal position, then this square layout has a length (*pl*) of 8.80 m [18]. The height of this polygon (*tl*) can be calculated as follows:

$$tl = \sqrt{pm^2 + tm^2} \tag{1}$$

Sample points are equally spaced and numbered in the longitudinal direction (*sp*) to the next row (*st*). Based on this information, the number of samples that are elongated (*nosp*) and the number of samples that are lined up (*nost*) can be modeled in a square shape as shown in Figure 2.

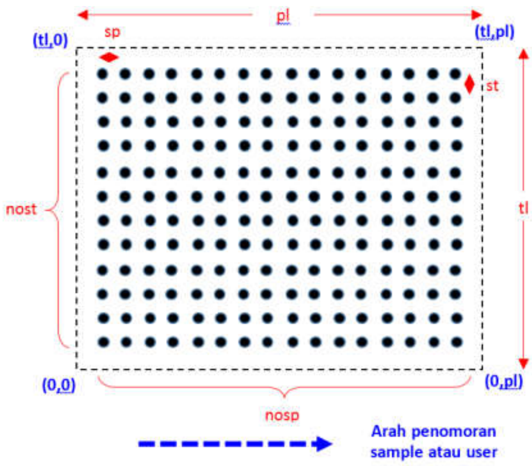

Figure 2. Parameters on Coordinate system

If the sample number is denoted by nos, then the x coordinates in the sample numbering starting from left to right can be arranged mathematically as follows:

a. The case in number **1** has the x coordinate: $\mathbf{1} \times sp$
b. The case in number **2** has the x coordinate: $\mathbf{2} \times sp$
c. The case in $\boldsymbol{nosp}$ numbering, have x coordinates: $\boldsymbol{nosp} \times sp$
d. The case in the numbering $\boldsymbol{nosp + a}$ have x coordinates: $\{\boldsymbol{rem(nosp, nosp) + a}\} \times sp$

So in $\boldsymbol{nos}$ numbering, each sample point will have an x coordinate with a mathematical equation:

$$x_s = \{\boldsymbol{rem(nos - 1, nosp) + 1}\} \times sp \tag{2}$$

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As for the y-coordinate in sample numbering starting from bottom to top, mathematical logic can also be arranged as follows:

a. The case number 1 has a y-coordinate: st
b. The case in number 2 has a y-coordinate: st
c. The case in $nosp$ numbering, have a y-coordinate: st
d. The case in $nosp + 1$ numbering, have a y-coordinate: $\mathbf{2} \times st$
e. The case in $2nosp + 1$ numbering, have a y-coordinate: $\mathbf{3} \times st$
f. The case in $a \times nosp + 1$ numbering, have a y-coordinate: $(\boldsymbol{a} + \mathbf{1}) \times st$
g. The case in $a \times nosp + b$ numbering, $b < nosp$, have a y-coordinate: $(\boldsymbol{a} + \mathbf{1}) \times st$

So in nos numbering, each sample point will have a y coordinate with a mathematical equation:

$$y = fix\left(\frac{\boldsymbol{nos} - \mathbf{1}}{nosp} + 1\right) \times st \tag{3}$$

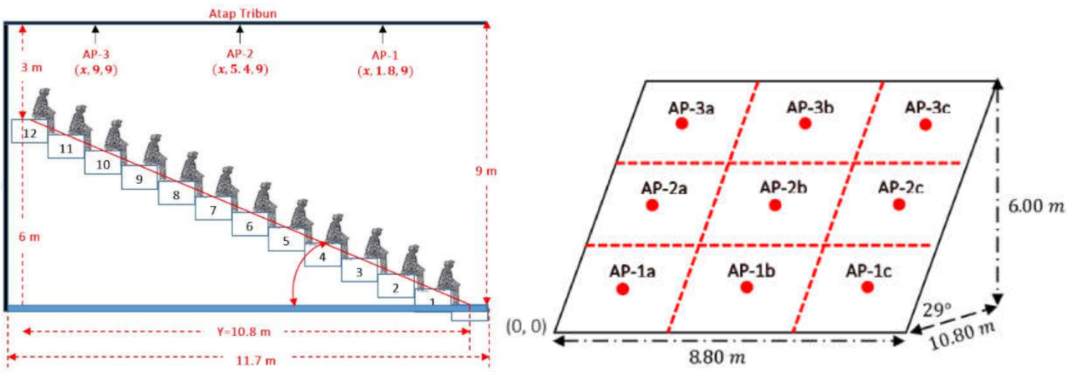
In determining the z-coordinate, it is necessary to look at the slope of the plane for each line. Therefore, the determination of this z value depends on the definition of the y coordinate, where y is the slanted side in the Pythagorean model. The value of the angle produced by the slope of the stands is:

