TESTING OF SMART ANTENNA SYSTEMS

Smart antenna systems must be tested to verify the various claims made by the system designer and manufacturer. The tests should be performed primarily to evaluate the most and least successful functions of the system under consideration. Extensive testing should also establish the best and worst propagation environments for system deployment. Most importantly, a comprehensive test of a smart antenna system should generate results that enable the service provider to examine cost vs. benefits based on a full understanding of the system's potentials and limitations. This article focuses on key tests that can be performed on switched-beam systems, which are considered the simplest, but most popular, among smart antenna technologies.

Several smart antenna systems have been deployed or are still under development at base stations in wireless communication networks all over the world. This article discusses the important issue of testing smart antenna systems before they are fully deployed in service. Testing of smart antenna systems is crucial to the service provider as it permits a full understanding of the capabilities and limitations of any candidate system. This testing is also key to making an intelligent decision on the selection of the most suitable system that meets both cost constraints and improved performance objectives.

Most smart antenna systems are designed to operate under specific multiple-access (MA) protocols. In addition, those systems designed for the same MA protocol may cause different assumptions to be made about the spatial and temporal structures of the wireless propagation channel, that is, the channel delay, Doppler and angle spreads as well as the channel joint-spread profiles. If these assumptions are satisfied, and the smart antenna system operates under the MA air interface it was designed for, the respective signal processing algorithms implemented at baseband will enhance the desired signal and remove (or at least attenuate) noise, multipaths and co-channel interferers, leading to improved capacity and range.

BACKGROUND

The basic principle of any communication system is the signal propagation from the transmitter to the receiver. Due to noise and scattering effects, a distorted version of the transmitted signal arrives at the receiver. In wireless communications, the desired signal is not always guaranteed to reach the receiver through a single propagation path (referred to as the direct path or line of sight). The transmitted signal is reflected from remote and local objects and reaches the receiver from other propagation paths after amplitude attenua-

David Robbins
Micronetics Wireless
Hudson, NH
Moeness G. Amin
Villanova University, Department of Electrical and Computer Engineering
Villanova, PA

tion, phase distortion and significant delays. This phenomenon is known as multipath.

Figure 1 shows the effects of multipath, including intersymbol interference (ISI) and co-channel interference (CCI). Multipath (along with other interfering signals competing for the same frequency bands or/and time slots occupied by the desired signal) impairs the radio transmission channel, leads to erroneous decisions at the receiver and produces higher bit error rates (BER). These factors limit both the traffic capacity and the range of the wireless communication network. Channel equalizations and signal processing solutions based on a single antenna receiver have mitigated some of these problems and improved communication quality, but can no longer keep up with the explosive growth in high bit rate digital mobile radio communications.

SMART ANTENNAS

The term smart antenna system refers to innovative signal processing techniques that are implemented efficiently to exploit the directional information of wireless communication network users. This directional/spatial information is carried by the users' respective waveforms and can be obtained only by using a multiple antenna receiver. The smart antenna is today's means of improving wireless data communications, including cellular, PCS and third-generation wideband CDMA systems, beyond the level already achieved through channel re-use and various modulation techniques.

The main objectives of any smart antenna system are reduction of ISI, removal of CCI, mitigation of adjacent-channel interference, enhancement of spectrum efficiency, improvement of BER, reduction of outage probability, improvement of transmission efficiency and reduction of hand-off rate and crosstalk. In turn, all of these desired effects result in improved capacity, range and frequency re-use. These objectives may be accomplished through steering nulls in the direction of co-channel interferers and multipaths, steering a beam toward the user's direct path or direct and multipaths, and increasing the signal-to-interference-and-noise ratio at the array output.

THE IMPORTANCE OF TESTING

In light of the numerous important smart antenna system offerings, the designers, developers and manufacturers of these systems are excited about their deployments in both outdoor and indoor communications and for serving wireless networks with various structures and protocols. On the other hand, service providers continue to assess this new technology and study its short- and long-term benefits to justify the cost of purchasing, installing, integrating, maintaining and updating a smart antenna system.

