**Low Bandwidth Techniques for Remote Observing**
**The WIYN 3.5m Telescope Control System**

The Low Bandwidth Manifesto
WIYN Command and Control Subsystem

- System architecture
- Client/Server design
- Network transparency
- Distributed control

WIYN Engineering Data Subsystem (EDS)

- Telemetry
- Compression
- Displays
- Archives

WIYN Progressive Image Transmission Subsystem

- Introduction
- Compression
- Progressive transmission
- Example of Progressive Transmission

## The Low Bandwidth Manifesto

Ship commands, not keystrokes

- Build commands locally (in user interface)
- Avoid full duplex latency
- Send command *messages*
- Perform validation, sequencing, arbitration at site
- Separate syntax/grammar from semantics (Commands don't always come from humans)

Ship data, not screens

- rlogin, telnet are bad
- X-traffic is worse
- Build displays at user end
- The same data may be displayed in many ways

Ship data once, not once per user

- Use "exploders" off-site to replicate data
- Integrate telemetry and science data for unified routing
- Use spacecraft-style data frames, not request/answer design

## WIYN Command and Control Subsystem

System architecture

- Even Telescope Operator is a remote observer
- Message router acts as hub

Client/Server design

- Clients have single purpose
- Clients can come and go during session

Network transparency

- Sockets used for all connections, even within site
- All data sent in machine-independent format
- No explicit floating point

Distributed control

- TCS sees only messages, not users
- Observers can delegate control to collaborators

## WIYN Engineering Data Subsystem

Telemetry

- EDS samples over 250 monitors every second
- EDS is a broadcast system, not a queried one
- EDS bandwidth *independent* of number of users
- EDS bandwidth: about 4 kpbs (23 kpbs uncompressed)

Compression

- Compute differences from preceding frame
- Run-length encoding works well
- Send encoded difference-frame
- Send full frame once per minute
- Factor of 5 is easy to get

Displays

- Character-based displays
- Graphical User Interfaces

Archives

- All-night archive $\approx$ 20 megabytes (compressed)
- Archives are part of routine operations
- Archives available in Madison and at WIYN
- Archives support session replay, debugging, observing reports and summaries

## WIYN Progressive Image Transmission Subsystem

Introduction

Current network image tools expect high bandwidth.
Current methods for reducing bandwidth:

- Static lossiness (predetermined)
- Static binning (postage stamp versions)

Standard compression is not always the answer

- Losslessness often gets only a factor of 2
- Static lossiness not OK for all images or users
- Static binning not OK for all users
- Sequential compression (e.g. LZ compress) still imposes sequential display

Progressive transmission

- See 2-D image as it arrives
- Image quality improves quickly with time
- Image quality is well behaved (no bad artifacts)
- Browse mode: cancel, next, etc.
- Dynamic lossiness
  - Must ultimately provide lossless transmission
- Dynamic binning
  - Must ultimately result in full resolution

## Compression

Sequential

- Run-length, Huffman, LZ
- Spoiled by noise

Thresholding

- Improves coding, sacrifices faint objects

Data transformations

- Exploit properties other than intensity
- Fourier bases (Fourier transform, DCT)
- Wavelet bases (multiresolution decomposition)

Wavelets

- Spatially localized basis functions
- Multiple spatial resolutions
- Haar basis
  - Nearest neighbors
  - Integer-based
  - Fast
  - Exactly reversible
- Retains any feature detectable with any block average

## Progressive transmission

Image decomposition

- By rows or columns, "raster mode"
- By bitplane

Data transformations

- None- work in image space
- Wavelets- multiresolution decomposition

Transmission protocol

- Navigation (directories, tables of contents)
- Negotiation (display resolution, window size)
- Transmission control (Stop, Start, Cancel, Next)

Graphical User Interfaces

- Under development
- SAOimage is interim GUI
- Tk and Motif clients will be produced

Example of Progressive Transmission

- 2400 baud connection: worst case, "needle's eye"
- 60-second (user time) cutoff for transmission
- No dynamic binning
- Three methods compared:
  - Raster mode
  - Image bitplanes
  - Wavelet bitplanes
- Coma cluster of galaxies
  - Point and diffuse objects
  - Fairly high contrast
  - 800x800 pixels, 16 bit values
  - 71 minutes at 2400 baud
  - 1 minute: 0.25 bits per pixel