A Novel Micro-Strip Phased-Array based Semi-Smart Antenna

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Abstract: In semi-smart antenna research, a distributed load-balancing scheme has already been investigated for cellular networks which intelligently changes cellular coverage according to the geographic traffic-distribution. Real time implementation is sort for by cooperative negotiation. To acquire the desired radiation pattern from the base station following the negotiation, a novel micro-strip, phased-array antenna with single-layer or dual-layer dielectric plates is presented in this paper. The dielectric plates are designed to work as phase shifters between the elements of the array. By non-mechanically adjusting the value of the effective dielectric constant or the length of the dielectric plates, it is possible to perform the beam steering without employing methods of digital phase shifting. This affords simpler construction and lower costs. Such a semi-smart antenna approach represents a modest cost-effective enhancement to system capacity when compared to the fully-adaptive approach.

1. Introduction.

To achieve the ambitious demands being placed upon future wireless systems, novel, highly efficient 'intelligent' or 'self-configuring' systems will be needed. In our previous work, a novel distributed load-balancing scheme has already been investigated for cellular networks which intelligently changes, in real time, the cellular coverage according to the geographic traffic-distribution at a given instant. By the use of real-time negotiations between adjacent base stations, optimum local coverage agreements can be reached in the context of the whole cellular network. The detail is described in section 2.

In order to acquire the desired radiation pattern from the base station following the negotiation, a phased array antenna is introduced. However, electronic phase shifters are expensive, relatively large and have power limitations. Due to high transmission powers and inter-modulation products resulting in out-of-band emissions, conventional electronic phase shifting is not practicable for the semi-smart base station application. A phased array which makes the phase shifter an integral part of the array antenna element will be a novel solution. Employing a dielectric phase shifter enables the establishment of feed lines for a beam steering array antenna constructed on a dielectric substrate. The dielectric phase shifter, which is constructed by placing a dielectric plate on the microstrip line, has an especially simple construction. The design and simulation results are reported in section 3.

2. Semi-Smart Antenna System.

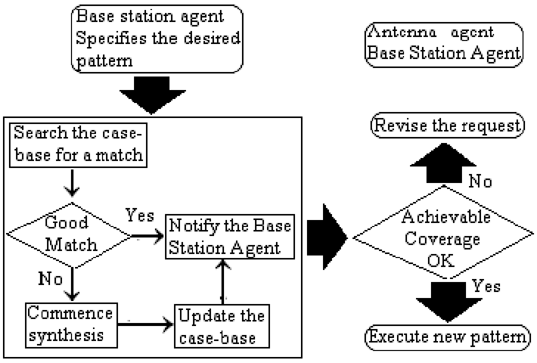


Fig.1. Basic concept of the semi-smart antenna approach using case-based reasoning

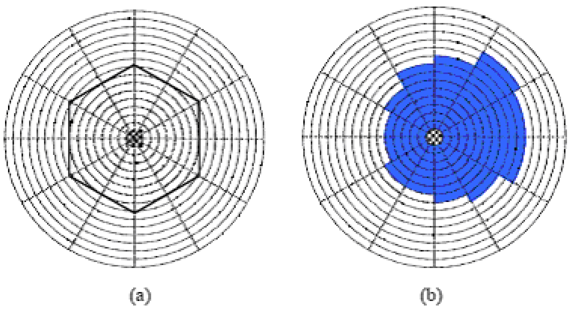


Fig.2. (a) Grid in polar coordinates representing coverage patterns; (b) An example of discrete desired pattern following negotiation

Fully adaptive antennas perform pattern optimization by real-time active weighting of the received signal (aiming individual beams to each mobile) in which digital signal processing technology plays an essential role, by providing the required ‘intelligence’. In contrast, the required ‘intelligence’ for the smart antenna to be used in a negotiation-based, load-balancing scheme, is provided by a software agent, namely the *antenna pattern agent*. To distinguish it from fully adaptive antennas we use the term semi-smart antenna. This semi-smart antenna approach offers a modest increase to system capacity. Simulations suggest around 20%, compared to the fully adaptive approach. This improvement in capacity is still significant with the cost of the antenna system being significantly lower.

