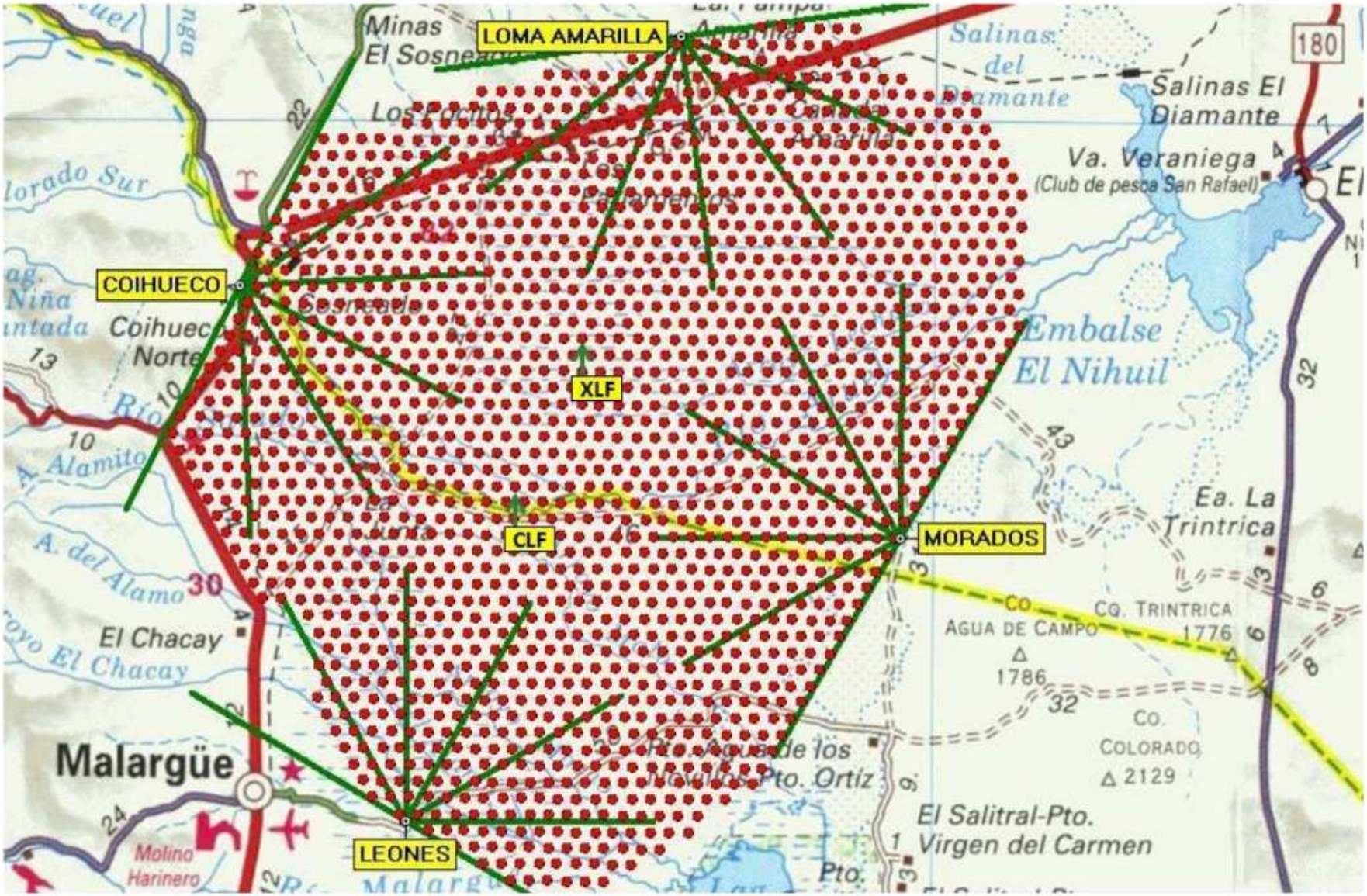
Wireless Data Networks