The two main deciding factors in the selection of an appropriate smart antenna system are the serviced urban/rural environment and the type of MA air interface (FDMA, TDMA or CDMA) protocol utilized. Once a smart antenna system is deployed in an environment that matches the presumed propagation conditions and communication channel characteristics properly, the service provider anxiously awaits the results and payoffs of this multiple antenna receiver (namely a significant increase in network capacity and range). With smart antennas in place and operational, the expectation is that more users can be added to the same network and that the network can be accessed from a longer distance than in the case of a single antenna receiver.

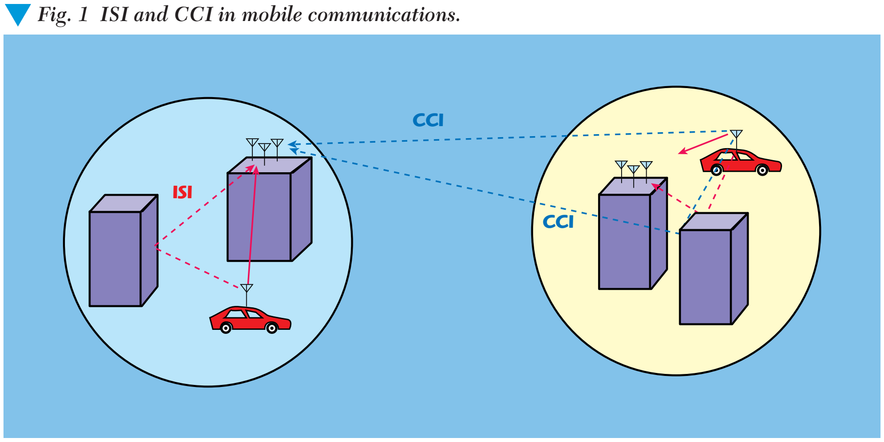
It is natural to assume that for any smart antenna system, a specific favorable setting (or range of settings) exists for the different parameters and statistical variables involved in defining the operating propagation environment. At these settings, the smart antenna performance is indeed at its best and its offerings are clear, crisp, cost justifiable and most convincing. On the other hand, at least one (or more) opposite setting probably exists in which smart antenna offerings are marginal, questionable and have a meager impact on enhancing spectrum efficiency.

Smart antenna systems must be tested to verify the various claims made by the system designer and manufacturer. The test should be performed primarily to evaluate the most and least successful functions of the antenna system in question as well as to assess the most and least suitable propagation environments for system deployment. A comprehensive smart antenna test should generate results that enable the service provider to make an intelligent decision on adopting an appropriate smart antenna system, evaluate the overall performance gain and short- and long-term benefits vs. need and cost, and deploy the right smart antenna system at the right base stations where multipath signatures and fading patterns are more tolerable of this specific system. In addition, the testing should enable the service provider to set the proper frequency re-use factor in light of the system's capability to combat CCI, determine the size of each cell in view of the smart antenna beamforming and nulling characteristics, and provide all of this information to the antenna manufacturer as valuable feedback to be considered for adjusting, tuning and extending the product strength and increasing its marketability.

SWITCHED-BEAM SYSTEMS

One of the most popular smart antennas is the switched-beam system in which multiple beams are formed by selecting several sets of steering

Fig. 1 ISI and CCI in mobile communications.



