Adopting multi-antenna signal processing in wireless networks

Wireless operators are increasing their focus on data and multimedia services to drive revenue growth. This is creating demands for substantially improved radio equipment performance. Unfortunately, years of innovation in wireless have left little new technology ore to be mined for performance improvements. Multi-antenna signal-processing (MAS) software provides more control over the spatial distribution of radio energy, yielding well-proven order-of-magnitude performance improvements. As a result, MAS is being embraced as a key part of next-generation wireless networks like 3.5G, 3G-LTE and WiMAX.

By Steven Glapa

Multi-antenna signal processing or MAS, also known as smart antennas, space-time processing, or multi-input, multi-output (MIMO), can quickly lead to detailed technical discussions, which we plan to explore in this article on specific implementations. It attempts to provide more commercial context for the drivers of adoption in 3.5G, 3G-LTE and WiMAX standards, to help system designers understand more fully why the performance gains being pursued are so critically important to the industry. Also, MAS may mean many different things to different users, but in this article we are focusing on the software part of the processing.

Wireless network operators are pursuing new sources of revenue growth as their current voice service markets become saturated, and as competition pushes down voice revenues per user (ARPU) despite rising usage. Non-voice service menus now go beyond just ring tones and SMS to include mobile video, Internet access, and myriad new applications, from on-line gambling to location-based traffic updates and m-commerce wallet functions.

The revenue share of data services in Asian markets is already on firm footing (DoCoMo in Japan[1] and SKT in Korea[2] both receive 27% of ARPU from non-voice services today), and the rest of the world is catching up (19% of ARPU for Vodafone in Europe, and 11 % to 12% for the major U.S. operators[1, 2]). All indications point to continued solid growth ahead.

Conversation about services beyond voice often glosses over an important point. The fundamentals of subscriber economics and experience metrics for data and video are substantially different from those for voice. Figure 1 tells a stark story about the economics of data and video. Using current mass-market prices in the United States to indicate subscriber value for voice, data and video services, dividing by the capacity they consume on average for each of these media every month, yields a dramatic illustration of the differences in willingness to pay per unit of capacity consumed. The conclusion: voice, data and video services are worth roughly $1.00, $0.10 and 0.3¢ per MB to subscribers, respectively. (For reference, on-demand movies alone net out to about 0.9¢ per MB.) A wireless cost structure that supports voice will require immense changes in the long run to profitably support mass-market data and multimedia services.

And what about a "mobility premium" for these wireless services? Note that cellular voice didn't reach mainstream adoption till its prices approached those of wired telephony. Furthermore, leading indicator networks in Australia[1] show minimal premiums for truly mobile

broadband access in practice. It appears that in the long run the service premium for mobility is small.

The other fundamental difference for non-voice services is client data rate. With voice, it is difficult for a subscriber to see or hear performance beyond the largely binary feedback of "has my call been dropped or not?" In contrast, with high-bandwidth applications like broadband Internet access or mobile video, the new dimension of client data rate becomes immediately obvious to users. They can watch their download or upload data rate—or video frame rate and quality—climb as they approach a base station in the network and then slow to a crawl as they reach a point of minimum signal and maximum interference at the cell edge. Product or service reviewers in the press can do their own thorough performance tests, and credible word-of-mouth reports on this performance metric have already spread quickly on the Internet. This spells new stress for operators and manufacturers concerned about share positions and brand assets.

Tapping space

The question now is, how can >10x performance improvements be achieved? While a number of approaches are being considered, the likely gains are marginal. However, there is plenty of ore left to be mined in the vein of radio system design by more fully using the dimension of space—in fact, at least 10x in the immediate future and a lot more in the long term. And, the mining of space need not wait for new innovation. It requires merely vigorous application of MAS technology that's already well proven.

Current wireless networks employ comparatively blunt instruments for the distribution of radio energy in physical space (Figure 2). As illustrated in the signal-pattern diagram of Figure 2, this approach creates vast amounts of waste in the system. Power is distributed where subscribers aren't and self-interference is created that degrades signal quality.

An approach using MAS software, in contrast, takes precise control of the space dimension and puts radio energy only where it's really required (Figure 2). MAS software drives an array of two or more antennas on either the client device, the base station, or both, leveraging the principle of coherent combinations of radio waves to create a focus of transmit energy (or receive sensitivity) on the intended recipient (sender) and the absence of energy (sensitivity) on sources of co-channel interference. MAS-enabled devices can take advantage of a number of possible gains from using multiple antennas, including link budget improvements from both diversity and combining gains, along with client data rate and overall network capacity benefits from active interference mitigation and spatial multiplexing.

Figure 3 illustrates how these different categories of MAS benefits add up to improve the overall performance envelope for wireless systems. Figure 4 shows how MAS software fits into common base station and client device architectures.