The antenna pattern agent provides the required pattern synthesis capacity. A suitable approximation of the desired pattern has to be synthesised upon request and in real-time. To aid the pattern synthesis artificial intelligence techniques such as *case-based reasoning* can be used. By building a case-base, the repeated synthesis of often-occurring pattern is avoided. A flow chart depicting the basic concept of our approach to a smart antenna solution is shown in Fig. 1.

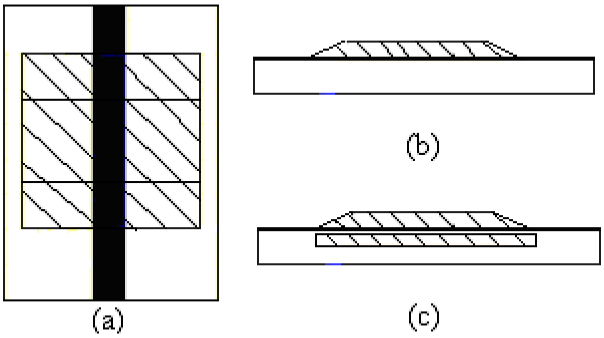
Since there are complex interactions over a physically distributed area, a multi-agent system (MAS) is used. Conceptually each base station agent and antenna agent has its own processing capability, and may be physically distributed. Cooperative negotiation between base station agents is used to find optimum cell coverage patterns. The negotiation is triggered when the local traffic exceeds a certain threshold, and results in some coverage changes. In order to realize the negotiation, coarse granularity of coverage patterns is used. Negotiation are performed based on the polar grid shown in Fig. 2(a), and example output is shown in Fig.2 (b)

3. Novel Micro-strip Phased Array.

Many methods have been proposed to achieve phase shifting without an electronic phase shifter, namely: Electromechanical tuning method using a piezoelectric transducer (PET) [1]; Beam steering by means of a coupled-oscillator technique [2]; Optical beamforming networks based on liquid crystal phase shifters [3]; Optical techniques for beam steering by ferrite-based patch arrays [4].

For the application of semi-smart antennas to achieve beam steering in real-time, a novel phase-shifting method is presented. By non-mechanically adjusting the value of the effective dielectric constant or the length of the dielectric plates, it is possible to perform beam steering without employing methods of digital phase shifting. This permits simpler construction and lower costs. The structures were simulated using the commercial software, Ansoft HFSS. It applies the Finite Element Method (FEM).

3.1. *Simulations of Transmission Line Phase Shifting with Dielectric Plates*



(a) (b) (c)

Fig.3. Top-view (a) and side-view (b,c) of the transmission line with the dielectric plate

Initially, we simulated a number of transmission lines with a dielectric plate to observe the phase shift produced by changing the effective permittivity and the length of the dielectric plate, at a frequency of 2.0GHz. The simulations are divided into two groups: the first is with a single-layer dielectric plate attached to the transmission line, as shown in Fig.3 (b); the second is with a dual-layer combination of dielectric plates, both attached to, and 0.1mm under, the transmission line, as shown in Fig. 3 (c). The edges of the upper dielectric plate are tapered at 60° to suppress the reflection loss. The substrate has a permittivity of 4.0 F/m and dimensions of (40 x 12 x 2) mm^3. The width of the transmission line is 2mm. The dimensions of the dielectric plate is (L x 10 x 1) mm^3, where $0<L<30$mm.