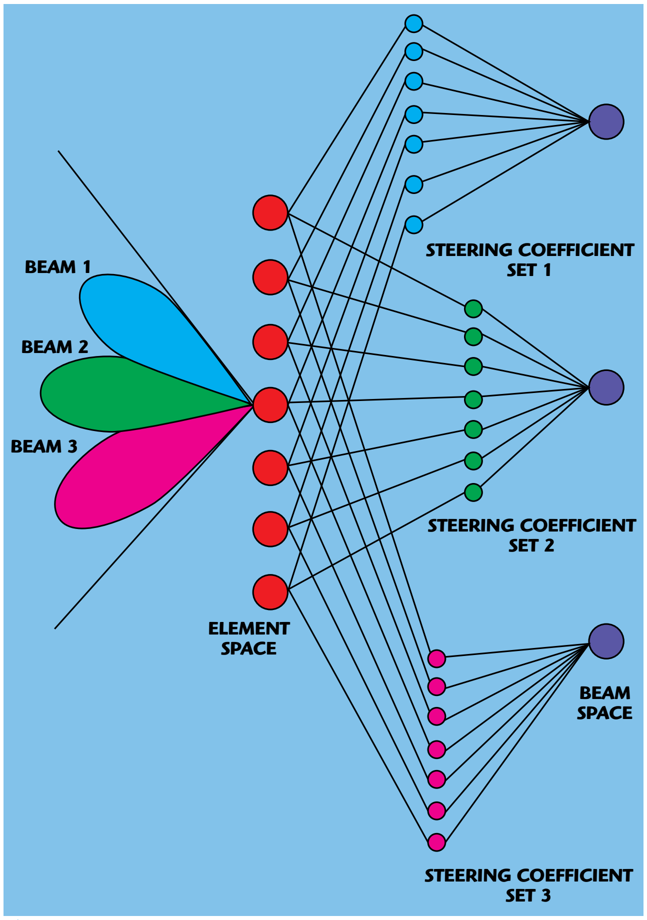


Fig. 2 Steering coefficients for switched-beam systems.

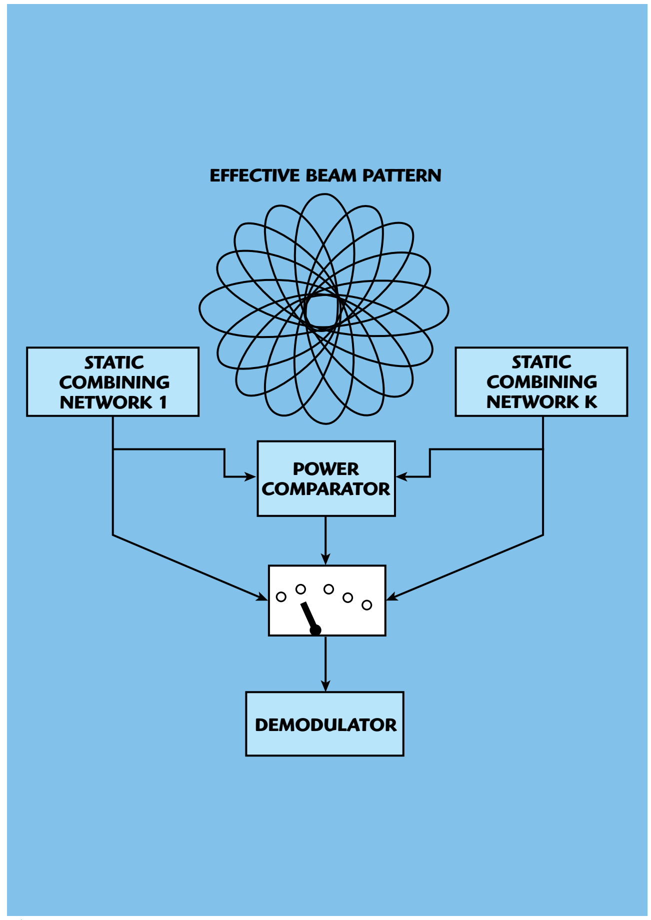


Fig. 3 A switched-beam smart antenna system.

coefficients, as shown in ***Figure 2***. Scanning receivers monitor the signal level for each beam at every assigned channel frequency (and time slot for TDMA systems), as shown in ***Figure 3***. Out of K constructed beams, typically the beam with the highest signal for the frequency assigned to the mobile unit is switched to the corresponding base station receiver. More sophisticated methods for selecting the most appropriate beam for each user probably exist. Any beam can be switched to any receiver, and all receivers can be connected to a single beam. Provided that the channel is slowly varying over frequency (time), in multibeam operation the same beam is used for both uplink and downlink operation in the assigned frequency band (time slot). This relatively simple architecture can be applied as an add on (appliqué) to existing base station equipment.