$$\theta = \sin^{-1}\left(\frac{tm}{tl}\right) \tag{4}$$

Then based on the nos numbering, each sample point will have a z-coordinate with the following mathematical equation:

$$z = y \tan\theta \tag{5}$$

2.2. AP Deployment



(a) (b)

Figure 3. AP deployment model (a) side view (b) top view

The APs are evenly spaced on the given layout, positioned in the center of the area as shown in Figure 3b. The side view layout simulation is given in Figure 3a so that the AP position is located on the roof. The total AP used in the simulation is 9 pieces spread over a 3 × 3 dimension in the x-y plane. To make it easier to recognize the identity of these APs, they are named AP-1a to AP-3c. Visually, the y and z-coordinates can be calculated simply in Figure 3b by dividing each dimension equally. Meanwhile, the x-coordinate is calculated based on the information given in Figure 3a.

2.3. Antenna Radiation

Based on the scenario design, this study requires an antenna model with three radiation pattern characteristics, namely: HPBW-elevation 20^0, 40^0, and 60^0. If the parameter a indicates the gain ratio that must be provided by the lobe and the parameter b is used to determine the FNBW and HPBW of the desired lobe, and the parameter c is used to shift the lobe results both to the right and to the left, then the radiation pattern mathematical model that can be used in radiation pattern engineering is:

$$a \sin(b \times \theta \pm c) \tag{6}$$

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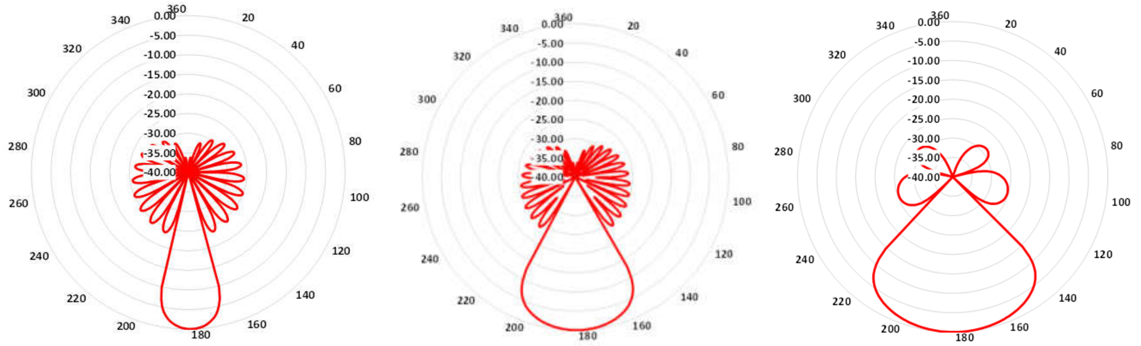
The implementation results in the process of determining HPBW 20^0 parameters, obtained values $a = 1$, $b = 6$ and $c = 90$, with FNBW results of 30^0 and the largest minor lobe of around 15^0. By calculating the area covered by the curve, a gain of $12.65\,dB$ is obtained. The following is a visualization of the antenna radiation pattern in Cartesian (see Figure 4.a).



(a) (b) (c)

Figure 4 Radiation pattern for HPBW elevation (a) 20^0, (b) 40^0 and (c) 60^0.

