Metamaterial Inspired Antenna Design for Massive MIMO, 5G Communications System

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***Abstract*—We present a metamaterial-based design of large scale antennas for massive multiple input and multiple output (MIMO) communication systems. The reliable data link and better performance over modern fifth generation (5G) wireless communication systems is possible with large numbers of such adaptive antennas. The miniature metamaterial antennas are best for practical implementation of such large antenna arrays. We investigate the design of meta-material antennas and analyze the S-parameter, radiation pattern, and define mathematical relationship to find the correlation coefficient and diversity gain.**

I. Introduction

Massive MIMO is an emerging technology for future wireless communication to provide higher spectral efficiency and data rate. This technology is the best candidate for 5G cellular systems due to reliable data link and better performance using hundreds of large antenna arrays in base stations. MIMO includes highly directed radiation beams through adaptive beam forming and signal processing algorithms for different pairs of antennas set. The thousands of user terminals are controlled using a full-dimensional MIMO scheme to reduce complexity/latency/interference using highly accurate channel state information (CSI) and simplified multiple access [1].

Several research investigations are made to address the size constraint within the large antenna array MIMO base station.The different test beds were designed using 64×64 antenna array operating at 2.4 GHz , and a 128×128 cylinderical array operating at 2.6 GHz for fewer number of users terminals. Recently, wireless mobile companies like Samsung and AT&T also trying to implement such types of testbed for their users. Therefore, the meta-material based, miniature antenna design is popular in hyper MIMO communities. Hundreds of such sub-wavelength dimension antennas can be fabricated in periodic fashion to produce exotic electromagnetic behavior in the microwave and millimeter frequency bands. The highly directed beam forming signal can be achieved by actively controlling the individual voltage to each meta-material unit cell. Nathan et. all (2015) investigated the use of such reconfigurable holographic meta-material antennas for satellite communications. These holographic antenna provide sidelobe cancellation using active electronic scanning and produces an optimized far field radiation pattern.

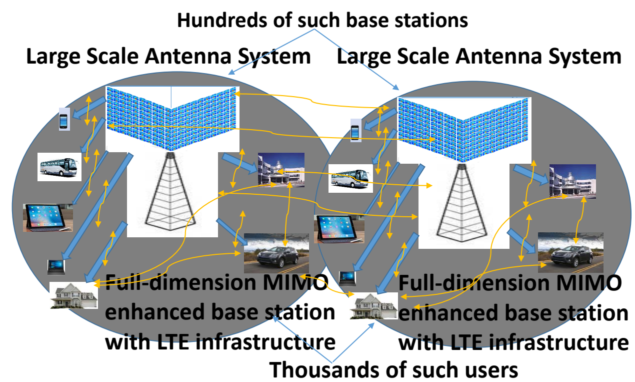

Fig. 1. The general layout of massive MIMO architecture. It consist of Full-dimension MIMO enhanced base station with LTE infrastructure, very large antenna array, and thousands of user equipment.

The general layout for full dimension MIMO system is illustrated in Fig. 1. This includes enhanced node-B for Long term evolution (LTE) base stations, 3-D channel propagation model, multi user shared acess, software defined air interface, large number of base station antennas, user equipment (UE) for mobile terminal, and reference signal for pilot signal. We focus here on the study of very large antenna array system. This paper explores the design of such meta-material based antennas for masive MIMO communication operating at 1 GHz. The unit cell has a simple inset feed patch structure to get a highly directed beam along a particular direction. The analysis of such structures will enable future studies on very large MIMO with channel correlation, diversity gain, mutual coupling, inter channel interference and other criteria [2] .

II. Design Of Massive MIMO Antenna

The meta-material inspired unit cell structure used for large array system operating at 11 GHz is shown in Fig. 2. It consists of an inset patch structure on a dielectric substrate layer. The Rogers RT5880 ($\epsilon = 2.2$) and RT5870 ($\epsilon = 2.33$) alternate layers can be used as dielectric substrates. These dielectric materials have very low loss and good electric properties over the desired frequency ranges. This simplest design produces a high-gain radiation pattern and can be fabricated within communication printed circuit boards (PCB).