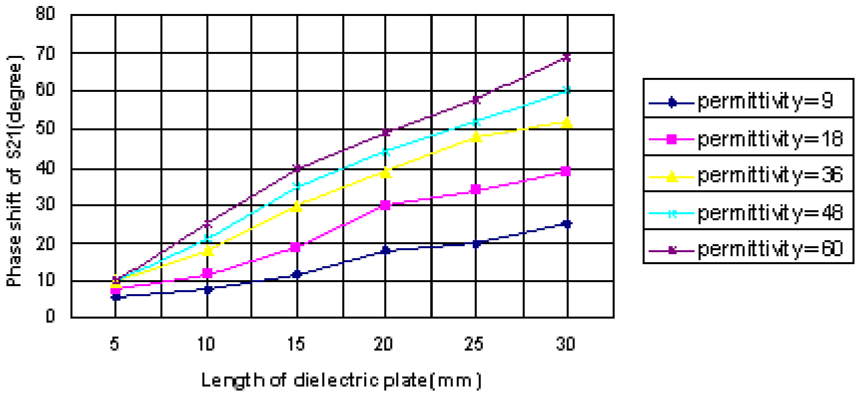


Fig.4. Phase shift of single-layer dielectric plate

Fig.4 shows the phase of S21 simulated with single-layer dielectric plate. Fig.5 shows the phase of S21 simulated with a dual-layer of dielectric plates. Clearly, phase shift can be seen introduced by using a single-layer dielectric plate or a dual-layer of dielectric plates. It is noticeable that phase shift increases with the increase of effective permittivity as well as with the increase in length of the dielectric plate. The dual-layer structure produces a more evident phase shift, of which the phase shift has increased nearly 66.7% (when L=5mm, ε_r=9 F/m), 107.7% (when L=20mm, ε_r=36 F/m) and 115.9% (when L=30mm, ε_r=60 F/m) respectively, comparing to single-layer structure. This is attributed to a heavier attenuation of the propagation constant.

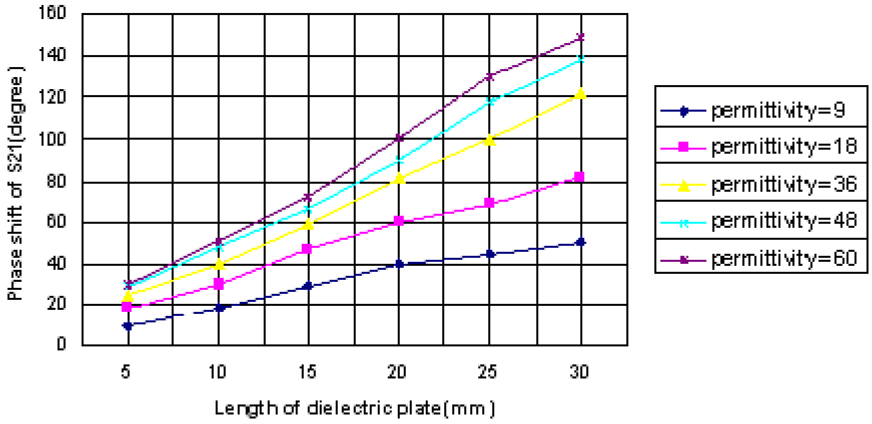


Fig.5. Phase shift of dual-layer dielectric plates

3.2. *Simulation of Phased-Array Radiation Patterns*

Fig.6 gives the prototype of the phased array antenna which was designed to operate at 2.0 GHz on a substrate with a permittivity of 4.0 F/m. Fig.7 shows the return loss (S11) simulated for the antenna array without a dielectric plate. As can be seen, it has a central frequency at 2.03 GHz and bandwidth of about 210 MHz.

Fig.8 shows the simulated radiation pattern for a four element phased array in three different situations: without a dielectric plate, with a single-layer dielectric attach to the transmission line and with dual-layer dielectric plates both attach to and 0.1mm under the transmission line. All dielectric plates have the permittivity of 36 F/m. The distance between two adjacent elements is $\lambda/2$ (75mm); the length (L) and width (W) of each element are 30.8 mm and 26.2 mm respectively. The length of the dielectric plates on the three transmission lines were chosen to be 5 mm (L1), 15 mm (L2) and 25 mm (L3). As can be seen, the directivity decreases from 7.62 dB to 6.74 dB when using the single-layer dielectric plate and 5.47 dB when using a dual-layer of dielectric plates.

