SINR Performance Comparison Of An Adaptive And Switched Beam Techniques For WCDMA System

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Abstract

The application and implementation of smart antenna system have been considered in the Second Generation (2G) system and the Third Generation (3G) system. By knowing the positions of mobiles, a base station can steer the beam and direct the power toward a single lone mobile or a groups of mobile stations. The system can be implemented using either an adaptive or a switched beam technique. In this paper, we evaluate the SINR performance of an adaptive and switched beam technique in WCDMA system for both links using simulation. Initial simulation shows that the SINR for an adaptive antenna is better than the SINR for a switched beam by 4.3 dB in the downlink, and 5.3 dB in the uplink.

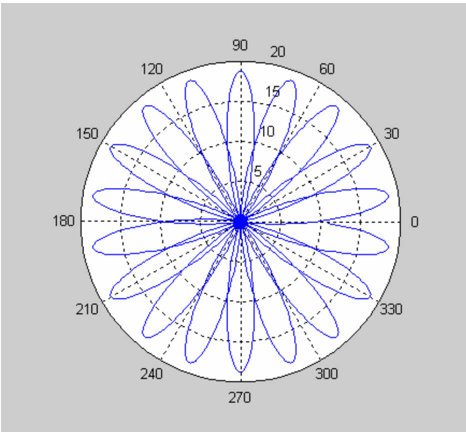
Keywords: Beamforming, Smart Antenna, WCDMA, SINR

1 Introduction

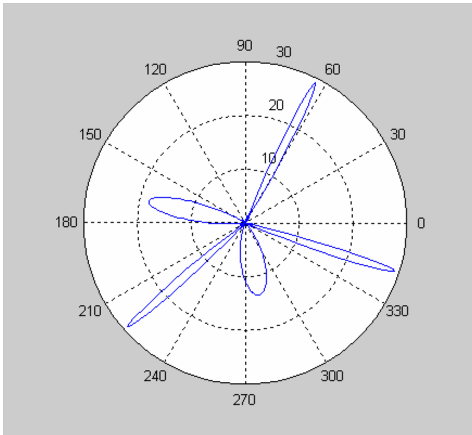
The third generation (3G) mobile telecommunication systems are being deployed and expected to be running globally in the near future. Wideband Code Division Multiple Access (WCDMA) has emerged as the mainstream air interface solution for the 3G networks. It was also selected as the Radio Transmission Technology (RTT) for Universal Mobile Telecommunications System (UMTS), which is the European Third Generation mobile communications system developed by European Telecommunications Standards Institute (ETSI) [1-4]. The system performance are expected to be improved in term of spectral efficiency, capacity, data rates, support for multimedia and packet switched services and innovative seamless applications such as mobile video conferencing and web browsing [5]. However, this technology needs to tackle challenges like path loss, multi-path fading, inter-symbol interference (ISI) and power control.

One potential solution to overcome these challenges is by using smart antenna technology. Smart antennas are an array of antenna elements that can change their antenna pattern dynamically to adjust to the noise, interference in the channel and mitigate multi-path fading effects on the signal of interest. Smart antennas are able to transmit and receive signals in an adaptive and spatially sensitive manner. An antenna element itself is not smart but with a combination of antenna elements to form an array and the signal processing software used, it will make smart antennas more intelligent and effective. Hence, this can dramatically increase the performance characteristics (such as capacity) of a wireless system.

Smart antenna has a property of fitting (adapting) its radiation pattern to spatial distribution of signal and interference sources in order to maximize Carrier-to-Interference Ratio (CIR) or Signal-to-Interference and Noise Ratio (SINR) for user admitted to the system. The highest level of intelligence is achieved in case of the adaptive antenna array which continuously estimates a direction of arrival of the required and interfering signals and adjust its radiation patterns so that the main lobe is directed toward the user and the null track all important interfering signals to maximize SINR [6-9].



(a)



(b)

Figure 1: Typical antenna pattern for (a) switched beam and (b) adaptive beam

2 Classification of Smart Antenna

Smart antenna sometime also referred to as intelligent antenna, adaptive array or dynamic or adaptive sectoring and can be implemented using either switched beam or adaptive beam technique. Figure 1(a) and (b) shows a typical antenna pattern for a switched beam and an adaptive beam implementation of a smart antenna.

