Developments and Advances in Smart Antennas for Wireless Communications

a report by
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The exponential growth of wireless communications systems and the limited bandwidth available for those systems has created problems that a large number of companies are working to resolve. A potential solution to the bandwidth limitation is smart antennas, a concept initially developed by the military but now a field that has attracted growing interest for commercial wireless systems. Advances in digital signal processor (DSP) and central processing unit (CPU) capabilities, improved smart algorithms and experimental validation of smart antenna systems, have created an environment in which it is feasible and cost-effective to use smart antennas in a variety of wireless markets.

Activity in the smart antenna space has been quite busy due to the major benefits that smart antenna systems provide. First, the effect of multipath fading in wireless communications environments can be significantly reduced. Since the reliability and quality of a wireless communications system can depend strongly on the depth and rate of fading, this reduction of the variation of the signal (i.e. fading) results in a more robust communications link (preventing dropped calls, dead spots in the network, etc.). Second, handsets used with smart antenna systems have longer battery life because the power required to transmit to the base station is lower than that for a conventional system. This is because the antenna array at the base station achieves antenna diversity gain and nullifying gain, reducing the required transmit signal level for the handset. Third, smart antennas improve the quality of service (QoS) of a network through range extension, hole filling and better building penetration. Those QoS advantages result in a reduced cost of infrastructure for smart antenna systems. Finally, the smart antenna system can be used to increase system capacity, which is often limited by the signal-to-interference ratio (SIR). A smart antenna system can improve the SIR of a wireless communications system significantly and thus increase the capacity of the system significantly.

Smart antenna systems do not actually use different types of antennas, contrary to some people's assumptions. The system uses multiple antenna elements on at least one side of the communications link and utilises signal-processing algorithms to achieve its advantages. The way in which signals from the multiple antennas are processed, usually at the baseband, is what makes the system 'smart'. There are many levels of smart antenna systems, ranging from those that require minimal processing to extremely advanced systems requiring antenna arrays at both the transmitter and receiver.

Switch diversity is an extremely simple version of smart antennas, where the signal from the antenna with the highest signal power, or signal-to-noise ratio (SNR), is chosen for processing and the signals from the other antennas are discarded. The idea behind this is that a signal can experience a large drop at one antenna due to multipath fading but have minimal fading (or even an increase in received power) at a neighbouring antenna. This increases the range and reliability of a system and is relatively inexpensive to implement. These types of systems have become extremely popular, used by virtually every cellular base station and wireless local area network (WLAN) access point. However, switched-beam systems have a number of severe limitations. That they are typically unable to combine coherent multipath components to take advantage of path diversity and that they are not able to provide any protection from multipath components that arrive at angles near the desired signal are two of the more serious limitations.

Beam-forming techniques have been studied to achieve greater performance enhancements than are attainable using switch diversity. These types of systems are generally used when the base station has multiple antennas and the mobile users are using conventional types of antennas (which includes switch diversity and single antenna systems). The signal received by each antenna element is multiplied by a weight vector and the signals are then combined. The weight vectors are computed to maximise the quality of the received signal according to the selected cost function. For downlinks, the weight vector for each antenna is applied before the signal is transmitted by each antenna. The cost function can be selected to maximise the range of the network (ideal for rural cellular environments or for extending the range of 802.11 systems[1]) or to reduce co-channel interference (ideal for Code Division Multiple Access (CDMA)-type systems with numerous co-channel users) to increase capacity, with trade-offs between range and capacity achieved.

Spatial Division Multiple Access (SDMA) systems can be used with virtually any current wireless standard, utilising beam-forming and other algorithms (scheduling, etc.) to boost the capacity of conventional systems. For example, conventional GSM™/GPRS allows one user at a time to transmit or receive in a frequency band to the base station, where GSM/GPRS with SDMA allows multiple simultaneous transmissions in that same frequency band, multiplying the capacity of the system. CDMA system capacity is limited by its SIR, hence, with SDMA boosting the SIR in the system, the network will be able to handle many times more users.

It has been projected that there will be more than one million smart antenna base stations in use for personal communications systems (PCS)/3G systems by 2006.[2] There are numerous examples of companies in this space:

- Arraycomm has installed over 100,000 smart base stations, with 60,000 of them for personal phone systems in Japan. They claim that their equipment cost is just 15% higher than conventional equipment for up to three to seven times capacity improvement.

- Metawave had sold over US$100 million in smart antenna products and services by July 2001, and are installed in 13 of the 20 largest US cellular markets. They claim up to a three times capacity increase with adaptive beam-forming.

