Modular High-Gain Antennas

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Introduction

In this paper we introduce the concept of modular high-gain antennas, which is based on allowing narrower elevation beamwidths than in conventional base station antennas to improve the antenna gain. We discuss potential issues of narrow beam antennas in real networks and present a robust solution suitable for macro-site installation. Finally, the performance of a modular high-gain antenna is verified in a field trial.

Background

Cellular communications systems are increasingly deployed to offer wireless services in rural areas with lower user densities than in urban and suburban areas. In such rural deployments, coverage is a key performance indicator and solutions that minimize the required number of base station sites are highly desirable to reduce capital expenditure and operational cost. One means for improving coverage is to increase the base station antenna gain. This is attractive, as it gives a balanced uplink/downlink link budget gain. The azimuth half-power beamwidth is set at around 65 degrees, depending on the specific cell plan [1], [2], which means that any gain increase must come from a decrease in elevation beamwidth, i.e., from a corresponding increase in antenna vertical size.

Propagation measurements at 1.9 GHz indicate that antennas up to 8 m tall can be desirable for high installations (~100 m tower) [3]. However, most base station antennas, even in rural areas, are installed on much lower towers or masts and the correlation over the elevation aperture may then be less favorable for very tall (“high-gain”) antennas. High-gain antennas may also lead to loss of signal strength coverage for areas illuminated by the sidelobe region below the main beam. For environments with line-of-sight propagation, with limited angular spread, coverage relates closely to the antenna pattern and null-depths may then cause time-invariant coverage holes.

Concept and implementation

A modular high-gain antenna (MHGA) consists of a number of subpanels (phase-matched subarrays, here about 2–2.5 m tall) that are connected via a feed network, see Fig. 1(a). Since it is modular, the antenna is easy to ship and handle, and is assembled to its full size once delivered to the base station site. Before installation, the subpanels are mounted on a common high-precision frame structure that ensures the required alignment accuracy, see Fig. 1(b) and (c).

We consider MHGAs with different numbers of subpanels, depending on the frequency. For “low-band” frequencies in the 850/900-MHz bands, a dual- and tri-subpanel MHGA is studied, whereas only a dual-subpanel configuration is considered for “high-band”
frequencies in the 1800/1900/2100-MHz bands. For both dual- and tri-subpanel configurations, the feed network outlined in Fig. 1(a) is designed to provide null-filling in order to maintain coverage below the narrower MHGA main beam. In the dual-subpanel case this is achieved by amplitude taper over the subpanels, whereas in the tri-subpanel case a delay taper is applied. The resulting radiation patterns are shown in Fig. 2, which shows that the gain drop below the single “mono” subpanel gain is about 12 dB at most.

The beam peak gain drop below the “standard” configuration with no taper (uniform subpanel weighting) is negligible, about 0.15 dB, as shown in Fig. 3 for the dual-subpanel case. The radiation patterns in Fig. 3 can be compared with the path loss curves that are drawn for different antenna installation heights (dash-dotted lines, for increasing heights from bottom to top). These free-space (distance squared) path loss curves are normalized at the geometric horizon to the peak antenna gain. Even at the largest shown installation height and for an untilted MHGA, the null-filled pattern gain is above the path loss curve, which means that the coverage is better in the direction of the null-depth than at the cell border (assumed to be at horizon). For propagation scenarios with greater path loss exponent and elevation angular spread, the gain margin becomes significantly larger.

Field trial

The performance of an MHGA was verified in a live GSM network at 1900 MHz. A cell with small terrain variations served by a base station site with a 28 m high tower was chosen as a typical site where a high-gain antenna would be suitable. We compare the performance of two antennas for this cell: one reference antenna with 18 dBi gain (with 2 degrees electrical tilt) and a dual-subpanel MHGA with 22.8 dBi gain. The CDFs of the predicted received signal strength (RSS) over the cell area, with a cell radius of 20 km, is
Figure 2. Modeled elevation patterns for single seven wavelengths tall subpanel (“mono”), dual-subpanel, and tri-subpanel, with null-fill within main beam of subpanel.

Figure 3. Elevation pattern for dual-subpanel antenna without (“standard”) and with null-filling, compared to free-space path loss for different antenna installation heights, with path loss at geometric horizon normalized to peak antenna gain. Subpanel is 14 wavelengths tall.

shown in Fig. 4, which shows that the full gain difference of about 5 dB is realized for almost the entire cell. Only a small part of the cell, near the base station where the signal anyway is very strong, has better signal strength from the reference antenna. Fig. 5 (top) shows calculated RSS along a straight line emanating from the trial site for a pure distance-dependent path loss model and Fig. 5 (bottom) shows a sample of measured RSS along a road leading straight to the cell border. The test results, although noisy, show a average relative coverage improvement to within 0.5 dB of the predicted improvement, verifying that the MHGA retains its gain characteristic in a real propagation environment.

Conclusions

A modular high-gain antenna, installed at a relatively low height, has been shown to provide link budget improvement over a large part of the serviced cell, including near the cell border which shows the potential for larger site separations. Signal strength below the relatively narrow main beam is maintained by using null-filling.
Figure 4. CDFs for predicted RSS for reference antenna and modular high-gain antenna.

Figure 5. Calculated (top) and measured (bottom) received signal strength for reference antenna and modular high-gain antenna. The MHGA coverage at small radii is maintained by the null-fill.

References