2.1 Switched Beam

Switched beam or switched lobe antennas are directional antennas deployed at base stations of a cell. They have only a basic switching function between separate directive antennas or predefined beams of an array. The setting that gives the best performance, usually in terms of received power, is chosen. The outputs of the various elements are sampled periodically to ascertain which has the best reception beam. Because of the higher directivity compared to a conventional antenna, some gain is achieved. Such an antenna is easier to implement in existing cell structures than the more sophisticated adaptive arrays, but it gives a limited improvement.

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The switched-beam system is achieved by utilizing multiple narrow fixed beams (15 to 30 degree horizontal beamwidth) in a single sector. Since the beam pattern in a sector is predetermined, the mobile station is not always in the main lobe or center of the beam. The beam can also be "on" or "off" depending on the spatial distribution of the mobile.

Switched-beam systems are more economical to implement, requiring only a static beamforming network, RF switch and control. A separate beam selection is continuously made for each subscriber unit as it moves through the cell's coverage area. Commercial deployments of switched-beam systems have demonstrated significant capacity improvements: over 100% capacity gain in analogue and GSM networks. For example, in Metawave Communications field trial, a GSM smart antenna system significantly reduced interference and achieved a 6 dB CIR improvement. In the same trial, the improvement in C/I led to a 50% reduction in dropped calls. Studies have also indicated that network capacity increases of 100% can be achieved with deployments at selected sites representing only 38% of the total number of base sites in a network [10].

2.2 Adaptive Beam

The adaptive array system used a similar idea but different approach in allocating the beams with respect to the user. It utilizes more complicated signal processing algorithms to allow the system to use a varying beam pattern in response to the movement of the user and the changing environment.

The main idea behind such a system is its ability to allocate the main lobe of the antenna array to the users and nulls to all the other interferers. This clearly optimized the performance of the wireless system. However, it added much complexity to the systems, as algorithms to continuously distinguished between the signals from the user, the interfering signals from other signals and multi-path signals are required. In addition, the angle of arrival for the signal must be determined so as to "point" the main lobe exactly at the desired signal.

Adaptive antenna are a set of antenna elements that can change their antenna radiation or reception pattern dynamically to adjust to variations in channel noise and interference, in order to improve the SINR of a desired signal. The name 'smart' refers to the signal processing power that is part and parcel of the adaptive antenna. It controls the antenna pattern by updating a set of antenna weights.

It is possible for adaptive systems to achieve greater system performance than switched-beam systems. Using array signal processing allows the antenna system to take advantage of path diversity by combining coherent multipath components. The adaptive pattern that is created can be optimised to enhance the desired user's signal while simultaneously suppressing interfering signals. However, the theoretical performance benefits achieved by an adaptive system may be offset by the cost and complexities encountered in implementation.

In addition, a number of technical issues complicate adaptive systems. Specifically, downlink beamforming is difficult due to the presence of multipath and frequency duplexing. Since the goal is to select the best single direction to transmit to the user, it is critical that the base station processor detect changes in power along the subscriber's path. However, as the subscriber moves quickly, this becomes more difficult because the received signal from the subscriber may change very rapidly. Signal degradation can occur if the downlink beamformer cannot track these changes. Further, the beams formed on the downlink are

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determined by uplink signal measurements. Because all cellular systems are frequency duplexed, errors in the downlink beamformer are introduced because of the different uplink and downlink signal characteristics.

3 Simulation Environment

In this research, we develop a simulation model to study the performance of a cellular system utilizing beam forming technique employing smart antenna, both adaptive and switched beam for WCDMA system. The basic components of this simulation are:

3.1 Cell topology

In the simulation, we use hexagonal shape cells without any overlapping area. The use of the hexagonal shape is dictated by the need to simply planning and design of cellular system. In this simulation, we use macrocell model consisting of 7 cells.

