Design and Testing of a Compact 'Semi-Smart' Base Station Antenna in Cellular Networks

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ABSTRACT: This paper presents a physical-level study on improving cellular-network system capacity by using the concept of semi-smart antennas. Practical implementation of the semi-smart antenna technology imposes several technical and environmental requirements on the antenna design. Therefore, novel cylindrically-conformal antenna array has been designed and tested. The new design is simple, robust, light and small in size (low profile), and most importantly, operates efficiently in providing dynamic radiation coverage in the azimuth plane. In comparison to the typical smart-antenna approach, semi-smart antenna technology has proven to be of much lower complexity and has minimal impact on the cellular system architecture.

INTRODUCTION

The continuing demands for expanding services in wireless systems have led to ambitious interests in advanced or 'smarter' network systems. The semi-smart antenna technique presented in this paper is based on shaped-beam antenna pattern synthesis that is aided by artificial intelligence techniques in order to balance the traffic load among neighboring base stations [1]. This method can provide significant advantages over conventional base stations and it requires relatively simple design criteria which imposes minimal infrastructural impact. Therefore, semi-smart antenna method can be used to exploits the available resources in the physical layer at a far-less cost and complexity than other 'smart' or adaptive antenna schemes where highly effective 'smart' or 'self-configured' beam pointing systems are required [2]-[5].

In Semi-smart approach, only few antenna elements are needed to create highly shaped beams with low angular accuracy and gain. The theory behind this approach is based on utilising a load balancing scheme to shape cellular coverage according to the traffic needs [6]-[8]. In this aspect, the traffic demand of the heavily loaded cell is decreased to match the available capacity by contracting the radiation pattern around the area of the peak traffic, while adjacent cells expand their radiation patterns to compensate for coverage loss (Figure 1).

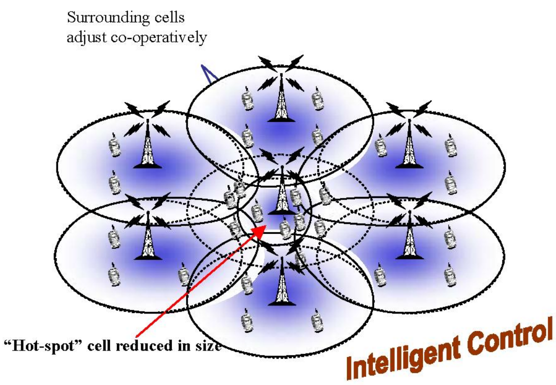

Figure 1: The basic operational principle of semi-smart antenna system in load balancing of a cellular network. Dashed cells represent the original uniform cellular network; solid cells representing the network employing the semi-smart system and showing adaptation to the high traffic load present at the central cell.

The basic criterion in designing the antenna for semi-smart method is to handle dynamic omni-directional azimuth coverage with minimal size dimensions and fewer hardware and control complexities. For this reason, cylindrically-conformal array consisting a number of radiating elements whose individual excitations are controlled to achieve the desired radiation pattern.

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DESIGN METHODS

The choice of base station antenna design has a significant influence on the base station antenna performance. The fundamental requirement here is the capability of dynamically control of the azimuth radiation pattern around the base station. The new design is based on a cylindrical array consisting of twelve radiating elements whose individual excitations are controlled in order to achieve the desired radiation pattern. The elements are mounted around a cylindrical metallic surface, forming three segments of 4-element sectors, to ensure 360° azimuth coverage (Figure 2-a). To demonstrate the practicality of the proposed semi-smart antenna, a simplified prototype base station antenna sector has been designed, constructed, measured and validated. In this sector, each of the elements is fed via a full-power phase/amplitude controllers which are mounted at the top of the tower. However, in the full base station design, the antenna will be composed of a stack of cylindrical arrays as shown in figure 2-b. By altering the phase of the elements in the vertical tack, the pattern from each column can be down-tilted. Therefore, the amplitude can be adjusted by altering the vertical phase to produce a down-tilt which can be used as an amplitude control method.

