Optical Communications for the Long Wavelength Array

Patrick C. Crane
30 September 2006

I will summarize what I have learned about optical-fiber technology in the last six months and outline a plan for its use in the Long Wavelength Array.

I. Technologies for data transmission

There are three distinct technologies for transmitting data on optical fibers:

1. The older technology for transmitting one data stream down a fiber. This hardware is probably the least expensive. Because the marginal cost of installing more fibers is low, when we are installing our own fiber, it may be optimum to use additional fibers and this inexpensive hardware instead of using wavelength division multiplexing (WDM).

2. The widest bandwidth data can be transmitted using dense wavelength division multiplexing (DWDM) using channel spacings of 100 (~0.8 nm), 50, or 25 GHz to support as many as 160 colors in a single fiber, each supporting data rates as great as 10 Gbps or even 40 Gbps (if consistent with channel spacings). The reference frequency is 193.10 THz (1552.52 nm). Because of the very stringent frequency tolerances, the supporting hardware requires stringent temperature stability (i.e., cooled lasers and filters) and is by far the most expensive to purchase and use.

3. Intermediate in cost and complexity is coarse wavelength division multiplexing (CWDM). It uses an ITU standard spacing of 20 nm (~2500 GHz) between 1310 and 1610 to support 16 colors each supporting the maximum data rate. Because of the less stringent frequency tolerance, the supporting hardware is uncooled, less expensive to purchase, and cheaper to operate (including lower power consumption).

II. Preferred type of optical fiber

The preferred type of optical fiber to use is single mode, full spectrum, and ultra-low PMD like Corning SMF-28e or Samsung Widepass. Full spectrum refers to fibers with low water peaks – low attenuation at 1383 nm for both short- and long-term performance. This opens the full optical spectrum from 1260 nm to 1625 nm for use, which permits CWDM to support sixteen instead of twelve colors. PMD refers to Polarization Mode Dispersion which limits the transmission of high data rates over long distances. SMF-28e has been available since 2001; earlier versions of single-mode fiber have been used since 1986 but have high water peaks and high PMD.

III. Existing or new optical fiber

For the New Mexico Array NRAO had planned to use, where available, existing “dark” optical fiber identified by Frazer Owen on several commercial networks that together serve most areas of New Mexico. Such optical fibers often may be leased for less than commercial rates. In a memo dated 26 January 2004 on "Fiber Miles for the New Mexico Array," Craig Walker used a nominal lease rate of $900/mile/year (not actual rates from companies). The existing networks serve most of New Mexico and could provide an excellent backbone for the LWA. However, most of the installed optical fiber probably predates the introduction of SMF-28e optical fiber and similar fibers.

Nevertheless, some areas of interest to the LWA are distant from the existing networks and we would have to install our own optical fiber. Operationally, buried optical fiber is preferred, for thermal stability, lightning protection, and protection from severe weather, for example. Craig Walker used an estimate of $35,000/mile for the installation of buried optical fiber. This number is roughly consistent with the cost of installing 100 miles of optical fiber in approximately 37 miles of trenches for the EVLA: $1,000,000.

Hanging optical fiber from existing utility poles is another possibility. The Socorro Electric Cooperative, for example, supports joint-use agreements for such installations in exchange for 1/6 of the fibers, but insists they are not a fiber-operating company. We would have to repair, maintain, and operate our fibers. Mike Ford of Kelly Utility Field Services estimates that the cost of hanging optical-fiber cable from existing utility poles is about $2/foot for labor. The type of optical fiber used is all-dielectric self-supporting (ADSS) which comes in bundles between 2 and 288 fibers. Above some number of fibers – perhaps 100 or so – a steel strand must be mounted to support the cable (at a higher cost, of course). The all-dielectric nature allows them to be hung on high-voltage lines, as high as 400 kV.