The main test objective in switched-beam smart antenna systems is to evaluate the system's response and performance as the user's position and angular spread change relative to the fixed beams' directions and bandwidths. The amplitude and direction of the multipath and CCI components of the signal arrivals can be set to confuse the receiver and thereby deteriorate system performance. These components can also be chosen to enhance system performance. In testing, an option should be provided to select the undesired components to fall onto the tip of one of the predetermined fixed system beams and, in turn, be received with a gain that is equal to or even higher than that provided to the desired user signal. These components can also be selected to fall in between beams and thus be received with much smaller gain and sensitivity than the user signal.

Testing smart antennas based on switched-beam technology should demonstrate the effective way the scanning receiver switches traffic channels among fixed beams, the frequency of locking onto interferers (beam falsing), the system's switching patterns in a multipath environment and the interference rejection capability of the system vs. azimuth and elevation angles. The test should also determine how the system combats flat fading and dispersive channels, how it tolerates large angular spread of the mobile and spatial dispersion, how sensitive the system performance is to the spatial distribution around the nominal direction and how the system performance is dependent on the fading correlations between the various array elements. All of these performance indices can be evaluated easily and compared with a single antenna case. Single antenna performance is provided by feeding the data to only one element of the array and ignoring the rest.

CONCLUSION

The importance of testing smart antenna systems prior to deployment at base stations serving specific environments and using specific MA air interface protocols has been addressed. The main purpose of performing such testing is to allow the service provider to gain confidence in the smart antenna system under consideration and to become acquainted with its potential and limitations. This article has focused on the various issues related to testing smart antenna systems that implement switching technologies. It was noted that testing the system using propagation channel parameter settings similar to and slightly or significantly different from those assumed by the manufacturer is key to understanding the offerings of the smart antenna system and to developing realistic performance expectations. ■

References

1. D. Robbins and M. Amin, "Cellular Mobile Radio Communication Channels in View of Smart Antenna Systems," *Microwave Journal*, Vol. 41, No. 4, April 1998, pp. 74–86.
2. A. Paulraj and C. Papadias, "Space-time Processing for Wireless Communications," *IEEE Signal Processing Magazine*, November 1997, pp. 49–83.
3. L. Godara, "Applications of Antenna Arrays to Mobile Communications, Part I: Performance Improvement, Feasibility and System Consideration," *Proceedings of the IEEE*, July 1997, pp. 1029–1069.
4. *Advanced Signal Processing Applications in Wireless Communications Proceedings*, Philadelphia, PA, October 1996.
5. *Proceedings of the Fifth Workshop on Smart Antennas in Wireless Mobile Communications*, Stanford University, Stanford, CA, July 1998.

David Robbins *received his BSEE from Southern Massachusetts University in 1986. That same year, he began his career at Micronetics Wireless as a design engineer creating fast, high performance RF switch components and overseeing their development. From 1990 to 1992, he was a senior design engineer at Alpha Industries. In 1992, Robbins returned to Micronetics as an engineering manager. In 1995, he was promoted to VP, engineering, a position he held until his 1997 promotion to COO. During his tenure at Micronetics, Robbins' product designs have been awarded two US patents.*

Moeness Amin *received his PhD degree in electrical engineering in 1984 from the University of Colorado, Boulder. He has been on the faculty of the department of electrical and computer engineering at Villanova University since 1985 and is now a professor. Currently, Amin is an associate editor of the* IEEE Transactions on Signal Processing *and a member of the technical committee of the IEEE Signal Processing Society on Statistical Signal and Array Processing. He was general chair of the 1994 IEEE International Symposium on Time-frequency and Time-scale Analysis. Amin's current research interests are in the areas of time-frequency analysis, spread spectrum communications, smart antennas and blind signal processing.*