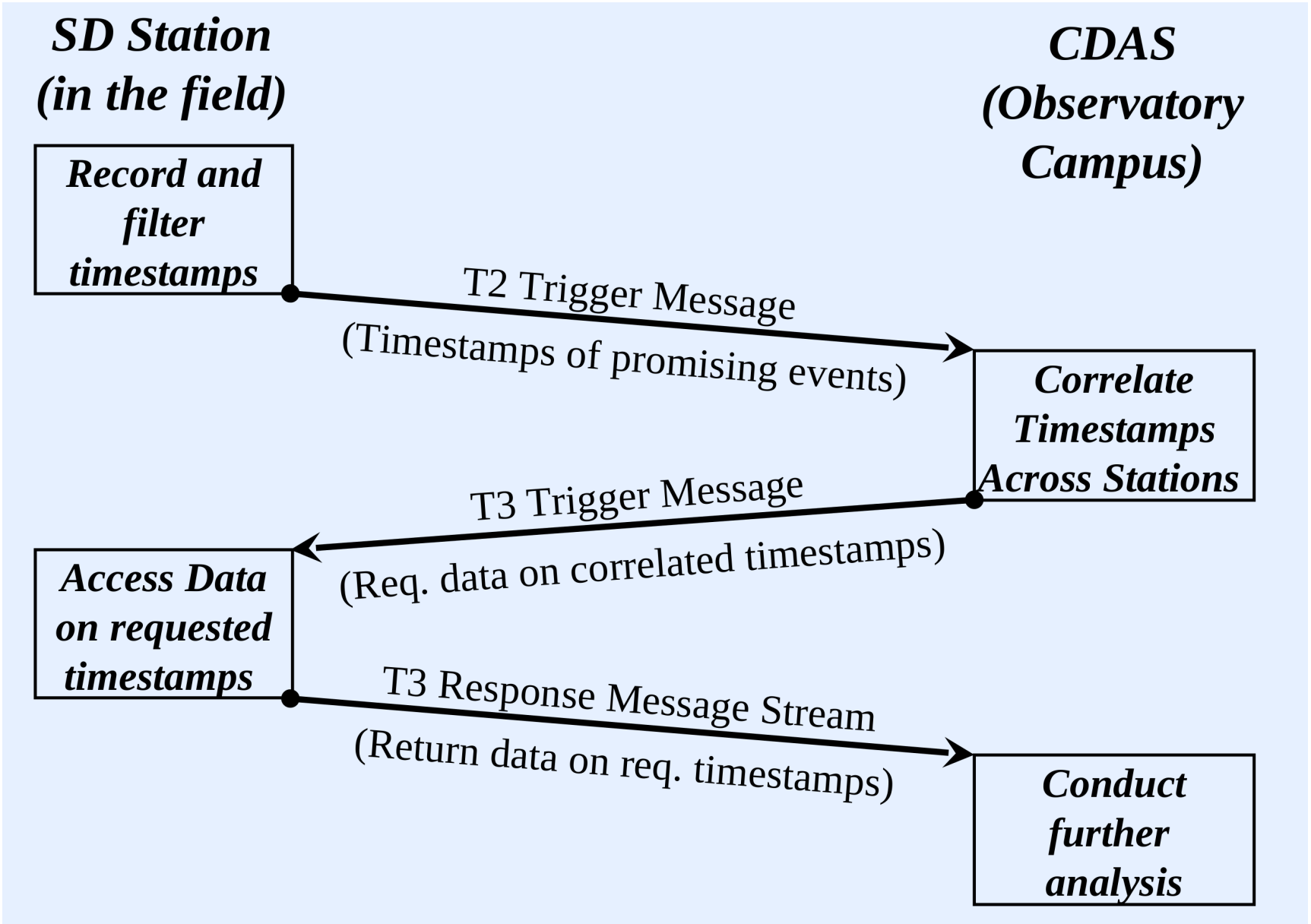
The Auger Experience; Options for Future Large Detector Arrays

