CHALLENGES ASSOCIATED WITH IMPLEMENTING FIBRE OPTIC LINKS FOR e-MERLIN

Roshene McCool[(1)], Bryan Anderson[(2)], Ralph Spencer[(3)], Simon Garrington[(4)]

[(1)] **University of Manchester, Jodrell Bank Observatory, Macclesfield, Cheshire, SK11 9DL, UK.**
rmccool@jb.man.ac.uk
[(2)] **As (1) above, ba@jb.man.ac.uk**
[(3)] **As (1) above, res@jb.man.ac.uk**
[(4)] **As (1) above, stg@jb.man.ac.uk**

ABSTRACT
This paper will provide a brief description of MERLIN (Multi element radio linked interferometer)**.** It will outline the proposed upgrade to e-MERLIN with particular reference to the fibre optic links that will be used for data transmission.
The requirements of the transmission system will be presented together with a discussion of the challenges associated with implementing such a system. The fibre optic network can be implemented using either dark fibre or a managed bandwidth solution. A comparison of these two methods is given.

INTRODUCTION TO MERLIN

MERLIN (Multi element radio linked interferometer) [1] is the UK's national imaging facility for radio astronomy, it is the only world class astronomical facility based entirely in the UK. Work began on the array in 1976, driven by the pursuit of high angular resolutions for astronomical observations and development continues to the present day.
The instrument combines 7 radio antennas with an overall array size of 217 km. The long baseline of the MERLIN array means that MERLIN can achieve resolutions of sub-arcseconds at centimetre radio wavelengths.
Whilst high angular resolutions require long baselines, this restricts instrument sensitivity because of the difficulties in transferring large amounts of data over long distances.

The radio receivers in the MERLIN array use HEMT transistor technology and are cooled to 15 K using helium gas refrigeration. They produce 2 GHz bandwidth in each of 2 polarisations. The signals, from each antenna are returned to Jodrell Bank for correlation over microwave links with a bandwidth of 30 MHz. The limited bandwidth of the microwave links means that not all of the information collected at the receivers can be transmitted. This is what restricts the performance of the current MERLIN array.
Developments in telecommunications in the past decade mean that the data transmission bandwidths required for the MERLIN array can now be achieved using fibre optic links. Replacing the microwave links with fibre optic links is a significant feature of the proposed upgrade to the MERLIN array. The new array will be called e-MERLIN [2].

FIBRE OPTIC LINKS FOR E-MERLIN

Optical Transmission

The addition of fibre optic data transmission to the MERLIN array will mean that all the information detected by the radio receivers at the antennas can be transferred to the correlator. This will result in a 10-fold increase in instrument sensitivity whilst maintaining resolution. With additional upgrades to the Lovell telescope and radio receivers e-MERLIN will be up to 40 times more sensitive the MERLIN.
The e-MERLIN fibre links will be digital, as is standard in today's telecom networks. The instrument will have two modes of operation:

(1) 2 GHz signals in each of 2 polarisations will be digitised to 3-bit precision at 4 Gsamples/sec, or
(2) 1 GHz signals in each of 2 polarisations will be digitised to 6-bit precision at 2 Gsamples/sec.

In both cases, after framing the resultant signals will produce 3 x 10 Gbits per second channels for transmission [3]. The digitisation and framing will take place at the focus box of the antenna. This imposes tight restrictions on the size of the transmitters and means they must be completely screened to prevent radio frequency interference. DWDM (dense wavelength division multiplexing) techniques will be used to consolidate as much of the array bandwidth as possible onto a single fibre.
Transmission over the optical fibre links will be limited by the propagation characteristics of the optical fibre itself [4]. The main characteristics affecting the maximum transmission distance over fibre are:

- Fibre attenuation: Transmission loss in single mode fibre is ~0.25 dB/km. Optical fibre amplifiers will be used to compensate for fibre attenuation throughout the fibre network.
- Chromatic dispersion: This is seen as a broadening of the received signal pulse that results in intersymbol interference between adjacent pulses in the bit stream. It is the result of propagation delay differences between the different spectral components of the transmitted signal. The effects of chromatic dispersion can be reduced by using non-zero dispersion shifted fibre that has a dispersion of between 2 and 6 ps/nm.km, in comparison to standard single mode fibre that has a chromatic dispersion of 17 ps/nm.km. Discrete dispersion compensators may be used if the total chromatic dispersion end to end exceeds limits quoted for the transmitter (typically 1440 ps/nm)
- Polarisation mode dispersion. : Single mode fibres support 2 independent polarisation modes in propagation. Imperfections in fibre geometry and stresses on the fibre cause the polarisation modes to travel at different speeds down the fibre, a phenomena known as birefringence. This causes a spread in the pulse and manifests itself as a 'fading' in the received signal, similar to that experienced on microwave links. It is a random effect, dependent on individual fibres and cannot be easily compensated. The limit of tolerated polarisation mode dispersion for 10 Gbits per second systems is generally accepted as 10 ps [5].