In the same way, the results of visualizing the radiation pattern of the HPBW antennas at elevations 40^0 and 60^0 are shown in Figures 4.b and Figure 4.c. While the comparison of the gain obtained on the radiation patterns of the three antennas is presented in Table 1.

Table 1. Characteristic of antenna radiation pattern

Parameter	**HPBW**		
	20^0	**40^0**	**60^0**
Gain Max	12.65 dBi	9.7 dBi	7.96 dBi
FNBW	30^0	60^0	90^0

Considering that the horizontally distributed radiation pattern is uniform for all azimuth directions, the gain experienced by the signal can be defined as:

$$g_i(d) = G_{max} + g_\alpha(d) \tag{7}$$

2.4. Received Singal Level

Calculation of signal reception begins with transmitting a certain amount of power from the AP antenna to the user's position, in this case, the sample position. The things that affect this reception include the gain of the antenna and the loss experienced by the signal along its path. The calculation of the loss experienced depends on the direction of the gain given by the AP antenna and the path distance. So the antenna gain elevation angle calculation model is:

$$\alpha = 180 + \theta = 180 + \tan^{-1}\left(\frac{|z_s - z_a|}{\sqrt{(x_s - x_a)^2 + (y_s - y_a)^2}}\right) \tag{8}$$

Pathloss can be calculated using *Free Space Loss* (FSL) formula, where the path length is:

$$r = \sqrt{(x_s - x_a)^2 + (y_s - y_a)^2 + (z_s - z_a)^2} \tag{9}$$

When the angle and length of the signal path have been determined, the signal power received by the user can be calculated by the following equation:

$$P_r(d) = P_t + G_{max} + g_i - FSL - otherloss \tag{10}$$

3. RESULT AND DISCUSSION

Here we analyze the stadium partially, namely the top stand that has the closest distance to the roof of the stadium. This section is a multiple of a row of stands consisting of 16 x 12 seats for spectators which are then used as coverage samples for analysis. AP layout and distribution details as shown in

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Figure 1-3. The analysis was carried out by installing a combination of antennas with different HPBW elevations (see **Figure 4**) on the roof of the stadium stands. Then the received signal strength will be measured based on the entire sequence of seats (see **Figure 2**).

3.1. Analysis of Transmitted Power

The HD-AP's power usage largely determines signal quality for each sector. The following is a visualization of power reception in the AP-1B sector (see Figure 5). The visualization uses 4 different colors for analysis, namely red-orange-yellow-green for the range -49dBm to 64dBm. If we want the power difference at the midpoint of reception with a minimum sector limit of 10.4dB, then the sector reference limit must be yellow with a value of 59.4 dBm. So that the coverage provided by AP-1B exceeds sector expectations both in width and length. This is possible because of the extent of HBPW used. Coverage with the same situation on AP-2B and AP-3B is shown in Figure 6.

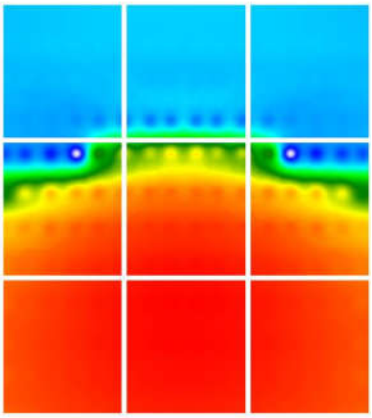
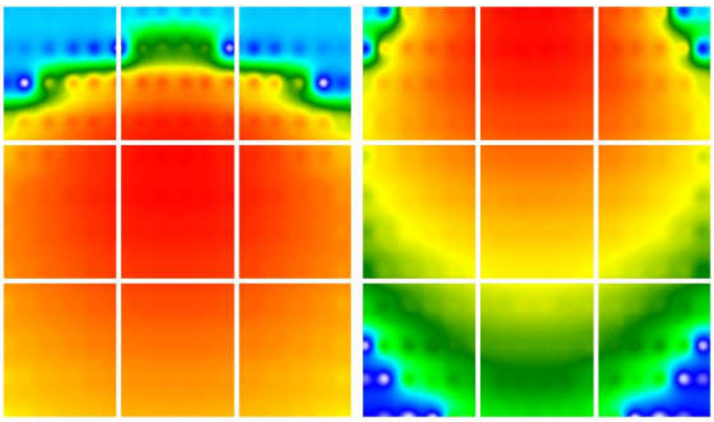