3.2 SINR Model and Antenna Parameter

SINR calculation for downlink and uplink respectively can be modified from [11]:

$$SINR(i)_{downlink} = \frac{G_P G_A P_{ki} / L_{ki}}{\sum_{k=1}^{N} I_{ik} + P_N} \tag{1}$$

$$SINR(i)_{uplink} = \frac{G_P P_{ij} / L_{ij}}{\sum_{k=1}^{M} I_{ik} + P_N} \tag{2}$$

where G_p is processing gain, P_{ki} is the transmit power for BS # k to MS #i, $L_{k,i}$ is the pathloss between BS # k to MS #i, P_{ij} is transmit power of MS #i to BS #j, N is number of base station interferer, M is number of mobiles interferer and P_N is thermal noise power.
The overall gains in look direction of horizontal plane depend on antenna 3-dB beam width, β and its deviation from the main lobe, ϕ. By assuming that gain, G, and directivity, D, are nearly the same, the gain versus beam width relationship can be approximated as follow [12]s:

$$g_w = G = D = \begin{cases} \frac{32{,}400}{\phi\theta} & \text{For small } \phi \text{ and } \theta (\phi \text{ and } \theta < 40^{o}) \\ \frac{41{,}253}{\phi\theta} & \text{For large } \phi \text{ and } \theta (\phi \text{ and } \theta \geq 40^{o}) \end{cases} \tag{3}$$

where ϕ and θ are the 3-dB beamwidth in two planes. The antenna pattern gain is modeled by a sinc^2 function [10].

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3.3 Propagation model

The performance of wireless communication systems depends significantly on the mobile radio channel. The radio wave propagates through the mobile radio channel through different mechanism such as reflection, diffraction, and scattering. Propagation models predict average signal strength and its ability at a given distance from the transmitter.

The macrocell propagation model is applicable for the test scenarios in urban and suburban areas, outside the high rise core where the buildings are of nearly uniform height. It can be approximated as follow [11]:

$$L = 40(1-4x10^{-3}h)\log_{10}(r) - 18\log_{10}(h) + 21\log_{10}(f) + 80dB \qquad (4)$$

where L is pathloss in dB, r is the BS-MS distance in kilometers, f is the carrier frequency in MHz and h is the height of BS.
Fading is a log normally distributed random variable with standard deviation, σ_i, for shadow fading.

3.4 Beamforming Technique For Adaptive

The beam formation at every base station is based on the mobiles' DOAs. Figure 2(a) shows the actual parameters used in the algorithm. Given the j^{th} base station and two mobiles, say the i^{th} and the k^{th}, the angles of arrival are denoted a α_{ij} and α_{kj} respectively while the separation angle between the mobiles is γ_{ik}^{j}. By setting a minimum separation angle between adjacent mobiles, say γ, we are then in a position to narrow or widen antenna beamwidths after all directions of arrivals have been sorted.

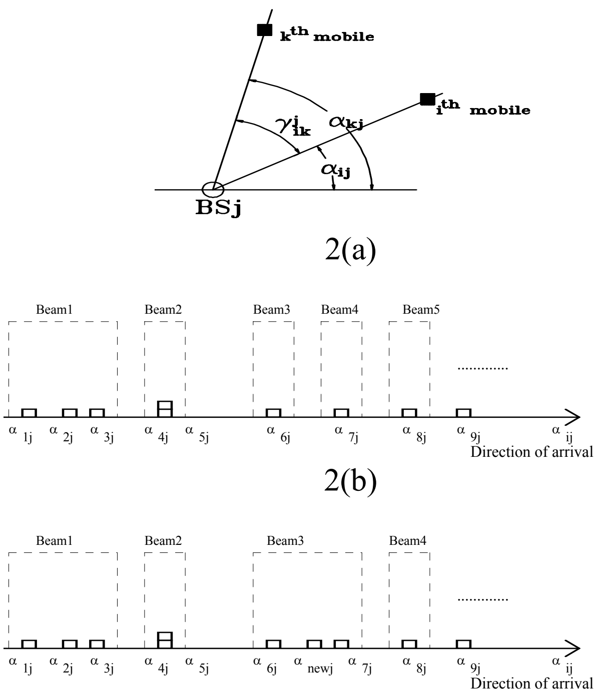

Figure 2: (a) Actual beam formation algorithm parameters, (b) Examples of beam formation and (c) Beam reformation to accommodate a new call

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Figure 2(b) shows an example of beam formation where