IV. Lessons from the EVLA

As I noted above, the marginal cost of adding additional fibers is very small. Steve Durand told me that increasing the number of optical fibers per EVLA antenna from six to twelve increased the cost of the optical-fiber installation by only $20,000 out of $1,000,000.

The optical transducers being used for the EVLA come in models with ranges of 40 km and 80 km.

Of the twelve optical fibers per EVLA antenna, seven are "dark". Of the remaining five, two are for the bi-directional distribution of analog local-oscillator signals, two support Gigabit Ethernet (bi-directional) for the monitor-and-control system, and one is for transmitting astronomical digital data from the antenna back to the correlator. The local-oscillator signal is at 512 MHz; 95 (I think) percent is reflected back and used to determine the round-trip phase correction; the LO system has very tight specifications because it is ultimately multiplied to as high as ~50 GHz.

V. A proposal for the LWA

I propose that the Central Core of the Long Wavelength Array be defined as that central, condensed part of the LWA that is supported by a dedicated power distribution network that supplies well-conditioned, uninterruptible power to the stations. Outside the Central Core the stations will be connected to the available commercial power supplemented by local uninterruptible power supplies. The stations in the Central Core will also be connected to a dedicated optical communications network, but some form of that network will connect all stations of the LWA to the correlator.

In the Central Core I propose that each station be connected to a bundle of twelve optical fibers in a system very similar to that of the EVLA:

7 dark fibers
2 fibers carrying analog local oscillator signals at 512 MHz (bi-directional)
2 fibers supporting Gigabit Ethernet (bi-directional)
1 fiber transmitting digital data from the station to the correlator

The local oscillator system will be based upon that of the EVLA with less stringent requirements. Gigabit Ethernet is an available standard. The data transmission will probably rely upon something like a synchronous optical network (SONET) or the more recently standardized (ITU G.707 and G.708) Synchronous Digital Hierarchy (SDH). The required analog bandwidth and digital data rates are not high by current standards; hardware should not be very expensive. These fibers should be buried.

It may be practical to extend this version of the optical communications network to nearby stations outside the Central Core. For more distant stations the most likely approach is to lease commercial dark fibers from the companies identified by Frazier Owen. Each fiber would connect many stations – like beads on a string (the available transducers support separations of as much as 80 km.) However, I think it is feasible to provide the full functionality described above for multiple stations on a single optical fiber by utilizing coarse wavelength division multiplexing (CWDM). If the fiber is full spectrum and ultra-low PMD like SMF-28e, CWDM will provide sixteen colors each of which can support bandwidths or data rates of 10 Gbps or higher. The sixteen colors could support 1) two colors carrying local oscillator signals, 2) two colors supporting Gigabit Ethernet, and 3) twelve colors transmitting digital data from the same number of stations. The local-oscillator and Gigabit Ethernet signals would be regenerated at each station along the fiber. Older types of fiber still should support twelve colors in total – enough to support eight stations.

However, many areas of interest for locating LWA stations may be in gaps between Frazer's networks or far from the closest fiber (like Dusty and Cuchillo). In such areas we should investigate the option of hanging our own optical fiber from existing utility poles – i.e., through joint-use agreements of the electric cooperatives. This option is likely to be less expensive than burying our own fiber. (Even if we had to install our own poles, I think it still would be cheaper.) If we do either, I favor the multiple-fiber rather than the multiple-color approach. Overhead fiber would be more exposed to more environmental damage but also would be easier to repair. We should double-check the coefficients of thermal expansion for optical fiber, but because of our long wavelengths, I think the round-trip phase correction should handle it.

VI. Summary

In this memorandum I have endeavored to describe a possible optical-communications system for the Long Wavelength Array. It is based upon the work that has been done for the EVLA but the field has made major advances since the specifications of the EVLA system were set four or five years ago. It should be possible to distribute local-oscillator signals and provide Ethernet service over the large area covered by the LWA. Obviously, most of the details remain to be filled in to complete the plan but I hope that I have outlined the path to success.