Figure 5. Coverage of AP-1B with transmitted power 10mWatt and HPBW 60^0.

In the AP-2B and AP-3B visualization, the dominance of coverage is still clearly visible in all sector coverage, especially in the AP-3B sector. If the power at the midpoint of the AP-2B sector is -46dBm, then it is expected that the power at the sector boundary is -58dBm or close to -61dBm shown in green. Likewise in the AP-3B sector, where the power at the midpoint is -43dB, it is expected that the power at the sector boundary is -55dB, which is shown in yellow. However, this 10mWatt power configuration can guarantee signal reception of at least -49 dBm.



(a) (b)

Figure 6. Coverage of (a) AP-2B and (b) AP-3B with transmitted power 10mWatt and HPBW 60^0.

In the same scenario for test-2, the transmit power is reduced to 5dBm, with the expectation that the 10.4dB difference does not exceed sector coverage. The legend for this coverage has a range of -52dBm to -67dBm. If the difference in received power between the strongest point and the sector boundary is 10.4 dB, then the sector boundary should be yellow, i.e. -62dBm. The footprint model given is still the same with 10mW power usage.

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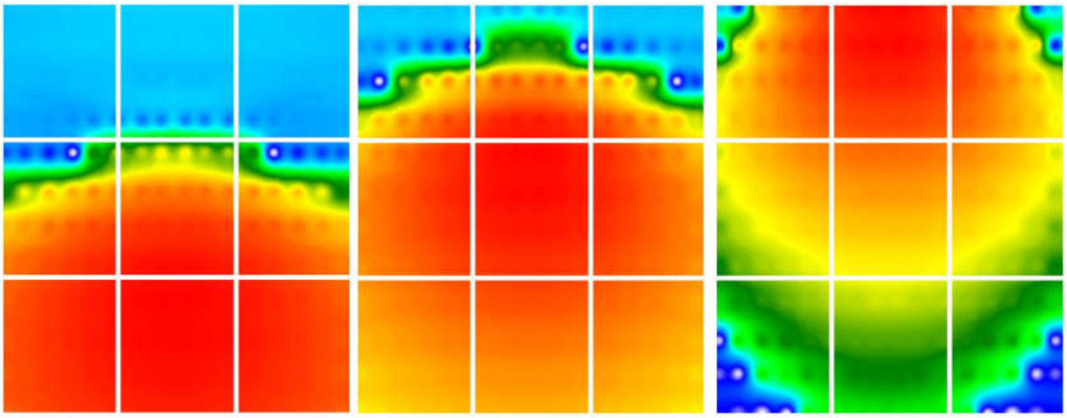


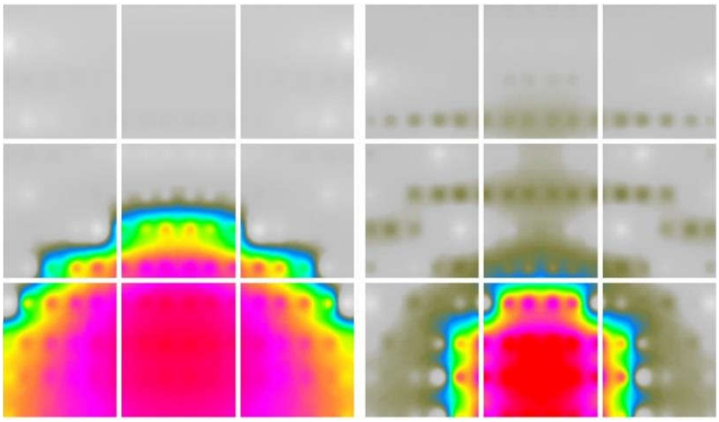
(a) AP-1B (b) AP-2B (c) AP-3B

Figure 7. Coverage with transmitted power 5 mWatt, HPBW-e 60^0.

