

LWA Data Communications - The Fiber Option

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1 Introduction

The desired mode of operating the Long Wavelength Array (LWA) is as a real-time connected element interferometer (Taylor et al. 2006). In this mode signals from each of the LWA stations are brought back to a central location (presumably the control building at the VLA). Here we describe a possible implementation plan for data communications using a combination of NRAO-owned fiber, Western New Mexico Telecom (WNMT) owned fiber, and Rio Grande fiber.

The full LWA is planned to have 53 stations, of which 15 are located in a core, and 38 are distributed around New Mexico. The immediate, funded, effort is to deploy 3 stations in 2009 and 16 stations by 2011. The 16 station array is known as the Long Wavelength Intermediate Array (LWIA), and has 6 core stations and 10 distributed stations with distances of up to 150 km from the control building which houses the correlator and is the nexus for all incoming signals.

The technical requirement for bringing back data from each station (defined in ECN 001) is 1920 Mbps for the core stations (those within 5-10 km), and 576 Mbps for the outer stations. The system architecture (Ellingson 2007, LWA memo 119) gives an example data rate of 576 Mbps assuming 3 beams, two tunings, two polarizations, 8 bit sampling at 1.5 times Nyquist rate, and 4 MHz bandwidth. The inner stations have an additional high bandwidth beam for looking at signals from the early universe (the “dark ages” beam).

Reliability may be affected by hardware failures or breaks in the fiber line. We expect a reliability of better than 99% on average, but do not consider it further in this memo.

2 Components

Taking advantage of commercial technologies we plan to transfer data using gigabit ethernet (1GbE) at full duplex from each station. Core stations will need to have sustained transfer rates of 2 Gbps. Outer stations will likely be operated at 1 or 0.5 Gbps depending on cost constraints. The Data

Aggregation and Communications (DAC) subsystem (described briefly in the LWA System Architecture by Ellingson 2007, and to be more fully described elsewhere) will be required to produce packetized ethernet signals that can go into a 1GbE switch connecting to the communications hardware. This equipment produces significant amounts of RFI. To avoid self-generated RFI the communications hardware will be housed in a shielded rack within the shielded instrumentation trailer at the site. Battery backup should provide at least 6 hours of continued operation of the communications network to allow for queries as to the health of the station.

The ethernet stream from each station will be aggregated onto a 10GbE stream for transmission between stations. A single fiber using Dense Wavelength-Division Multiplexing (DWDM) or possibly Coarse Wavelength-Division Multiplexing (CWDM) transceivers at multiple frequencies to allow for bi-directional transmission will be lit. Amplification of the signals will be carried out within the instrumentation trailers at LWA stations, or at intervening locations if necessary for long runs. The fiber will terminate at the Control Building of the VLA. Current plans allow for two 19" racks in the old correlator room.

There are likely to be four separate fibers terminating in the Control Building. One fiber is already in place and brings in the signals from the LWDA site, we refer to this as the LWDA fiber. The northern fiber will carry the aggregated signals from the NA and from the other 5 core sites (see Fig. 1). The western fiber will carry the signal from SJ, MC, HS, HM, and PT. The eastern fiber will bring in the signals from AC, BH, SV and MA. All these assignments are TBD and could be revised subsequent to further developments. Possible substitute sites include EA, RC, AM and VS, along with others not shown on Fig. 1.

2.1 Core Stations

For the core stations there is a requirement of an extra beam with bandwidth 56 MHz, and possibly up to 7 tunings of 8 MHz each in order to study dark energy and/or solar physics. This increases the data communications requirements for the core stations to a total bandwidth of 1.92 Gbps. All of the core stations are expected to ride down the northern fiber connection. Thus any equipment purchased for the NA station should be capable of feeding 6 x 2 Gbps or 12 Gbps minimum down the north arm fiber. An alternative possibility would be to implement a single point-to-point 1GbE connection for the NA station, and then replace it later.

3 Timescales

The initial deployment in late-2008 will be to connect the NA station by implementing the northern fiber run. Then in early 2009 we plan to implement the western fiber run from HS to the VLA, aggregating HM along the way. In late 2009 we plan to implement the eastern fiber run from MA to the VLA. These plans are TBD and subject to change.

3.1 Monitor and Control

Monitor and control (MCS) commands for the stations are naturally delivered over full-duplex fiber. The MCS design should still operate efficiently and use less than 2 Mbps in either direction.