It is possible that optical to O/E/O (optical to electrical to optical) regeneration will be needed at some point in the link. This will be necessary if the total end-to-end polarisation mode dispersion of the link exceeds 10 ps. It may be also be used as a practical method of consolidating channels from different antennas onto a single fibre. Wherever possible O/E/O regeneration will be avoided to reduce the cost and complexity of the system.

Whilst the data transmission system for e-MERLIN will use techniques developed for the telecommunications industry, this application has some unique properties that set it apart from other telecoms applications.
The total bandwidth of the e-MERLIN array will be 210 Gbits per second. This bandwidth is greater than the requirement of any single, current telecoms application. In comparison, the London internet exchange (LYNX), Europe's largest internet exchange experienced a peak traffic flow of 14 Gbits per second, about 140 times more than its nearest UK rival [6]. A single antenna in the e-MERLIN array will produce in excess of twice this peak traffic.
When compared to standard telecoms applications, the bandwidth of e-MERLIN may be great, but the performance requirements are much more flexible. Whilst telecoms applications require a BER (bit error rate) of 10^{-12} and an availability of ~99.9%, e-MERLIN will operate at BER of 10^{-6}. Availability is less of an issue for e-MERLIN, since it will not run continuously. The MERLIN array currently operates at 80% availability during its 9 months of operation per year.

In this section of the challenges posed by this project have been outlined.

- The data transmission system has to transfer high data rates over long distances and is subject to the propagation characteristics of fibre.
- The compact size of antenna focus boxes will compound the problems associated with interference when integrating optical transmission equipment into the back-end of highly sensitive radio receivers.

These are technical challenges are well understood they are not insurmountable. Additional challenges are posed by the fibre infrastructure itself.

Fibre Infrastructure

Fibre capable of carrying the large bandwidths required for e-MERLIN, is, in general located along the major transport routes of central England, this is illustrated in Fig.1. In practise this means there is a great deal of capacity between the large cities in the UK, but very little anywhere else. By the very nature of radio astronomy, most of the antennas in the e-MERLIN array are in rural locations. This means that fibre has to be installed from the antenna to an appropriate access point on a trunk fibre network. Estimates for the e-MERLIN network suggest up to 150 km of new fibre cable will be required.
The civils aspect of any fibre network is by far, the most costly element. Typical quoted values for fibre cable installation are £75/m. It very quickly becomes apparent that according to these estimates, the fibre installation alone would cost more than the £8.6 Million budget for the whole e-MERLIN project.
In order to reduce the civils cost for the e-MERLIN data transmission system it will be necessary to:

- reduce the amount of cable installation required or,
- reduce the cost of the fibre installation.

