PHYSICS OF MULTIANTEenna SYSTEMS AND THEIR IMPACTS ON WIRELESS SYSTEMS

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ABSTRACT

The objective of this presentation is to present a scientific methodology that can be used to analyze the physics of multiantenna systems. Multiantenna systems are becoming exceedingly popular because they promise a different dimension, namely spatial diversity, than what was available to the communication systems engineers: The use of multiple transmit and receive antennas provides a means to perform spatial diversity, at least from a conceptual standpoint. In this way, one could increase the capacities of existing systems that already exploit time and frequency diversity. In such a scenario it could be said that the deployment of multiantenna systems is equivalent to using an overmoded waveguide, where information is simultaneously transmitted via not only the dominant mode but also through all the higher-order modes. We look into this interesting possibility and study why communication engineers advocate the use of such systems, whereas electromagnetic and microwave engineers have avoided such propagation mechanisms in their systems. Most importantly, we study the physical principles of multiantenna systems through Maxwell’s equations and utilize them to perform various numerical simulations to observe how a typical system will behave in practice. There is an important feature that is singular in electrical engineering and that many times is not treated properly in system applications: namely, super position of power does not hold, but the principle of superposition does hold for voltages and currents. This is why another name for electromagnetic theory is field theory as the voltages and currents are reflected in the fields and their superposition provides the complete picture. Hence, we need to be careful when comparing the performance of different systems in making value judgments. In addition, appropriate metrics which is valid from a scientific standpoint should be selected to make this comparison. Examples will be presented to illustrate how this important principle impact certain conventional way of thinking in wireless communication.

Also, we examine the phenomenon of height-gain in wireless cellular communication, and illustrate that under the current operating scenarios where the base station antennas are deployed over a tall tower, the field strength actually decreases with the height of the antenna over a realistic ground and there is no height gain in the near field. Therefore, to obtain a scientifically meaningful operational environment the vertically polarized base station antennas should be deployed closer to the ground. Also, when deploying antennas over tall towers it may be more advantageous to use horizontally polarized antennas than vertically polarized for communication in cellular environments. Numerical examples are presented to illustrate these cases.

We next look at the concept of channel capacity and observe the various definitions of it that exist in the literature. The concept of channel capacity is intimately connected with the concept of entropy – hence related to physics. We present two forms of the channel
capacity, the usual Shannon capacity which is based on power; and the seldom used
definition of Hartley which uses values of the voltage. These two definitions of capacities
are shown to yield numerically very similar values if one is dealing with conjugately
matched transmit-receive antenna systems. However, from an engineering standpoint, the
voltage-based form of the channel capacity is more useful as it is related to the sensitivity
of the receiver to an incoming electromagnetic wave. Furthermore, we illustrate through
numerical simulations how to apply the channel capacity formulas in an
electromagnetically proper way. To perform the calculations correctly in order to
compare different scenarios, in all simulations the input power fed to the antennas needs
to remain constant. Also conclusions should not be made using the principles of
superposition of power. Second, one should deal with the gain of the antennas and not
their directivities, which is an alternate way of referring to the input power fed to the
antennas rather than to the radiated power. The radiated power essentially deals with the
directivity of an antenna and theoretically one can get any value for the directivity of an
aperture. Hence, the distinction needs to be made between gain and directivity if one is
willing to compare system performances in a proper way. Finally, one needs to use the
Poynting’s theorem to calculate the power in the near field and not exclusively use either
the voltage or the current. These restrictions apply to the power form of the Shannon
channel capacity theorem. The voltage form of the capacity due to Hartley is applicable
to both near and far fields. Use of realistic antenna models in place of representing
antennas by point sources further illustrates the above points, as the point sources by
definition generate only far field, and they do not exist in real life.

The concept of a multiple−input−multiple−output (MIMO) antenna system is illustrated
next and its strengths and weaknesses are outlined. Sample simulations show that only
the classical phased array mode out of the various spatial modes that characterize spatial
diversity is useful for that purpose and the other spatial modes are not efficient radiators.

Finally, how reciprocity can be used in directing a signal to a preselected receiver when
there is a two way communication between a transmitter and the receiver is demonstrated.
This embarrassingly simple method based on reciprocity, is much simpler in
computational complexity than a traditional MIMO and can even exploit the polarization
properties for effectively decorrelating multiple receivers in a
multiple−input−single−output (MISO) system.