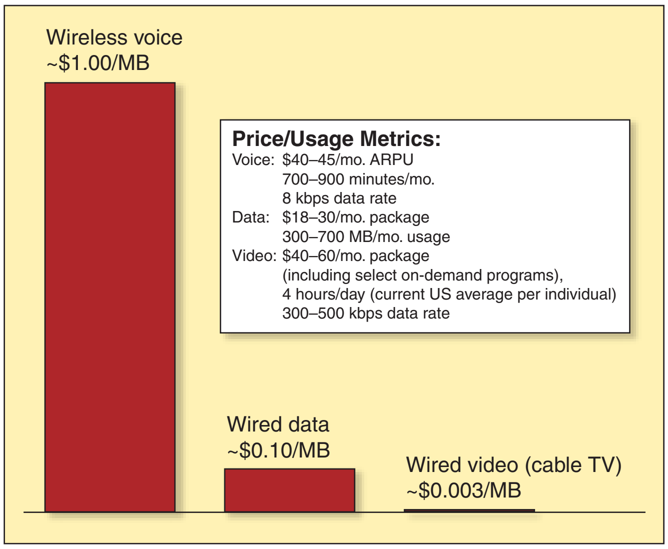

Figure 1. When expressed as willingness to pay per unit of network capacity consumed, subscriber behavior for voice, video, and data services show dramatic differences in fundamental economics[1].

MAS for next-generation systems

In response to operator's demands for performance improvement, MAS takes different forms in existing networks and in next-generation mobile broadband networks.

Operators rolling out services based on HSDPA and EV-DO technology are discovering the client data rate problem previously outlined. They are finding that their existing 3G network footprint creates "Swiss cheese" coverage for high data-rate services, and that their suppliers' client devices' performance varies widely from one model to the next.

Because there are often significant constraints on deploying MAS-based infrastructure solutions in existing networks, 3.5G operators are urging their client device suppliers to develop MAS implementations on the client side. In response, Qualcomm has added receive diversity and some simple coherent-gain processing to its chipsets, and EV-DO data cards from Sierra (for example) have implemented

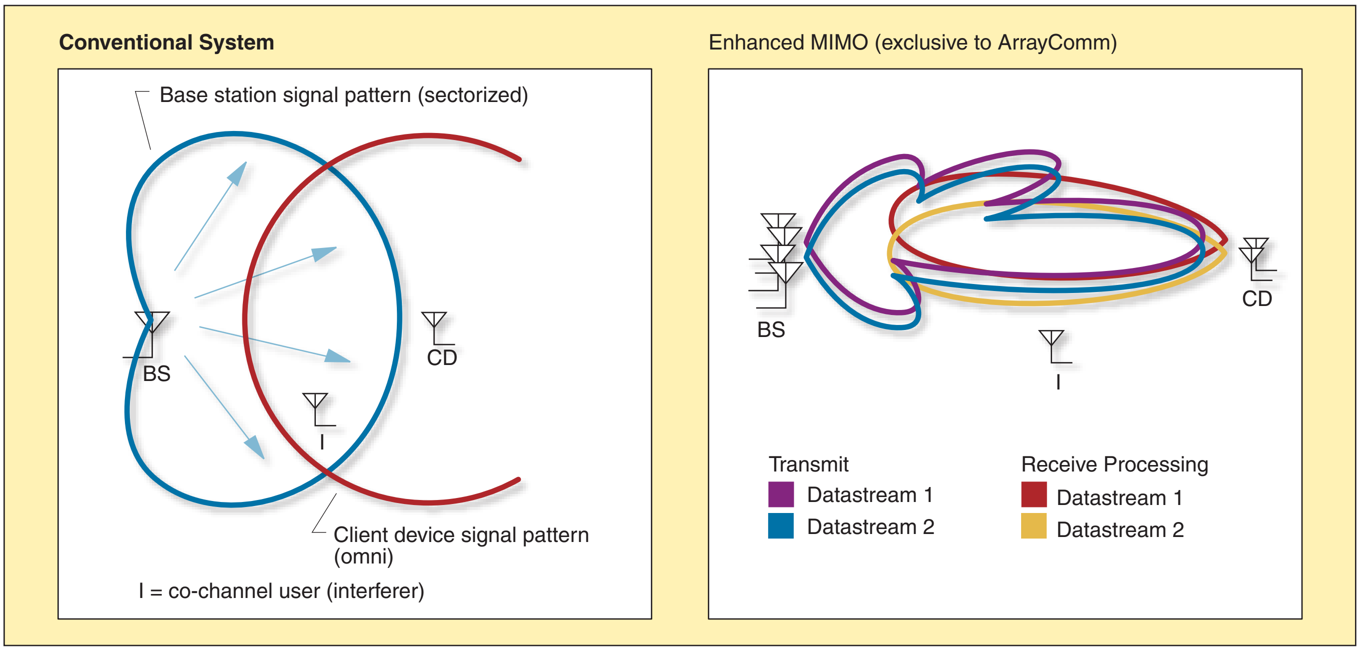

Figure 2. Multi-antenna signal processing enables much tighter control over the distribution of radio energy in space.