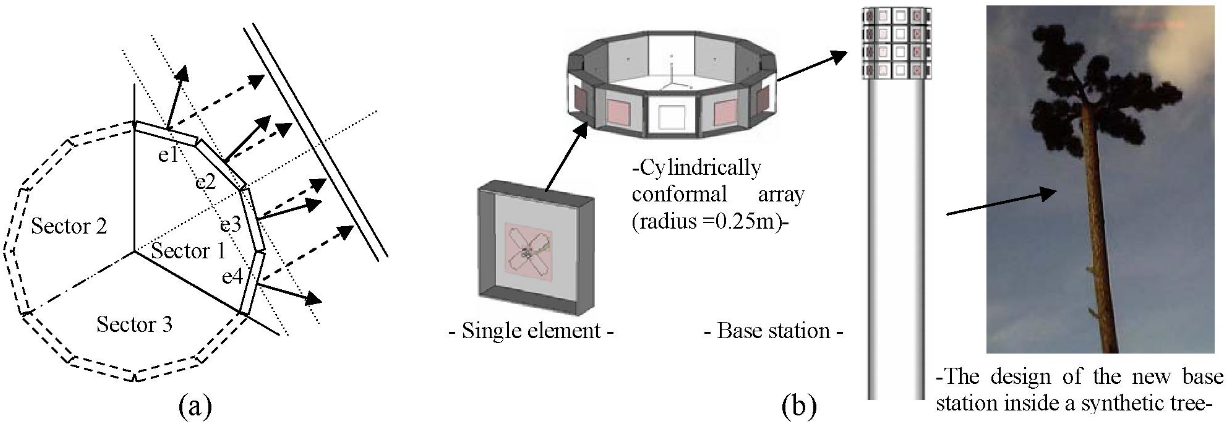

Figure 2: (a) A 12-element cylindrically-conformal array; (b) The structure of the proposed base station – stacks of cylindrical arrays.

As shown in figure 2, each of the elements has been separated by half-wavelength and positioned at 30° from each another, forming a 120° arc. With such arrangement, the overall base station diameter can be contained within 0.5m.

The excitation weight of each element is predicted by synthesising the overall array pattern produced by the elements positioned around the cylinder. The contribution of each element pattern and phase on the total radiation is considered individually as the antenna elements do not point towards the same direction. This means that a common element factor is considered individually for elements around the cylindrical array. Therefore, an adequate synthesis technique is needed for calculating the fields radiated by the cylindrical distribution of element excitations.

In our analysis, the scenario is simplified to an equivalent linear array of unequally spaced elements with each element pattern pointing to various directions. This is achieved by projecting the contribution of each element on a plane perpendicular to the beam pointing direction. This approach has been applied here for simplicity and can significantly improve by formulating the conformal array directly.

In order to obtain in-phase addition of the elements, a feed network with appropriate phasing has been designed using mechanically-driven phase shifters. The control and testing has been fully automated using custom developed software.

The sector feed-network has been designed as a 4-way power splitter, where each of the signals derived is connected to an independent variable phase-shifter which is dynamically adjusted to satisfy the necessary coverage requirements (Figure 3). With this arrangement, the amplitude control is satisfied by introducing a stack of cylindrical arrays as shown in Figure 2-b. Therefore, the amplitude can be adjusted by altering the vertical phase to produce a down-tilt which is used here as an amplitude control method.

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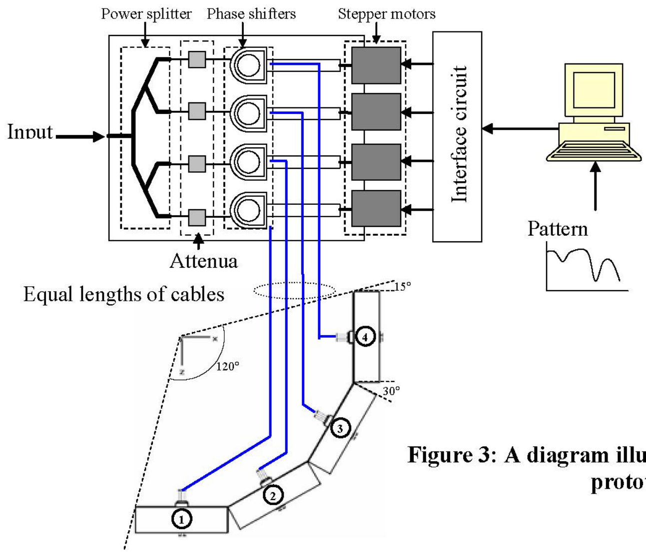

Figure 3: A diagram illustrating the main design of the prototype system.

RESULTS AND DISCUSSIONS

The initial step in the study has involved verifying the performance of the single radiating antenna element via simulation and measurement. Figure 4 illustrates a good agreement between the measured and simulated radiation patterns and the return loss of a single element.