February 9, 2015

The Auger Detector Layout



Hard Real Time Network



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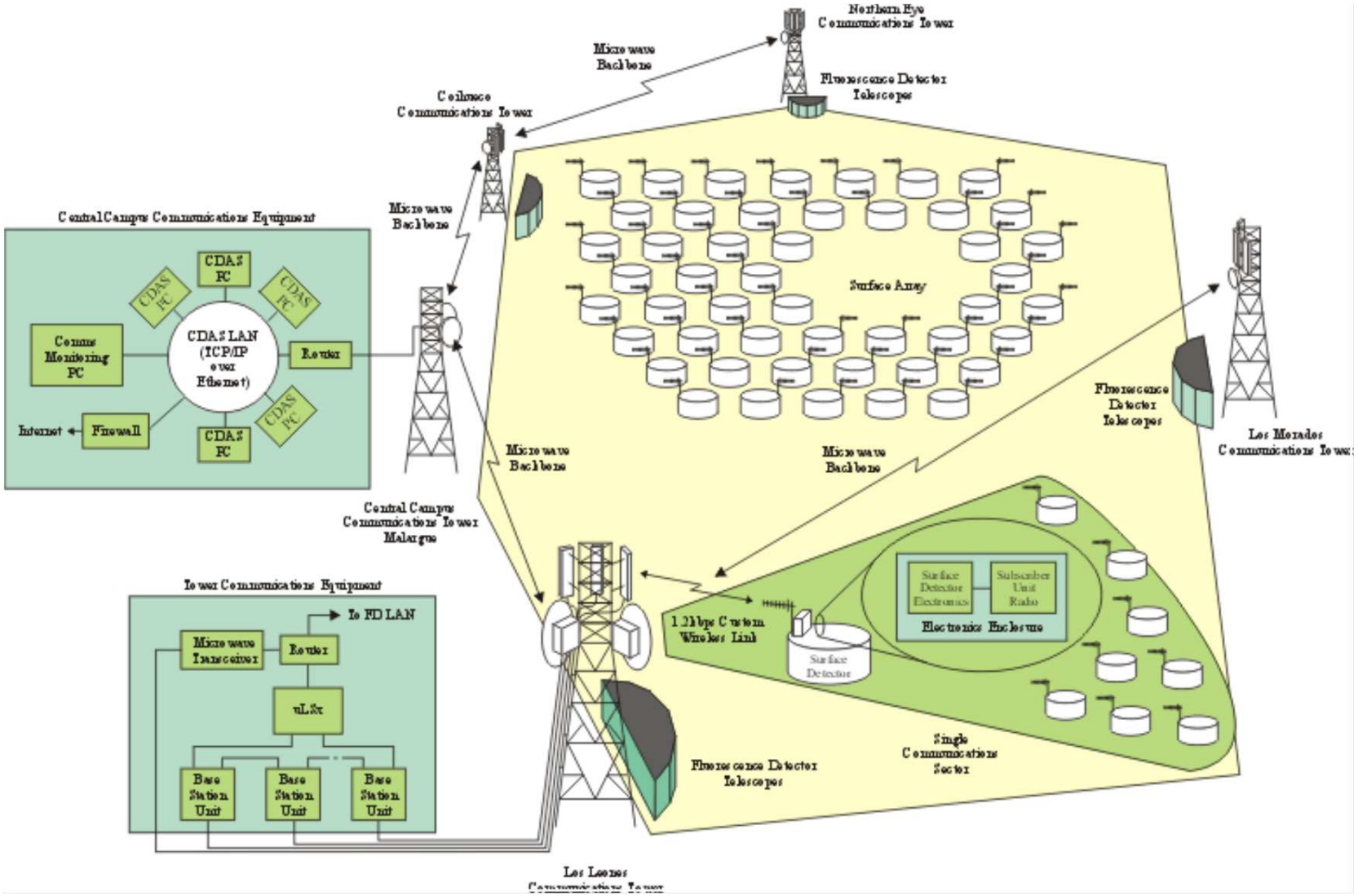
Implementation

- Hard real-time network
  - Guaranteed bandwidth per station
  - Hard maximum packet delivery time
- Asymmetric protocol
  - Individual uplink per station
  - Broadcast (shared) downlink to stations reserves most bandwidth for uplinks
- Frequency band choice
  - Modest frequency to simplify RF design: 902-928 MHz
  - ISM band: No license fees, components more readily available
  - Spread spectrum makes system robust against interference
    - Frequency hopping chosen for low power & ease of implementation
  - Government decree giving project first priority in detector region added extra insurance

Network Layout



SD Station

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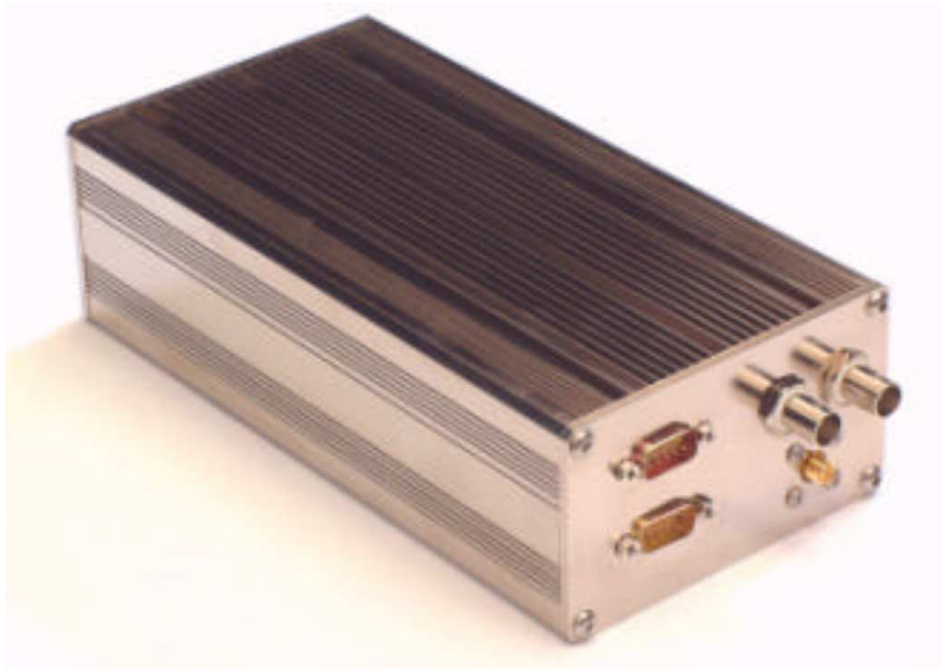
Tower