By introducing single-layer and dual-layer dielectric plates to three of the four transmission lines it is possible to observe a beam steering from 0° to 22° and 51° respectively (see in Fig.8). Larger beam steering can be achieved by using a higher permittivity or longer dielectric plate. A branch transmission line using switches can achieve different lengths of the dielectric plate. Future work will focus on searching for an appropriate method to achieve non-mechanical adjustment of the value of the effective dielectric constant of the dielectric plate.

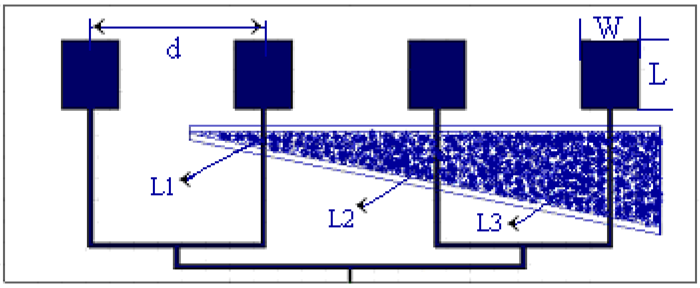


Fig.6. Four-patch array with the dielectric plate

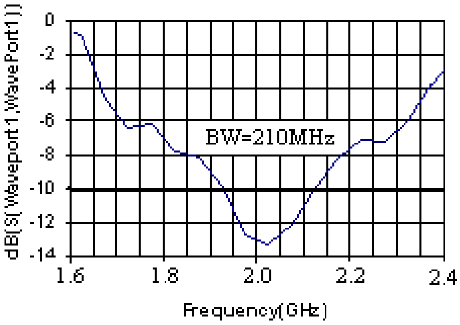


Fig.7. S11 of designed array at 2.0GHz

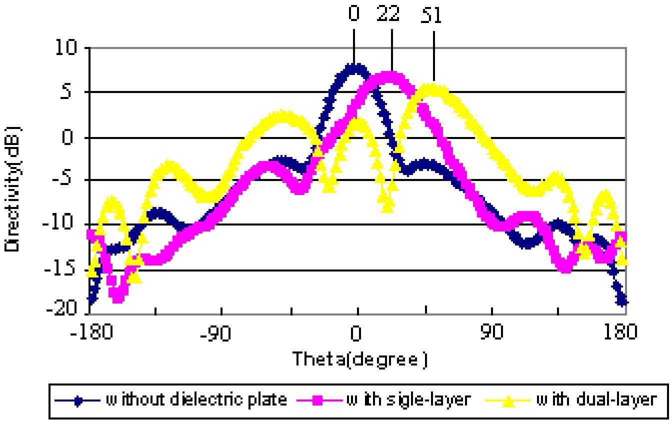


Fig.8. Radiation Pattern of the phased array simulated in three situations

4. Different Methods to Control the Permittivity of Substrate

A variety of methods have been considerated to non-mechanically control the permittivity of substrate. With identification of an appropriate piezo- or pyro- or photo-activated effective dielectric constant, experimental work is to follow to demonstrate real-time beam steerage.

5. Conclusions.

To acquire the desired radiation pattern from the base station following negotiation, a novel micro-strip, phased-array antenna with single-layer or dual-layer dielectric plates has been presented. The dielectric plates are designed to work as phase-shifters between the elements of the array. By non-mechanically adjusting the value of the effective dielectric constant or the length of the dielectric plates, it is possible to perform the beam steering without employing methods of digital phase shifting. This affords simpler construction and lower costs.

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