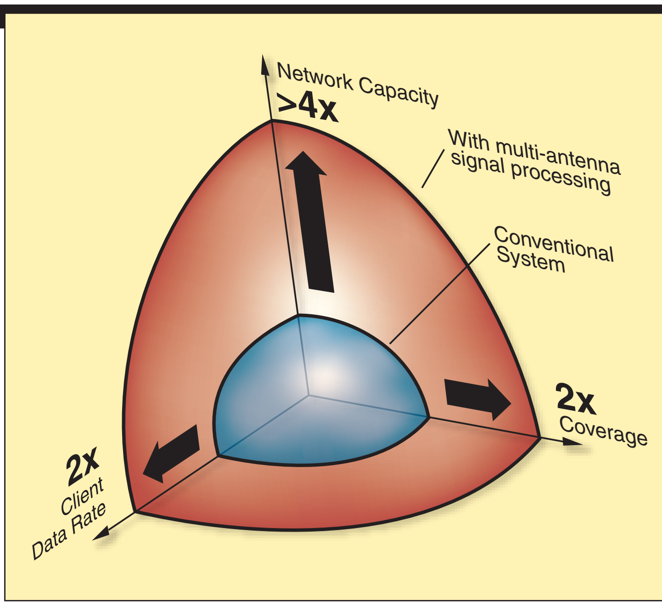

Figure 3. MAS software drives significant improvements in wireless device and system range, client data rates, and capacity.

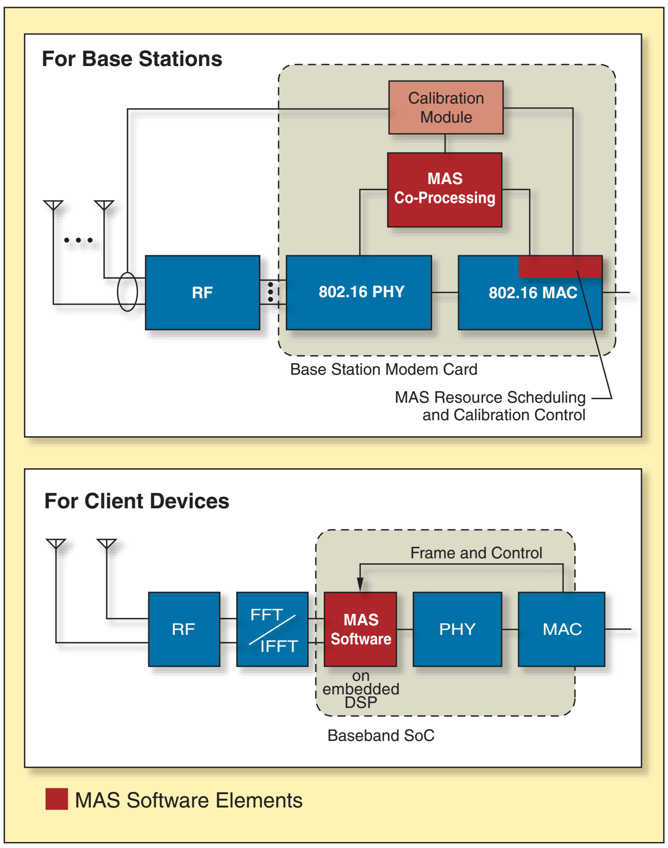

Figure 4. MAS software operates between the analog front end and the digital baseband of either base station or client device architectures.

two-antenna solutions on this basis. Others are working to catch up on diversity solutions, as well. To indicate what's coming next in this area, Figure 5 shows the output of detailed real-world network simulation (using a European operator's planning tool and network configuration) for ArrayComm solutions that add interference mitigation to the diversity+combining baseline established by Qualcomm. Even in lightly loaded networks, interference from the neighboring base station or a single dominant co-channel user can substantially degrade data rates at cell edges. Adding a second antenna to the client allows