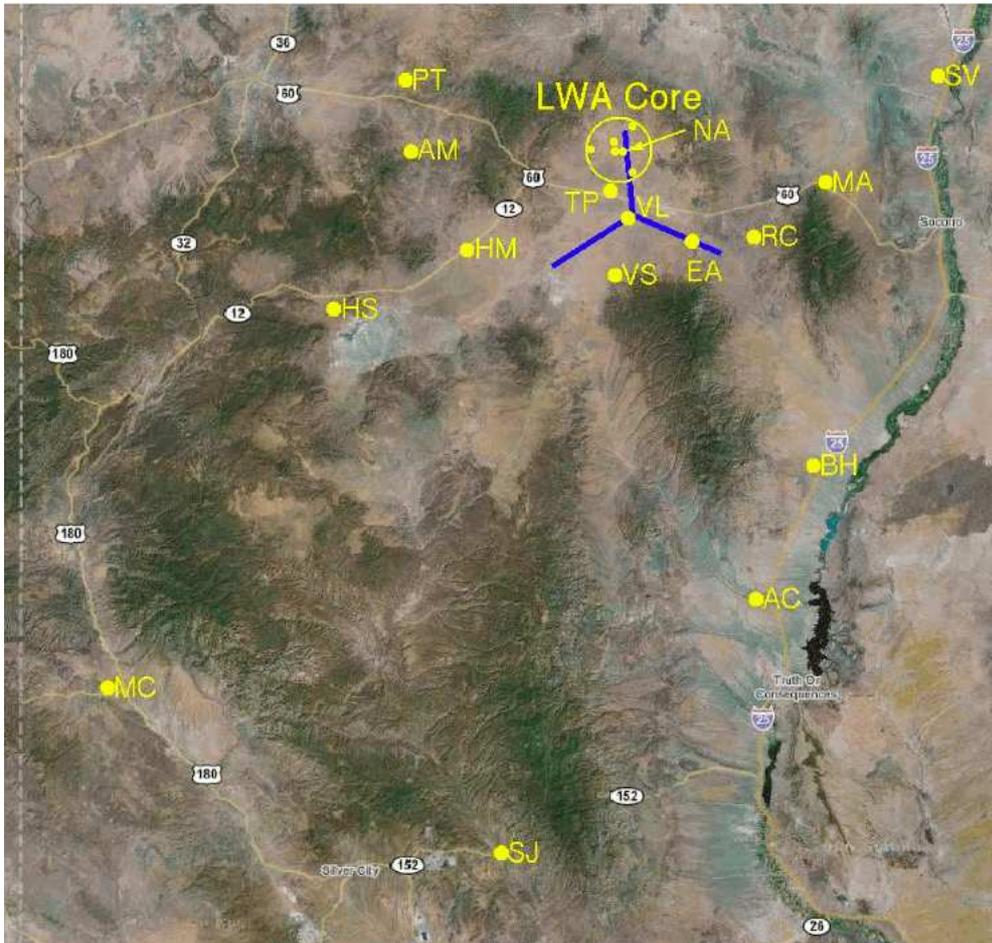


Figure 1: Likely sites for the Long Wavelength Intermediate Array (LWIA). For more detail see the discussion in Cohen & Taylor 2007.

3.2 Time Keeping

Connected element interferometers generally maintain phase stability by distributing a common LO signal. Given the challenges associated with sending a reference signal over ethernet, we consider an alternative option.

In very long baseline interferometry (VLBI) systems where it is not practical to link the elements, data is time stamped using a Hydrogen Maser. The stability of the time standard limits the phase stability of the observations at the radio frequency. A rule-of-thumb is that one needs a time standard that is stable in frequency by a factor 20 better than the highest frequency of interest. For the LWA operating below 100 MHz, we need a time standard stable at the 2 GHz level, or ~ 1 part in $10^{-9.3}$ over time lengths of at least 1 second. GPS receivers which will be present at each LWA station for ionospheric requirements come with oven-controlled crystal oscillators which should be good to about 1 part in 10^{-11} , or about a factor 50 better than we require. Temporal stability of these systems is not yet known and will need to be investigated. A rubidium oscillator might also be an option in some GPS units and would provide even greater temporal stability. Frequency accuracy requirements will also need to be addressed in future work.

3.3 Buffering

Given the latency required to form ethernet packets, transmit them, then re-assemble them, correlation will proceed in near real time only. A disk buffer will be required at the correlator. Assuming an incoming aggregate data rate of 16 Gbps, a 10 Tbyte disk array would provide a 5000 second (1.5 hour) buffer.

4 Cost Model

Given the placement of fiber in the ground, every station will have a “last mile” cost to hook up to the fiber. This may also include costs for communications equipment.

Inner stations have greater construction costs since all fiber connections will have to be established by the project, but lower recurring costs. Outer stations fall into two subcategories: (1) those that we plan to run over commercial fiber; and (2) those that we plan to run over a non-profit fiber (e.g., controlled by UNM, NRAO, NMT, or the State). Outer stations of type 1, on commercial networks, have low initial costs but high recurring annual expenses. Outer stations of the 2nd type have moderately high initial costs for equipment and perhaps some fiber, but operations costs that are substantially less than commercial fiber. Exact pricing of the monthly connection charge to each station will have to be negotiated with the provider of that service. Even in the case where there is no recurring cost (e.g., loan of a dark fiber along the north arm), we will have to budget some money to maintain equipment.