Radios

Subscriber unit



Base station

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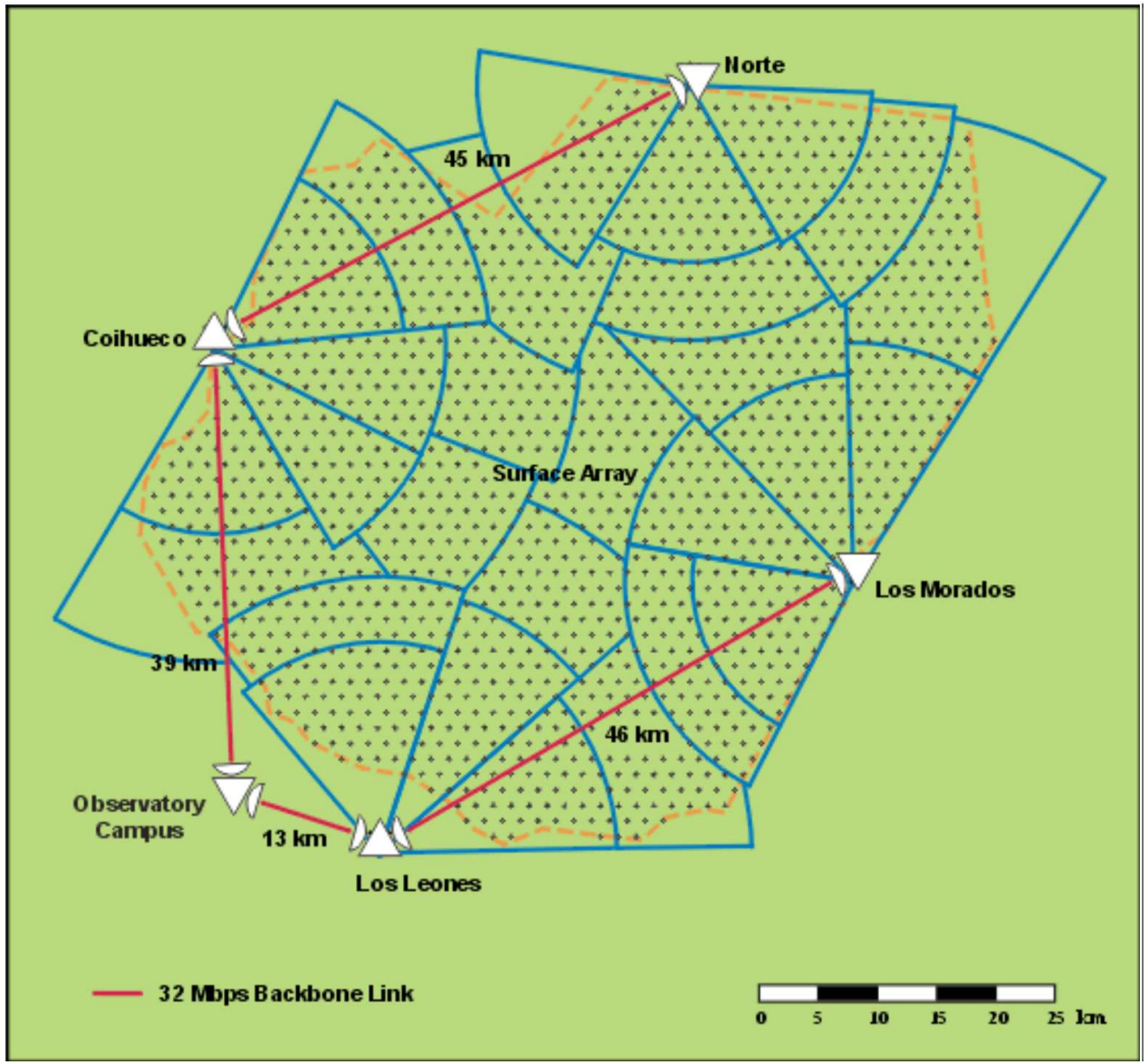
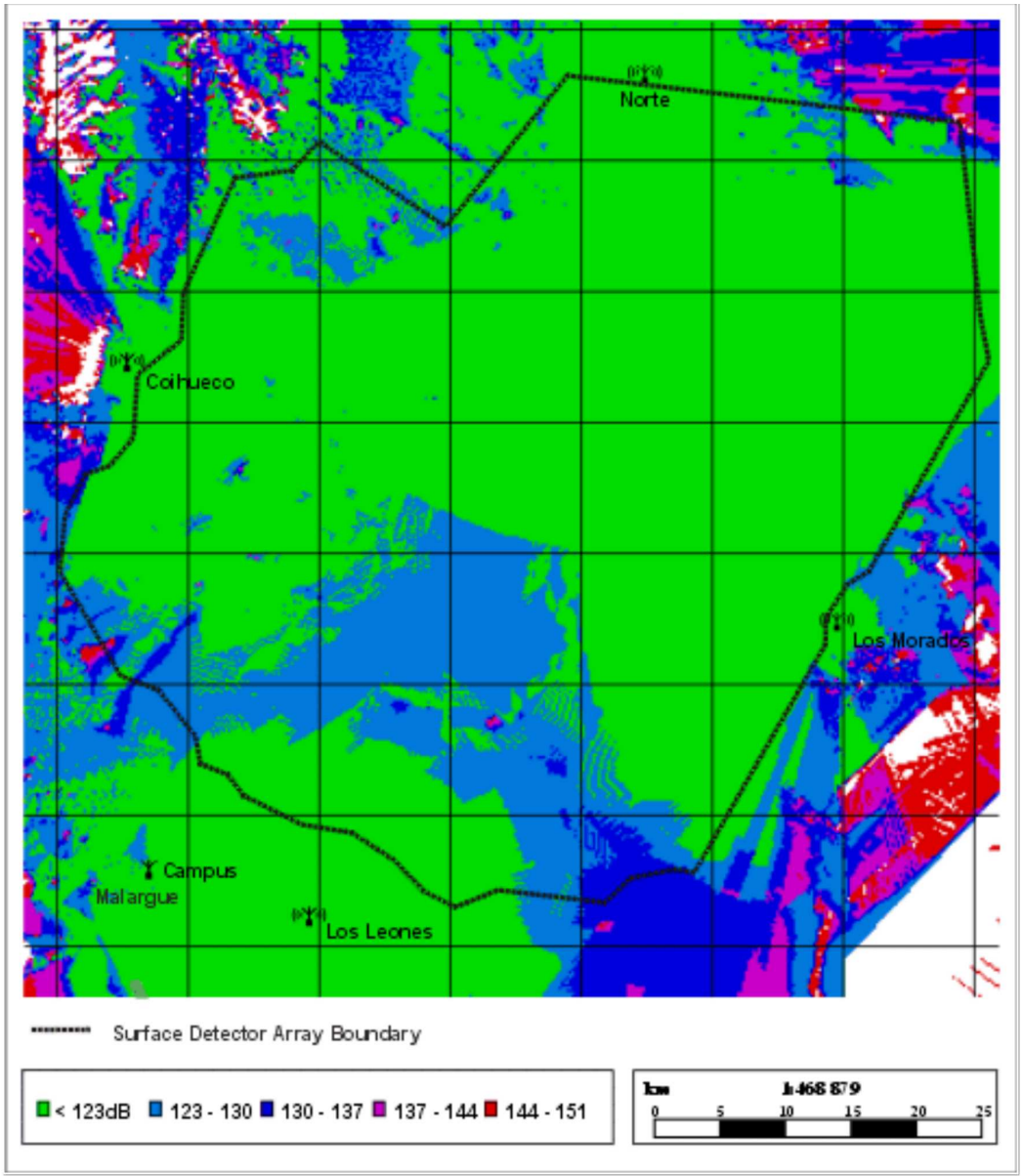
Realized Network Parameters

Microwave Backbone Network	
Links:	4
Frequency	7 GHz
Data Rate	24 Mbps
Wireless LAN	
Nodes	1600
Frequency	902 to 928 MHz ISM band
Protocol	TDMA, custom
Subscriber Unit over-air rate	200 kbps
Effective payload rate	1200 bps uplink
Typical daily data packet loss rate	less than 0.002%