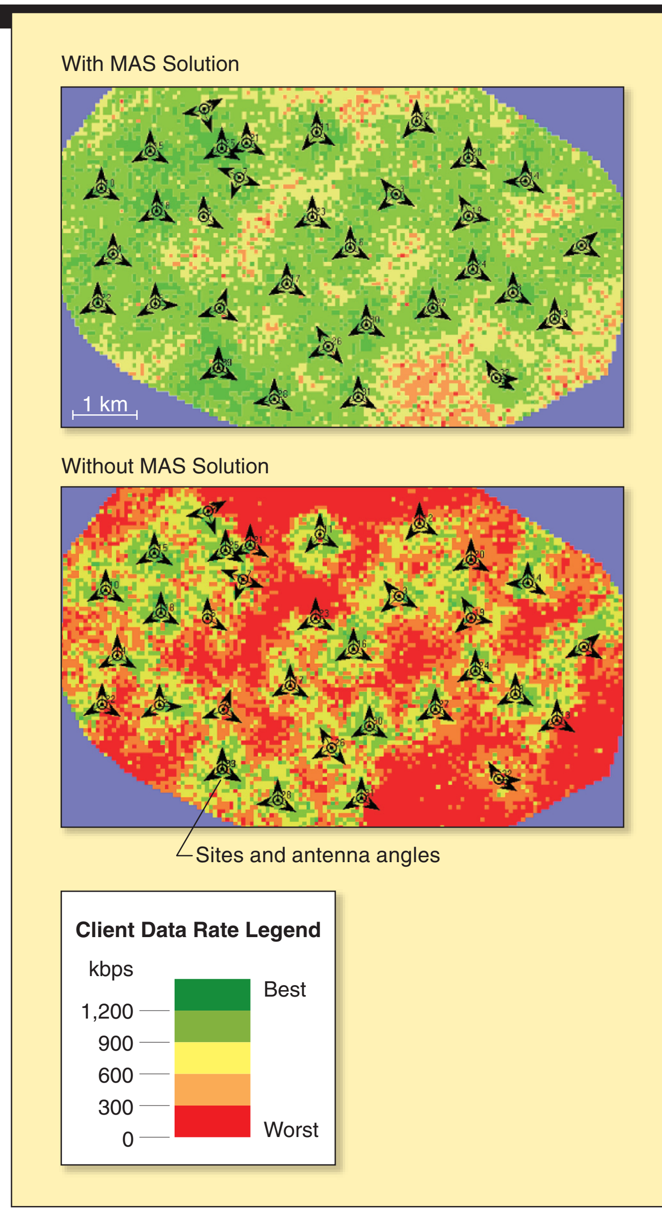

Figure 4. MAS-enabled client devices in HSPA networks deliver more than 2x improvement in subscriber experience.

it to ignore a number of co-channel interferers, with significant net results—more than doubling data rates throughout the network in real-world conditions. These interference-cancellation techniques continue to advance in the 3GPP RAN4 discussions of future interoperability standards for 3G client devices.

Likewise, the 3GPP discussions of 3G long-term evolution (LTE) and the Mobile WiMAX profiles established in the WiMAX Forum process are both embracing the combination of orthogonal frequency-division multiplexing (OFDM) and MAS architectures.

Not all MAS approaches are equal

Many approaches to MAS concepts have been attempted over the past 15 years. Some early trials involved large, expensive, and precisely calibrated arrays that in the end didn't work well, and some involved so-called "appliqué" solutions—aftermarket add-on boxes that also yielded generally poor performance because of limited integration with the existing radio hardware and necessarily unsophisticated algorithms.

As the MAS software source with 14 years of experience in the field, the company can offer a few guidelines for MAS implementation.

A technical discussion of specific algorithms is beyond the scope of this article, but here are some general principles:

■ **Do your homework thoroughly:** Many tools for network or economics analysis and performance simulation from single-antenna domains (e.g., interference averaging) yield misleading results when applied to MAS-enabled gear. Getting MAS analysis right is admittedly more complicated, but essential.

■ **Think integrated:** The highest performance for the least marginal unit cost is obtained by integrating MAS into client and infrastructure designs from the outset, not adding them on after the fact.

■ **Consider network performance, not just the link:** MAS modes that achieve useful results for an individual link (e.g., the baseline form of STC MIMO in WiMAX) can fail in a multicell, multi-user context. Network-level analysis of fully loaded systems is essential.

■ **Use multiple approaches:** Use the right tool for the job. Operator requirements and subscriber behaviors vary from one market to another and from one moment to another. Different MAS architectures have unique strengths and weakness in different applications—there is no single "best" approach. It is much better to include all approaches in the system (possible, since this is software) and let environmental conditions dictate which one is used.

This brings us to anticipate dynamic, seamless use of all approaches. It has been shown in the PHS implementation, where eight different MAS algorithms are selected on the fly for optimized performance—on a frame-by-frame and user-by-user basis—that MAS architectures can be dynamic systems. Many levels of radio system control (beyond individual cells to the network level, for example) can be incorporated into this sort of self-organizing optimization process. RFD

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