Below we break out average costs for the inner and outer stations and then consider the total cost for the LWIA.

4.1 Construction costs

The cost for stringing fiber up on power-line poles runs about \$2 to \$3 per linear foot. The cost to bury fiber runs about \$6 to \$9/ft. For the purposes of this memo we assume fiber on poles though

a detailed study of the trade-offs is needed in the future. The inner stations are spread out over about 7 miles. Assuming that we use a combination of existing and new poles, and a total run of ~ 20 miles, we can estimate the inner station construction cost at \$316k. The outer stations are selected with fiber placement in mind, and for these experience so far is that we can get within 2 miles of the fiber, or more appropriately, to an access point to the fiber since the fiber cannot be broken into arbitrarily. Some of the outer stations (BH, AC) are highly likely to require longer fiber runs. We adopt an average fiber run of 3 miles, and a total fiber run for the outer stations of 30 miles. Total construction costs for the 10 outer antennas is estimated at \$475k. The total construction costs of fiber are thus \$790k.

Equipment costs for the core stations may be somewhat higher as it is necessary to support 2 x GbE. Distant stations will run at 0.5 x GbE, providing some cost savings, but will also likely require a repeater and/or switches. A possible fiber solution for the core stations is the PL-400 CWDM/DWDM appliance by RADirect. A preliminary estimate for 2 x GbE service to the NA station, with expansion capability to handle up to 8 stations, is \$45k. Additional core stations could be added at a cost of \$20k/each. Total cost for the inner 6 stations is thus \$145k. For the outer stations Western New Mexico Telecom is quoting us an equipment charge of \$6k for commercially supported stations. For stations where we have access more directly to the fiber via collaborations with non-profit groups such as NRAO, UNM, NMT, and the State (perhaps 6 out of the 10 outer stations), we can expect to pay more equipment costs, perhaps \$50k on average though this is a WAG. Total equipment costs for all stations are estimated at $150 + 25 + 300 = \$475k$.

Total startup costs for all stations, fiber and equipment is \$1265.

4.2 Operations costs

Operations costs for the core stations are simply the maintenance cost of the equipment and the fiber lines. Assuming no annual cost for the fiber and 5% maintenance cost for the equipment we get \$24k in total per year.

Operations costs for the outer stations are dominated by the cost to lease the fiber. For commercial carriers we can expect to pay about \$25k/year/station. The number of such stations assuming configuration 7 of Cohen & Taylor (2007; LWA Memo 113) is 4 (MC, SJ, HS and HM). Total cost of these is \$100k/year.

Assuming configuration 7 of Cohen & Taylor (2007; LWA Memo 113) then reduced cost stations are SV, VL, AC, BH, MA, RC. These are expected to cost about 25% of the conventional fiber rate, or \$6k/year/station. Total cost for fiber leases and equipment maintenance on these is \$36k/year.

Total annual operation cost for fiber is \$136k/year. Adding equipment maintenance we get a bottom line operational expense of \$160k. See Table 1 for a summary of costs.

5 Summary

A fiber network for data acquisition and for monitor and control of the 16 station LWIA can be realistically implemented as described here. The initial hardware costs for 16 stations as planned would be \$1300k initially and have recurring expenses of \$160k annually. Thus, the construction cost is over twice that of the sneakernet option (\$512k; Taylor 2007), while the operating expenses are similar (\$160k vs \$132k annually). In fact the sneakernet option presented in Taylor (2007) did

Table 1: LWA Fiber Costs

Type	Number (N)	Fiber Const (k\$)	Equip (k\$)	Maintenance (k\$)	Fiber Ops (k\$/year)
Inner	6	316	150	7.5	0
Outer-Com ¹	4	190	24	0	100
Outer-NP ²	6	285	300	15	36
Total	16	791	474	22.5	136

¹ Outer-Com = Outer station on commercial fiber. ² Outer-NP = Outer station on non-profit fiber.

not consider the added expense of operating the core stations at 2 Gbps bandwidth; this increases the construction cost to \$704k, and the operations cost to \$138k. There are considerable scientific and operational advantages to going with the fiber option, and these will influence the final decision. Hybrid designs employing some combination of fiber and sneakernet are not likely to be viable as we would have to pay for the initial hardware costs for both fiber and sneakernet at some subset of sites (Taylor 2007).

References

Cohen, A., & Taylor, G.B. 2007, LWA memo 113

Ellingson, S. 2007, LWA memo #119

Taylor, G. B., et al. 2006, LWA memo #56

Taylor, G. B. 2007, LWA memo #110