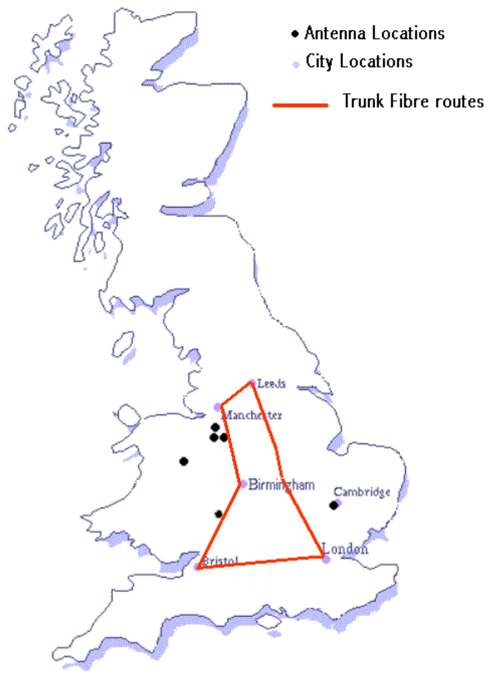

Fig.1. Locations of antennas in relation to trunk fibre routes

In practise significant reductions in the amount of cable installation required are difficult to achieve. The antennas are fixed and so are the fibre trunk networks. Some suppliers have spur links to major towns off the trunk network, but in this case, it makes no significant difference to the amount of fibre dig required. The fibre installation cost however, can be dramatically reduced by using direct buried cable or microcabling techniques. The £75/m installation costs are an average of installation costs for both urban and rural conurbations. Since installation is significantly more expensive in urban areas these estimates will be reduced in the case of e-MERLIN where the installation will be almost entirely in rural areas. In addition quoted costs are based on the type of installation required to maintain network availabilities of 99.9%, In the e-MERLIN case a 99.9% availability level is not required and it is therefore possible to take advantage of cheaper installation techniques.
Whilst the final fibre link to the antenna will require a fibre dig, a commercial telecommunications company will provide the trunk fibre. The trunk routes could be provided on a dark fibre or managed bandwidth basis.

DARK FIBRE OR MANAGED BANDWIDTH

There are two possible methods of delivering the trunk network for E-MERLIN.

- Dark Fibre: here, trunk fibre connections are leased on a long-term contract. The links will be between the closest network node to an antenna and the correlator. The fibre will be ‘lit’ by transmission equipment built and maintained by the E-MERLIN team. In this case transmission is entirely the responsibility of Jodrell Bank, but the integrity of the fibre links will be part of the lease contract with the fibre network supplier.
- Managed Bandwidth: in this case, the network supplier provides both the fibre links and the transmission between appropriate network nodes. The responsibility for transmission and fibre network integrity will lie with the network supplier.

There are pros and cons with each method.
The dark fibre solution will enable the E-MERLIN team to re-use many of the designs currently being developed for ALMA (Atacama Large Millimetre Array). This equipment is specifically designed with the requirements of a radio telescope application in mind where equipment used for standard telecoms applications is not suitable. The optical transmitters are a good example of this.
The transmitters built for ALMA are designed specifically for the compact environment of an antenna focus box and are packaged to prevent interference in the radio receivers. However, the digital boards in the ALMA transmitters use

proprietary data formats and bit rates developed specifically for ALMA. Using the current design the ALMA transmitters could not be used in a managed bandwidth solution where these proprietary formats are not readily accepted by industry standard telecommunications equipment. Unfortunately the telecommunications equipment commonly used in a managed bandwidth solution is not suitable for installation in a focus box because of its size. This means that if a managed bandwidth solution is used additional development time is required to produce transmitters suitable for installation in a focus box, and which are compatible with industry standard formats such as SDH.

In a managed bandwidth solution the burden of transmission over long distances lies with the network supplier. This significantly reduces the operational burden on the e-MERLIN staff.

Ultimately the decision on which type of network to choose will lie in the relative costs of the two solutions.

CONCLUSIONS

The addition of an optical data transmission system to MERLIN will result in a 10-fold increase in its sensitivity. The technical challenges associated with implementing fibre optic links for e-MERLIN are significant, but not insurmountable. These technical challenges include:

- Implementing transmission equipment suitable for a focus box environment.
- Overcoming fibre transmission impairments such as attenuation, chromatic dispersion and polarisation mode dispersion.

The technical challenges are well defined and solutions exist that can be implemented by Jodrell Bank. The fibre infrastructure will be provisioned in partnership with a commercial supplier.

REFERENCES

[1] MERLIN/VLBI National Facility, http://www.merlin.ac.uk/

[2] *e*-MERLIN: UK Astronomers to Build Unique Radio Telescope, http://www.jb.man.ac.uk/news/e-merlin/

[3] Steven Durand, Digital transmission signalling protocol , *EVLA memorandum No 33* http://www.aoc.nrao.edu/evla/geninfo/memoseries/evlamemo33.pdf

[4] John M. Senior, *Optical Fiber Communications, Principles and Practise*, 2nd Ed, Prentice Hall, 1992

[5] Rajiv Ramaswami, Kumar N. Sivarajan, *Optical Networks, a Practical Perspective*, Morgan Kaufmann, 1998

[6] Europe’s Largest Internet Exchange Switches 250 Trillionth Packet, http://www.linx.net/press/releases/074.thtml