$(\alpha_{2j}-\alpha_{1j}) < \gamma$ and $(\alpha_{3j}-\alpha_{2j}) < \gamma$,
$(\alpha_{4j}-\alpha_{3j}) > \gamma$ and $(\alpha_{5j}-\alpha_{4j}) < \gamma$,
$(\alpha_{6j}-\alpha_{5j}) > \gamma$,
$(\alpha_{7j}-\alpha_{6j}) > \gamma$ and
$(\alpha_{8j}-\alpha_{7j}) > \gamma$

Henceforth, beam number 1 and 2 respectively will cater for a group of three and two mobiles, while beams numbers 3, 4 and 5 will cater each for a single mobile. The beams sizes are given by $(\alpha_{ij}-\alpha_{pj} + \gamma)$ where *i* and *p* represent the first and the last mobiles in the same beam respectively. If a new call arrived and served by the same BS_j such that,

$(\alpha_{2j}-\alpha_{1j}) < \gamma$ and $(\alpha_{3j}-\alpha_{2j}) < \gamma$,
$(\alpha_{4j}-\alpha_{3j}) > \gamma$ and $(\alpha_{5j}-\alpha_{4j}) < \gamma$,
$(\alpha_{6j}-\alpha_{5j}) > \gamma$, $(\alpha_{newj} - \alpha_{6j}) < \gamma$, $(\alpha_{7j}-\alpha_{6j}) > \gamma$ and
$(\alpha_{8j}-\alpha_{7j}) > \gamma$

then the new formation of beams are as shown in Figure 2(c). It can be seen that the number of beam is reduced from five to four and there are only two beams serving lone mobile instead of four.

3.5 Simulation cycles and parameters

Figure 3 shows the simulation process cycle. The cycles include generation of BS, MS and cell topology parameters. The MSs are generated uniformly within the cells and considered as static. The program then calculates the RSSI and SINR based on the AOA, antenna gain and path loss. The uplink interference at the serving BS arrives from other MSs in the same and neighboring cells while the downlink interferences at the serving MS are the signal from other BSs. The noise is considered due to the thermal noise power. Other simulation parameters are tabulated in Table 1.

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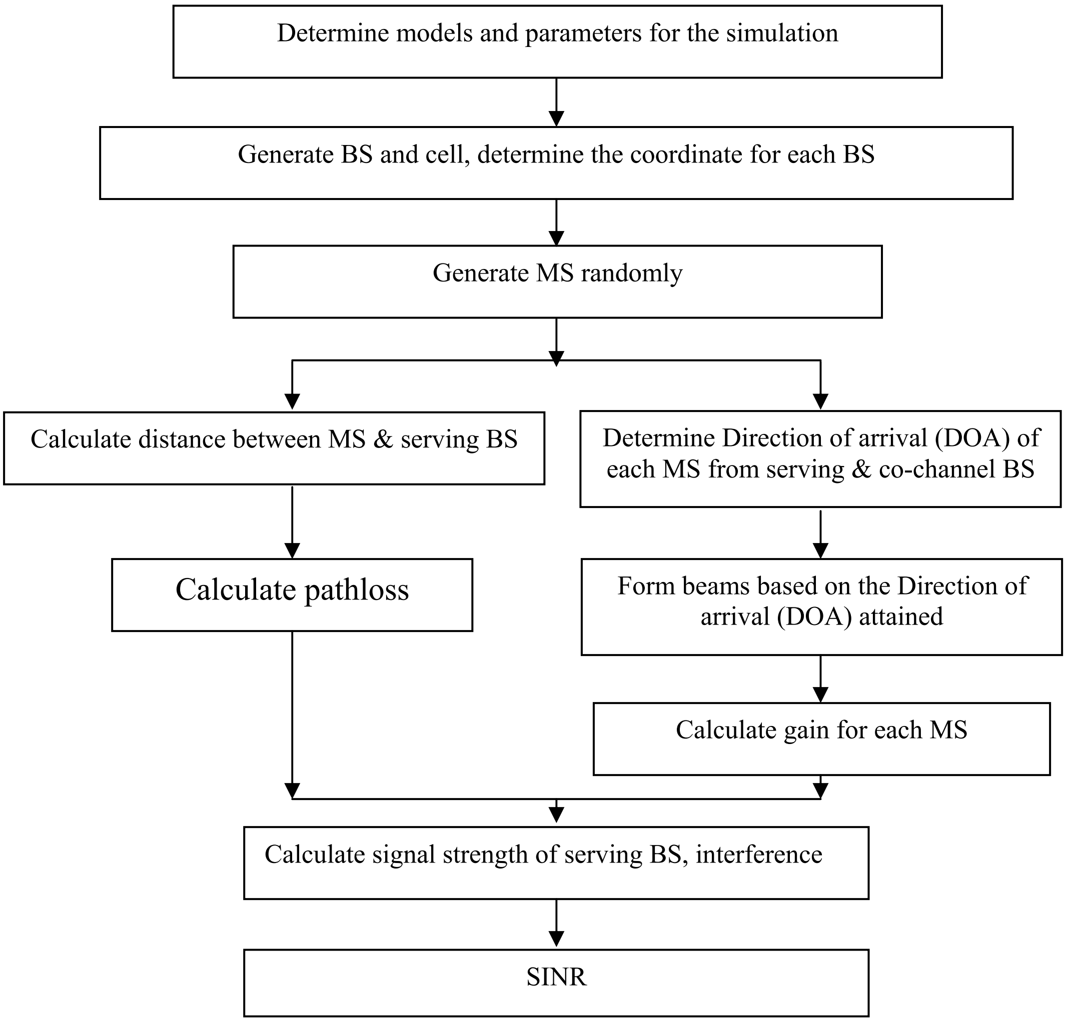

