Chapter 1
Introduction

As the signal arriving from a receding deep-space spacecraft becomes weaker and weaker, the need arises for devising schemes to compensate for the reduction in signal-to-noise ratio (SNR). With maximum antenna apertures and lower receiver noise temperatures pushed to their limits, one remaining method for improving the effective SNR is to combine the signals from several antennas. This is referred to as arraying, and it has enabled the National Aeronautics and Space Administration (NASA) Deep Space Network (DSN) to extend the missions of some spacecraft beyond their planned lifetimes. A related benefit provided by arraying has been its ability to receive higher data rates than can be supported with a single antenna. As an example, symbol-stream combining was used to array symbols between the Very Large Array (VLA) radio telescope, located in New Mexico, and Goldstone's antennas, located in California, during Voyager's encounter at Neptune [1,2]. That technique increased the scientific return from the spacecraft by allowing data transmission at a higher rate. In general, arraying enables a communication link to operate in effect with a larger antenna than is physically available.

Antenna arraying can be employed with any signal modulation format, be it binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), continuous phase modulation (CPM), etc. In this discussion, the NASA standard deep-space signal format will be used to illustrate the different arraying techniques, but the results can be extended to other formats, including suppressed carrier.

This monograph compares the various arraying algorithms and techniques by unifying their analyses and then discussing their relative advantages and disadvantages. The five arraying schemes that can be employed in receiving signals from deep-space probes are treated. These include full-spectrum combining (FSC), complex-symbol combining (CSC), symbol-stream combining (SSC), baseband combining (BC), and carrier arraying (CA). In addition, sideband aiding (SA) is also included and compared even though it is not an arraying scheme since it employs a single antenna. Combinations of these schemes are also discussed, such as carrier arraying with sideband aiding and baseband combining (CA/SA/BC) or carrier arraying with symbol-stream combining (CA/SSC), just to name a few. We discuss complexity versus performance trade-offs, and the benefits of reception of signals from existing spacecraft. It should be noted here that only the FSC method has application for arraying of signals that are not telemetry. Consequently, all of the analysis and comparisons referred to above are done using telemetry signals. There is no reason to believe that the performance of FSC on non-telemetry signals will not yield similar results.

The most recent implementation of arraying for telemetry within the DSN is the Goldstone array [3], which supports full-spectrum combining of up to six antennas within the complex. Specific techniques that are used in this array are discussed, and results from several experiments are presented. Finally, directions for future research and implementation are discussed.

1.1 Benefits of Arraying

Arraying holds many tantalizing possibilities: better performance, increased operational robustness, implementation cost saving, more programmatic flexibility, and broader support to the science community. Each of these topics is discussed further in the following sections.

1.1.1 Performance Benefits

For larger antennas, the beamwidth naturally is narrower. As a result, antenna-pointing error becomes more critical. To stay within the main beam and incur minimal loss, antenna pointing has to be more precise. Yet this is difficult to achieve for larger structures.

With an array configuration of smaller antennas, antenna-pointing error is not an issue. The difficulty is transferred from the mechanical to the electronic domain. The wider beamwidth associated with the smaller aperture of each array element makes the array more tolerant to pointing error. As long as the combining process is performed with minimal signal degradation, an optimal gain can be achieved.

Arraying also allows for an increase in effective aperture beyond the present 70-m capability for supporting a mission at a time of need. In the past, the Voyager Mission relied on arraying to increase its data return during Uranus and Neptune encounters in the late 1980s. The Galileo Mission provides a recent example in which arraying was used to increase the science data return by a factor of 3. (When combined with other improvements, such as a better coding scheme, a more efficient data compression, and a reduction of system noise temperature, a total improvement of a factor of 10 was actually realized.)

Future missions also can benefit from arraying. These include the class of missions that, during certain operational phases, require more performance than a single antenna can offer. For example, the Cassini Mission requires only a single 34-m antenna during cruise phase, but upon entering the Saturn orbit, in order to return 4 Gbits/day mapping data, it will need an array of a 70-m and a 34-m antenna [4]. Missions that need to relay critical science data back to Earth in the shortest possible time also are potential beneficiaries. The Stardust Mission, for example, can reduce single-event risk by increasing the data rate for its encounter with the Wild 2 comet in 2004.

1.1.2 Operability Benefits

Arraying can increase system operability. First, higher resource utilization can be achieved. With a single-aperture configuration, a shortfall in the 34-m link performance will immediately require the use of the 70-m antenna, increasing the potential for over-subscription of the 70-m service. In the case of an array, however, the set can be partitioned into many subsets supporting different missions simultaneously, each tailored according to the link requirements. In so doing, resource utilization can be enhanced.

Secondly, arraying offers high system availability and maintenance flexibility. Suppose the array is built with 10 percent spare elements. The regular preventive maintenance can be done on a rotating basis while allowing the system to be fully functional at all times.

Thirdly, the cost of spare components would be smaller. Instead of having to supply the system with 100 percent spares in order to make it fully functional around the clock, the array offers an option of furnishing spares at a fractional level.

Equally important is the operational robustness against failures. With a single resource, failure tends to bring the system down. With an array, failure in an array element degrades system performance but does not result in a service shutdown.

1.1.3 Cost Benefits

A cost saving is realized from the fact that smaller antennas, because of their weight and size, are easier to build. The fabrication process can be automated to reduce the cost. Many commercial vendors can participate in the antenna construction business, and the market competition will bring the cost down further.

It is often approximated that the antenna construction cost is proportional to the antenna volume. The reception capability, however, is proportional to the antenna surface area. For example, halving the antenna aperture reduces the construction cost of a single antenna by a factor of 8; however, four antennas would be needed to achieve an equivalent aperture. The net advantage is an approximate 50 percent cost saving. Note, however, that antenna construction is only a part of the overall life cycle cost for the entire system deployment and operations. To calculate the actual savings, one needs to account for the cost of the extra electronics required at multiple array elements and the cost related to the increase in system complexity. Reference [5] documents the most recent DSN effort in estimating such cost.

1.1.4 Flexibility Benefits

Arraying offers a programmatic flexibility because additional elements can be incrementally added to increase the total aperture at the time of mission need. This option allows for a spread in required funding and minimizes the need to have all the cost incurred at one time. The addition of new elements can be done with little impact to the existing facilities that support ongoing operations.

1.1.5 Science Benefits

An array with a large baseline can be exploited to support science applications that rely on interferometry, such as very long baseline interferometry (VLBI) and radio astronomy. With future development of the large array described in Chapter 10, the DSN implementation would be synergistic with the international Square Kilometer Array (SKA) effort. Such a system, if implemented in time, can serve as a test bed for demonstration of capability, albeit on a smaller scale.

References

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