From these two tests, it can be concluded that the effect of transmit power is linear for power settings, but the effect is different for each sector line. In the AP-1 sector, the overshooting provided is farther than in the AP-3 sector. Higher power usage is to guarantee greater minimum power reception. The appearance of the white spot as the worst legend in each scenario is caused by the side lobe in the antenna radiation pattern. While the overshooting footprint width is caused by the large HPBW-e used. So in this case the HPBW-e 600 is not suitable for all sector lines.

3.2. Analysis of HPBW

The HPBW simulation results with an elevation of 60^0 have been shown in Figure 7, where the beam width used is still too large to exceed the specified sector. This sector division must accommodate side lobe impacts besides the 3dB main lobe. Therefore, in the next simulation, 2 other HPBW will be tested as alternatives given in this research activity, namely 40^0 and 20^0.



(a) (b)

Figure 8. Coverage 1B with HPBW-e (a) 40^0 and (b) 20^0.

The coverage provided by the HPBW-Elevation 40^0 can still be said to be beyond its neighboring sectors. Even so, the reception level has decreased when compared to HPBW-Elevation 60^0. Based on the research target to get the strongest difference in the reception with a sector boundary of 10.4 dB, sector boundaries are colored between yellow and green. While HPBW-elevation 20^0 can be limited to sector boundaries, the area with a red signal only occupies a smaller portion than using HPBW-elevation 40^0. After that, the signal immediately drops to -70dBm (see Figure 8). This means that if HPBW-elevation 20^0 is used, blank spots will occur in the service sector itself. So, in the AP-1 range, it is better to use HPBW-Elevation 40^0.

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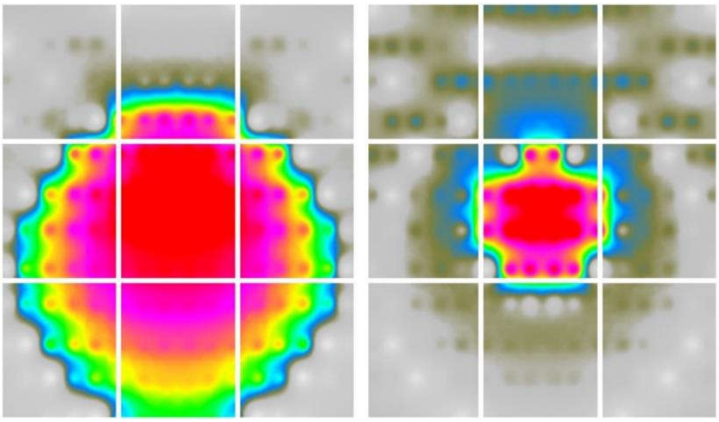
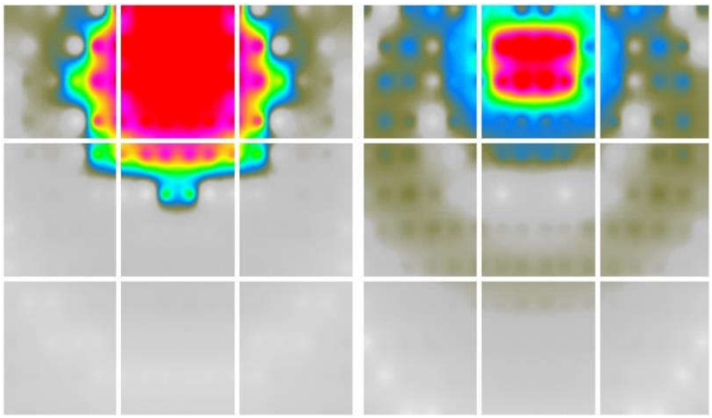


(a) (b)

Figure 9. Coverage 2B with HPBW-e (a) 40^0 and (b) 20^0.