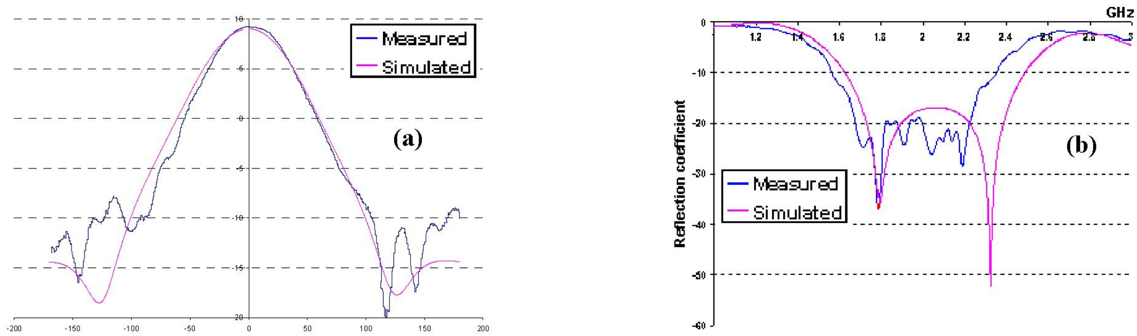

Figure 4: A comparison among the simulated and measured (a) radiation patterns; and (b) return loss of a single element.

Further electromagnetic modelling was conducted to test the performance of the 4-element conformal array sector. Figure 5 shows the computed radiation patterns which result from alternating the input power among each of the array elements. It can be seen that switching the radiation source from one element to another results in a main beam pointing at directions corresponding to the element angle, which is 30° in this particular case. Therefore, we can conclude that a full cylindrical array can generate a 360° azimuth scanning by switching the input power to the elements pointing in each direction.

Figure 6 illustrates the radiation pattern produced when simultaneously exciting all of the four elements. Here, the resulting main radiation pattern is fully controlled by adjusting the phase and amplitude weights of the individual elements. It is worth highlighting the fact that arranging the square elements around the cylindrical array have resulted in separating the element cavity edges by triangular gaps. These gaps can reduce the interaction between elements and can act as secondary sources which may interfere with the overall radiation pattern. Therefore, the gaps have been filled with a conductor material to minimise this effect.

In our initial set of results, it can be observed that the front to back ratio produced here is of much worse than theory suggests. This can be regarded to the on third construction of the prototype.

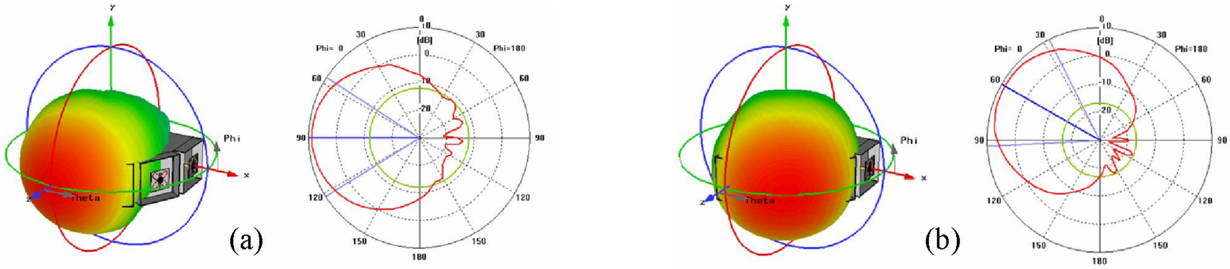

Figure 5: Computation of the conformal array sector; figures illustrate the radiation pattern generated when switching the power into (a) port 1 & (b) port 2 respectively. Similar response has been observed when switching elements 4 and 3.

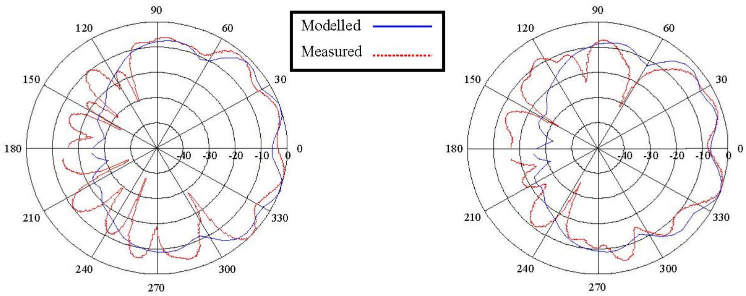

Figure 6: Measured and computed radiation pattern of the prototype antenna array. In all configurations, the centre of the antenna array pointing in the 0 degree direction, the excitation amplitudes for all elements was made equal, and the phase has been allocated for elements 1, 2, 3 and 4 as (a) 0, 0, 0 and 0 degrees, and (b) 34, 29, 0 and 22 degrees.

CONCLUSIONS

When compared to typical smart-antenna approach, the semi-smart antenna technology has proven to be of much lower complexity and has minimal impact on the cellular system architecture. A cylindrically-conformal array antenna with appropriate feed network has been designed and tested. The new design is simple, robust, light and small in size (low profile), and most importantly, operates efficiently in providing dynamic radiation coverage in the azimuth plane. Despite the various difficulties associated with analysis and synthesis, this approach offers substantial improvements on the cellular system capacity. The design of the base station antenna has been verified and optimised by measurements and by using electromagnetic modelling and analysis.

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