Figure 3: Flowchart of simulation cycle

Table 1: Parameters of simulation

Parameters	Typical Values
P_{TX}/TCH (dBm)	30
P_{RX} (dBm)	41
P_N (dBm)	-128
P_{TX}/TCH (dBm) (uplink)	24
P_{RX} (dBm) (uplink)	24
P_N (dBm) (uplink)	-128
Code rate (Mchip/s)	3.84
Userdata rate (Kchip/s)	15
Reuse factor	1
Number of BS	7
Radius of cell (km)	10
Height of BS (m)	30

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4 Simulation Results

Figure 4 shows an example of simulator GUI output consisting of cell topology and beam pattern for adaptive and switch beam.

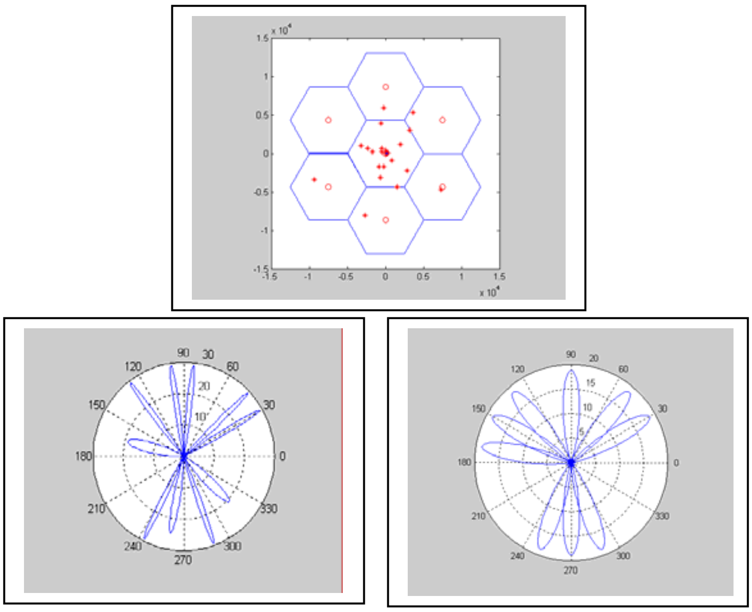

Figure 4: Cell topology (7 BSs, 20MSs), beam pattern at BS 1 by adaptive and switched beam antenna respectively.

Figure 5(a) and (b) show the cumulative distribution of SINR for an adaptive and switched beam antenna in the downlink and uplink respectively. Simulation results show that SINR for an adaptive antenna is better than SINR for a switched beam. The improvement for the downlink and the uplink is about 4.3 dB and 5.3 dB respectively. This is due the fact that switched beam antenna does not necessarily aligned the interfering signal to the nulls and thus the gain is not optimum. Conversely, in an adaptive antenna, the MS is aligned to the center of the antenna main lobe while the interfering signals are directed to the nulls, thus an optimum gain was achieved.