The same thing happened to the AP-2 and AP-3, where the use of the HPBW-Elevation 20^0 was less effective in dominating a particular sector. This can be seen visually in Figure 9 and Figure 10, where sector boundaries must be colored between yellow and green. Therefore, AP-2 and AP-3 should also continue to use HPBW-Elevation 40^0.



(a) (b)

Figure 10. Coverage 3B with HPBW-e (a) 40^0 and (b) 20^0.

3.3. Analysis of HD-AP

Based on the previous conclusion, radio conditions on HD-AP for each sector can be generated using a scenario with HPBW 400 elevation. Radio conditions can be analyzed based on three conditions, namely channel dominance, best level distribution, and best SNR. The visualization of coverage domination is presented in Figure 11.

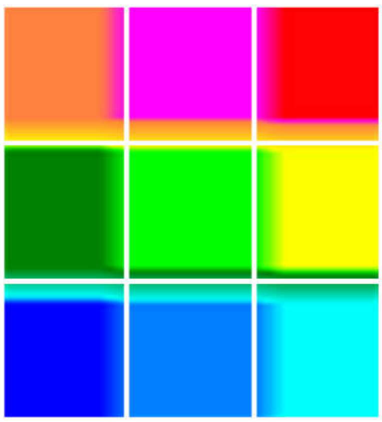


Figure 11. Best channel coverage with HPBW-e 40^0.

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In the figure above, channel dominance must meet sectoral requirements. The complications or errors in the cell boundaries are caused by errors at the Mapinfo application level in visualizing. In other words, individually the value of each user in the stands can be served by the intended AP with the best acceptance rate. The power reception level and signal quality visualization are shown in Figure 12.

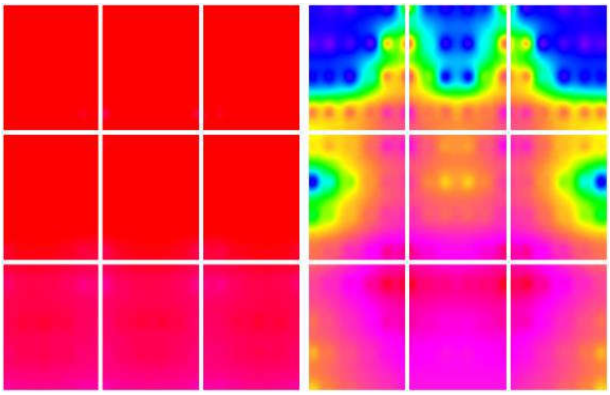

Figure 12. Coverage Best Level dan SNR dengan HPBW-e 40^0.

Based on the radio quality results, it can be seen that the HD-AP design using the HP-BW Elevation 40^0 is not perfect, especially for the AP-1 and AP-2 sectors. This is because the overshooting produced by this HPBW is not optimal, thus exacerbating the state of interference in the sector below it. If a smaller HPBW (20^0), the radio condition may not be as good as it is now, because there are still blank spot areas as discussed previously. Probably the best solution is to use an additional HPBW at an angle range of 20^0 to 40^0.

4. CONCLUSION

We have simulated the reception signal strength in the stands of the stadium. The combined use of the antenna targets a minimum difference in signal strength reception of 10.4 dBm, to obtain the desired access speed. We found the fact that the use of transmit power on each AP tends to have a linear impact. However, the impact is different for each sectoral row, where the revenue impact will be wider at the AP-1 and AP-2 sector stands. HPBW-Elevation 40^0 in this scenario environment is more effective than other HPBW. This condition applies to all APs, both lines 1, 2, and 3. Meanwhile, the HD-AP condition given for this scenario is effective in terms of receiving power but lacking in terms of signal quality. This is due to the lack of a given HPBW variation.

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