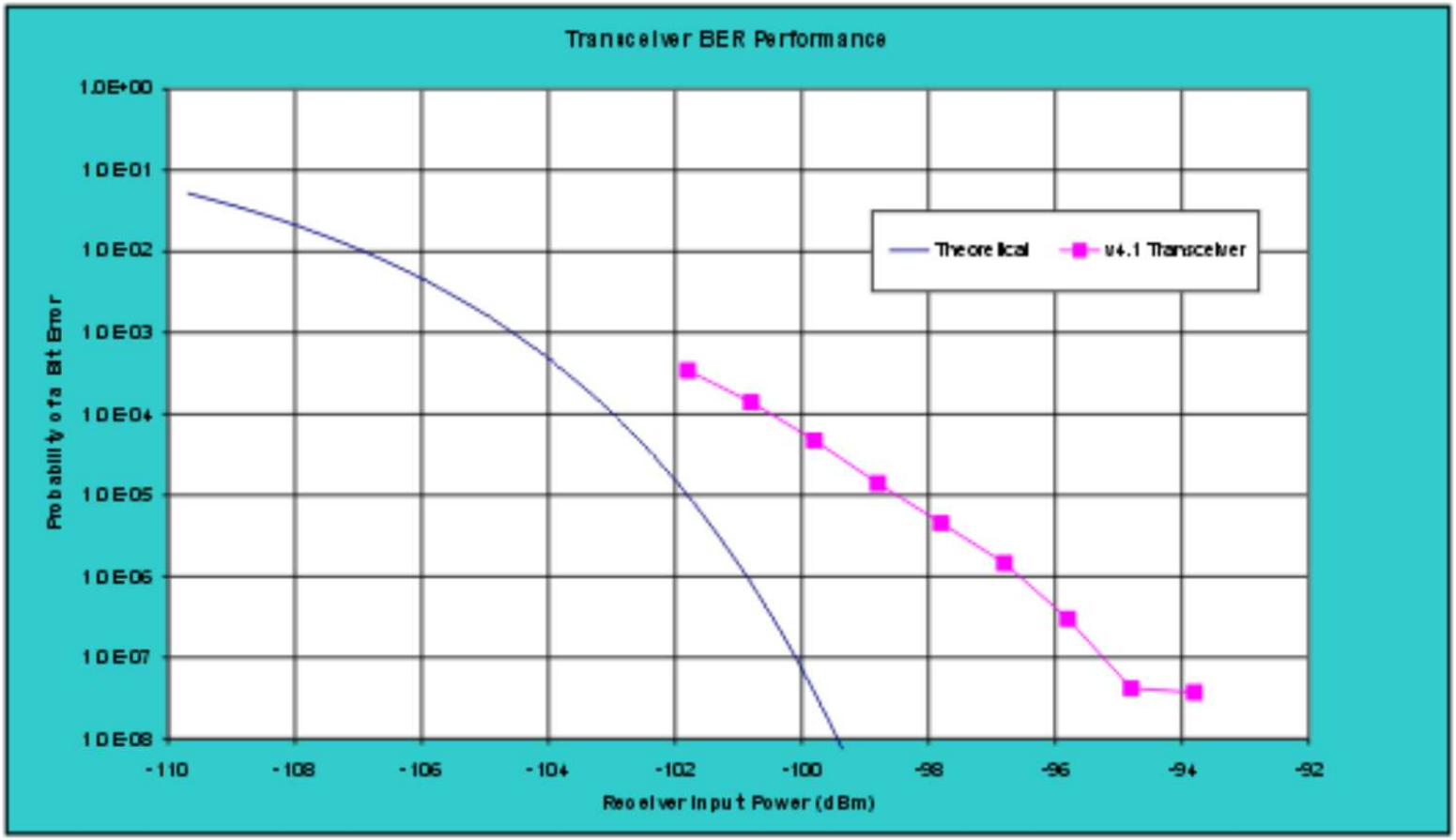
Comms Sectors



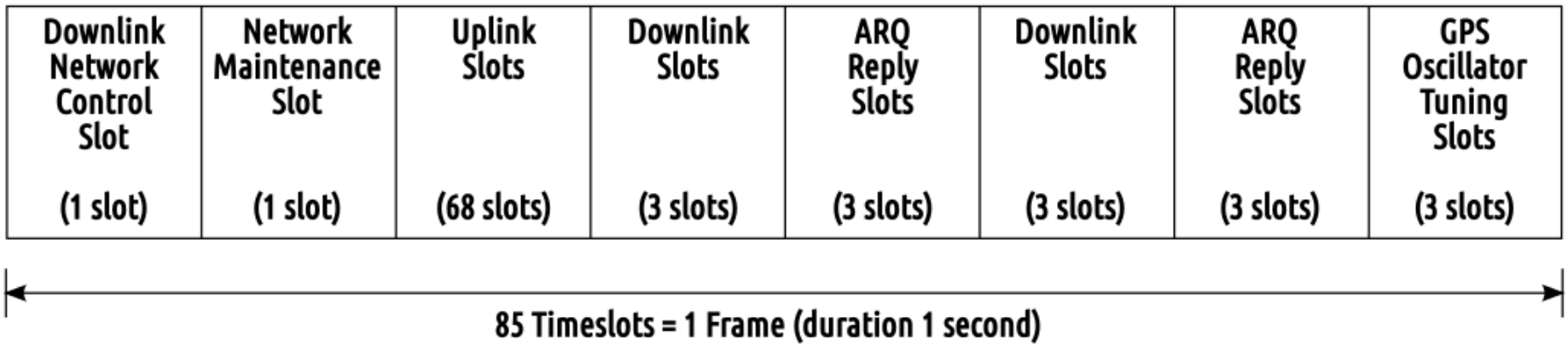
Pathloss Calculations



Error Rates


Transceiver BER Performance
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
Probability of a Bit Error
-110
-108
-106
-104
-102
-100
-98
-96
-94
-92
Receiver Input Power (dBm)
Theoretical
v4.1 Transceiver

TDMA



- Asymmetric structure
  - 68 uplink slots
  - 6 downlink slots
    - 2 slots used to double the downlink bandwidth
    - messages each repeated 3 times to reduce message error rate

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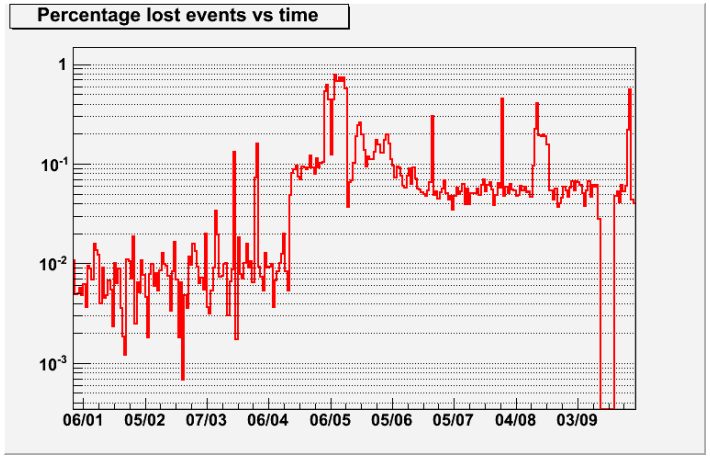
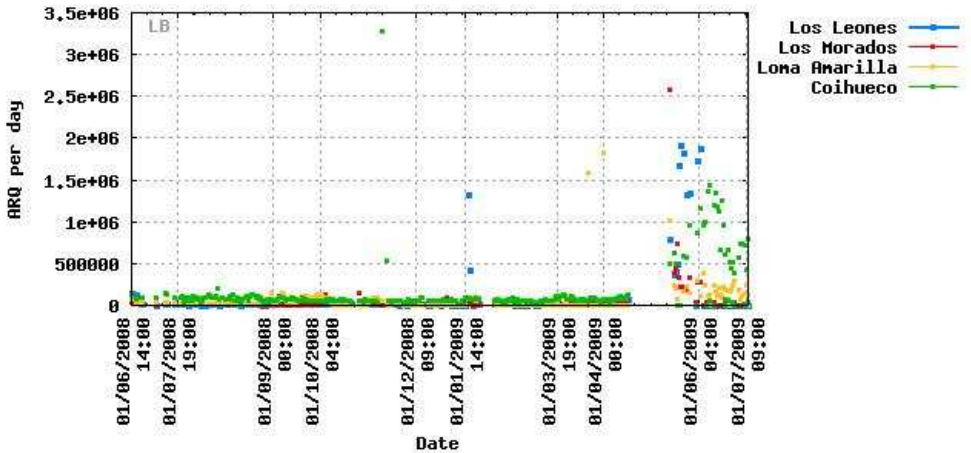
Throughput

Link Description	Maximum Physical Interface Data Throughput	Maximum Protocol Data Throughput	Maximum Required Data Throughput	Condition
Local Station to Subscriber Unit	38.4 kbps	36.1 bps	1.2 kbps	Unconditional
Subscriber Unit to Base-station Unit	96 kbps	1.2 kbps	1.2 kbps	A single uplink slot allocated to the subscriber. Base-station units support up to 68 subscribers.
Base-station Unit to Base-station Controller	2.048 Mbps	180.4 kbps	96 kbps	Three E1 timeslots allocated to the Base-station Unit. A base-station controller supports a maximum of 8 base-station units.
Base-station Controller to Backbone interface unit	640 Mbps	75 Mbps	768 kbps	Unconditional
Backbone interface unit to CDAS	8.2 Mbps	7 Mbps approx.	768 kbps	7 Mbps for the protocol data throughput is approximated as the TCP/IP protocol used on the backbone is contention based and therefore heavily dependent on the number of users.