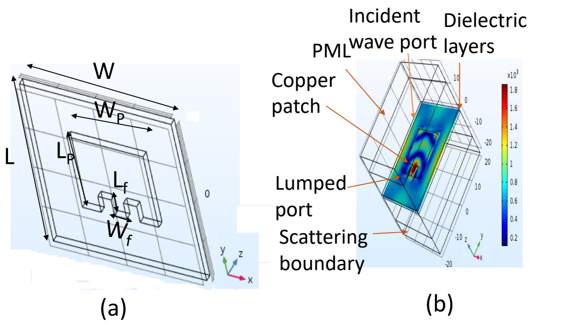

Fig. 2. (a) Unit cell structure. W=L=40 , $W_P = 20, L_P = 18, W_f = 3.5,$ and $L_f = 20$ mm (b) COMSOL design layout showing the electric field pattern.

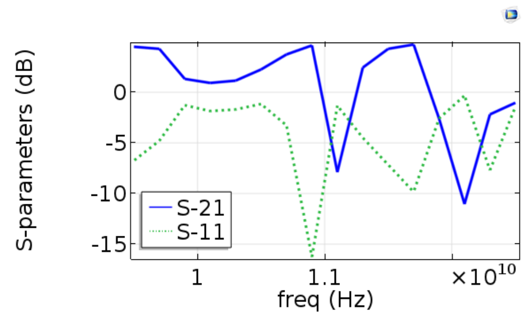

Fig. 3. S parameters of 4×4 MIMO unit

The mutual coupling between many antennas is important to reduce the diversity factor in very large MIMO array. Antenna diversity performance can be evaluated to increase radiation efficiency of such array systems. The envelope correlation coefficient is defined as the average correlation between the total radiated power within 3-D space. The envelope correlation can be calculated from the S-parameters of the antenna as [3],

$$\rho_e = \frac{| S_{11}^* S_{12} + S_{21}^* S_{22} |}{(1 - (| S_{11} |^2 + | S_{21} |^2))(1 - (| S_{22} |^2 + | S_{12} |^2))} \quad (1)$$

The approximate diversity gain of MIMO antenna can be related to correlation coefficient as,

$$G_{app} = 10 \times \sqrt{1 - | \rho_e |} \quad (2)$$

All the designs are simulated in three dimensional COMSOL Multiphysics finite element analysis tool. The Perfect electric conductor (PEC) is used to model thin metallic antenna part. This is due to the small copper thickness compared to the skin depth. The lumped port is used in the antenna feed and the input signal is applied using port 1 via a slit.The Perfect matched layers (PMLs) on the top and bottom are used to absorb all the port and higher order mode signals. The scattering boundary helps to scatter all the signal coming out from the antenna unit. Finally, a Periodic boundary condition is set to get identical 10×10 arrays of such antennas.

III. Results and Discussion

The radiation characteristics for inset patch antenna as a meta-material unit cell for frequency ranges 9 GHz to 12 GHz are analyzed. The Fig. 2 shows electric field pattern near resonance of such a structure. Further, we create the model of 4×4 array of such unit cell as basic MIMO cell. The Fig. 3 shows the good resonance of such meta-material antennas array having S_{11} around -16 dB and low mutual coupling less than -10 dB. From this design, we found the highly directed beam patten with 6.88 dB gain along the direction of maximum radiation.

The Fig. 4 shows 3-D radiation pattern, azimuthal and elevation pattern for such antennas. Moreover, we can find the correlation coefficient and diversity gain using equation 1 and 2 for such antenna in order to analyse mutual coupling and interference between numbers of antenna arrays.

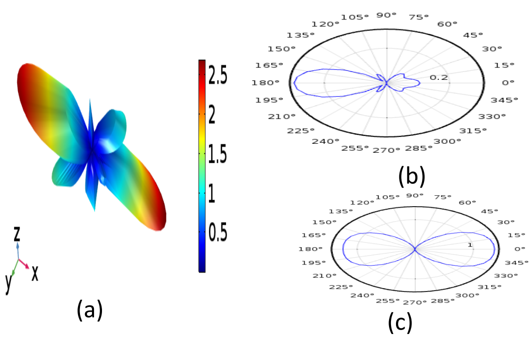

Fig. 4. (a) The 3-D radiation pattern (b) Azimuth radiation pattern (c) Elevation radiation pattern for 4× 4 Massive MIMO array unit.

IV. Conclusion

In this paper, we presented the design of array antennas for use in massive MIMO wireless communication system. We discussed the overall architecture of full dimension MIMO used for next generation cellular technology. The meta-material inspired inset patch antenna solves the problem of size constraint, mutual coupling, channel correlation and produces a highly directed beam pattern. The qualitative design and analysis of such antenna arrays will enable energy and spectrum efficient future wireless connectivity between thousands of users.

References

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