Another problem is that the switch beam system is not capable of identifying which signal is the desired signal. In simpler terms, the system can lock onto the wrong beam in the presence of multipath of interference signals. Unlike the adaptive system, the switched beam does not react to the movement of the interferers. As long as both the interfering and desired signal is in the same beam, there is no way to differentiate between the two. As a result, the signal to interference and noise ratio of switched beam worse than adaptive antenna.

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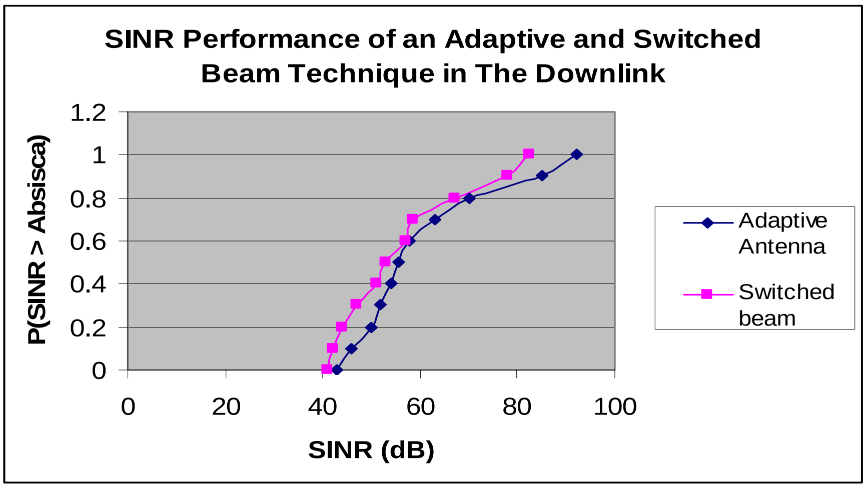
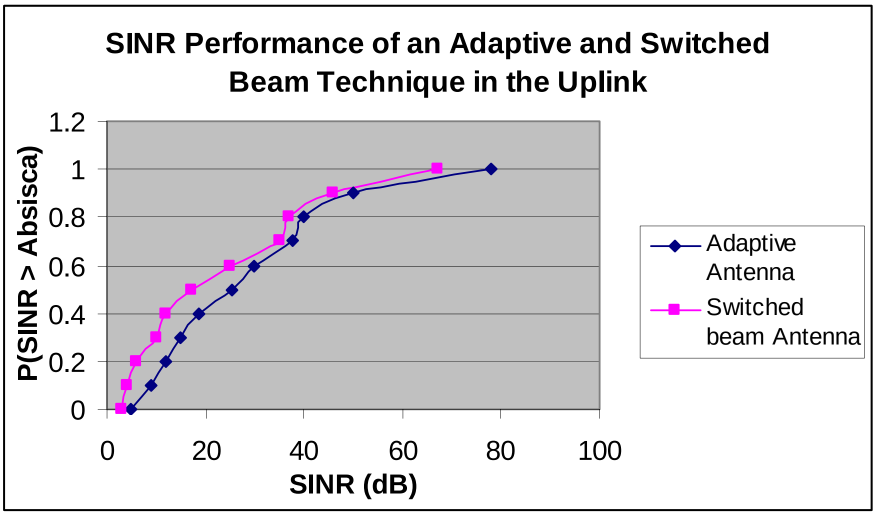


(a)



(b)

Figure 5: SINR performance of an adaptive and switched beam antenna in the (a) downlink and (b) uplink

5 Conclusion

SINR performance of an adaptive and a switched beam antenna for WCDMA system was simulated. The result of the simulation shows that the SINR of adaptive antenna better than the SINR of switched beam antenna by at least 4 dB in both links. It due switched beam antenna does not necessarily aligned the interfering signal to the nulls and it does not provide optimal gain, it is not capable of identifying which signal is the desired signal and does not react to the movement of the interferers. In the near future, other results on capacity improvement and traffic performance will be presented.

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