- Wireless Online's smart base station had 60% less dropped calls and an 18 decibel carrier-to-interference ratio increase.

- Ericsson has results showing that they can add one smart base station for every 2.5 conventional base stations they would have added in an example scenario.

- Nortel and Sprint had smart antenna trials that doubled the capacity for a CDMA system.

- Lucent has announced that embedded smart antenna solutions for all of their 3G base stations will be added to their product lines in 2004 or 2005.

- Navini recently signed an agreement with Sprint and provides a broadband Internet solution, with up to 50% lower total cost of ownership than digital subscriber line or cable, and up to 70% lower total cost of ownership than 1G fixed-wireless systems.

The sluggish economy over the past year, combined with the fierce competition in this space, has resulted in some casualties and consolidations. For example, in June 2002, Wireless Online closed and Metawave laid off 42% of its workforce. However, new competitors are regularly emerging, and recent start-ups have advertised a three-times capacity gain for far less cost than current products.

The WLAN market has also been a breeding ground for smart antenna development, driven by the limitations of 802.11 products and the amazing rate of growth of 802.11 deployments.[1] 802.11b, or wireless fidelity (Wi-Fi), is being adopted virtually everywhere and 802.11a and 802.11g provide interesting higher-throughput alternatives to 802.11b. Virtually every access point currently uses switching diversity. A number of companies have been looking at using beam-forming to boost the range of 802.11 systems and some have been looking at increasing the range by using directional antennas, with the access point providing coverage in sectors (similar to what is undertaken now in the cellular world). However, this sectorisation comes with increased cost and complexity. Several wireless LAN start-ups have looked at implementing SDMA for 802.11, achieving up to five times the range and up to eight times the capacity of conventional access points.

The highest level of smart antennas, in terms of complexity and performance, is called multiple-input/multiple-output (MIMO). In these types of systems, both the transmitter and receiver have multiple antennas, which allows for significantly better performance than other smart antenna techniques. However, this is not really compatible with current PCS/3G or 802.11 standards, so it mainly is being looked at for fixed wireless (multipoint multimedia distribution systems, local multipoint distribution system) scenarios.

Several papers in this area have been published in the past three years and a growing number of companies are studying MIMO for future use. Several companies have been created recently that are trying to commercialise MIMO systems and number of larger companies are also studying this area.

The following reasons explain why smart antenna-enabled systems have not been deployed more widely:

- DSP and CPU speeds need to be fast enough to handle the increased computations needed for smart antenna algorithms to be able to be

1. *802.11 refers to a family of specifications developed by the Institute of Electrical and Electronics Engineers, Inc. (IEEE) for wireless LAN technology. 802.11 specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. The IEEE accepted the specification in 1997.*
2. *Allied Business Intelligence.*

implemented in realtime. This was a big problem until 1999 or so, particularly for low-cost solutions. However, computing power has now progressed to the point where smart antenna systems can feasibly be installed using inexpensive processors.

- The value proposition provided by smart antenna systems needs to outweigh the additional cost of a smart antenna system. In the early days of advanced mobile phone systems, one base station could cover a large area and there was no need for multiplying the capacity of a base station. Today, when microcells and picocells need to be used at times and spectrum is a precious commodity, the differentiation that smart antennas provide justifies the additional cost in a variety of scenarios. As the value of the capacity/range of a system grows to clients and the cost of implementing such systems drops due to continual advances in the field, it is expected that the usage of smart antennas will continue to grow.

- The number of people that truly understand how smart antennas work is limited. Each year the number of people in this group grows, especially due to National Science Foundation funding and commercial projects, but the supply of experts is limited. A serious problem is the lack of universities offering classes in smart antennas.

- Decision-makers in the wireless industry have experienced a high level of scepticism about implementing smart antennas, partly due to a lack of understanding on the subject and partly because the systems were not proven to work in commercial environments. The successes have helped to assuage those worries, as have the various test-beds created by academia.

The increasing demand for wireless voice/data access and the limited bandwidth available creates a demand for solutions that increase system capacity. Complaints about the QoS of current wireless implementations creates a demand for solutions that reduce dropped calls, eliminate dead spots, boost battery life and maximise interference suppression. Increasing pressure to reduce costs creates a demand for solutions that increase the range of a wireless device, reducing the number of base stations needed to cover the same area.

All of these needs can be addressed via smart antenna systems, and work is currently under way to bring the next generation of smart antenna-enabled products to the marketplace as soon as possible. By 2005, smart antennas will transition from a largely unknown technology to a valuable option for all wireless communication applications. ■