Comms Crisis





Lost events in infill (high rate region)

ARQs in entire array

- In April, 2009 there was a large increase in lost packets (& events) in infill region
  - T2 packet lost => missing data for central trigger
  - T3 packet lost => missing event data for reconstruction
  - Correlated with an increase in the ARQ rate
- Eventually tracked to the "switching-on" of a transmitter outside of Auger
  - Increased "noise" level $\Longrightarrow$ increased ARQ rate
- The problem was exacerbated by several factors
  - There was a bug in the radio firmware in which the 2nd arq block did not get filled, cutting maximum number of ARQ requests in half
  - Stations have limited event buffering & takes ~2 minutes to read event
    - Regular array: ~2 events/station/day, Infill: ~1 event/station/10 min.

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10 Years On

- Comms system has generally been extraordinarily reliable, but there is room for improvement:
- Issues
  - Bug in ARQ code only discovered when background increased in 2009
  - Custom hardware means obtaining spares non-trivial
  - Spares for Base Station Units limited
  - Forward error correction code could be more robust
    - Retransmission of packets cuts into bandwidth
    - Start to lose data when trigger rate pushed beyond design rate - insufficient remaining bandwidth to read out traces
  - Broadcast protocol runs into problems downloading large files
    - Even small error rate means many packets need to be retransmitted
    - Can be easily fixed by implementing redundant network coding
  - Have been some problems with interference from external transmitters
    - Not easy to track down where the interfering signals originate
  - Use of dedicated band, had one been obtainable would have been less prone to interference

Developments for Auger North

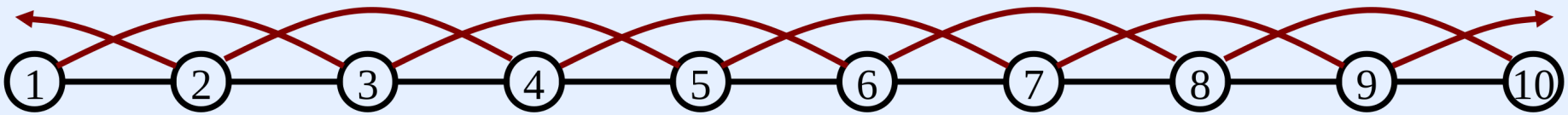
- The network topology used in Auger (South) is optimal for the terrain
  - Flat plateau surrounded by hills is ideally suited for direct links from detector stations to concentrator towers
- However, that solution may not be optimal if
  - There is a lack of suitably placed hills for towers
    - Tall towers are expensive
  - Terrain between towers is not suitably flat
    - Intervening hills can block line of site from detector stations
- The planned Auger North site had rolling hills and no suitable tall hills for towers
- Therefore we embarked on the development of a peer-to-peer network system

WAHREN

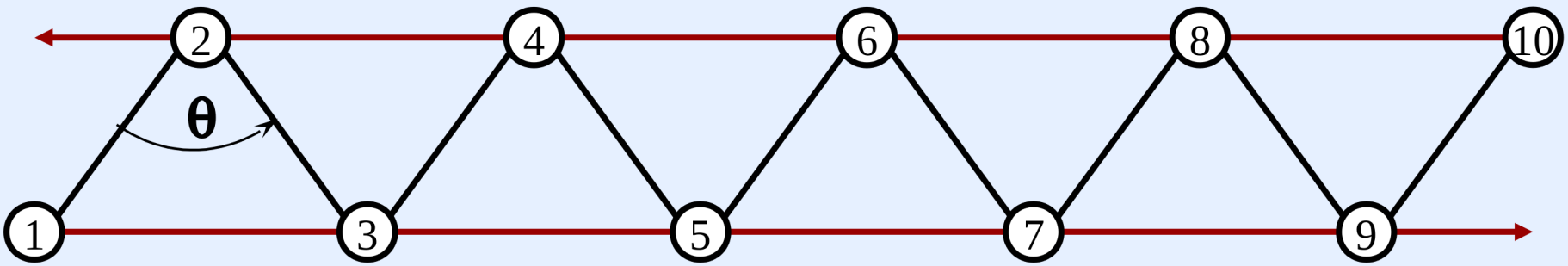
Wireless Architecture for Hard Real-time Embedded Networks

2nd Order Power Chain

- *Graph Topology:*
  - * Start with a basic chain – nearest neighbor comm only
  - * Extend range to reach second-nearest neighbors

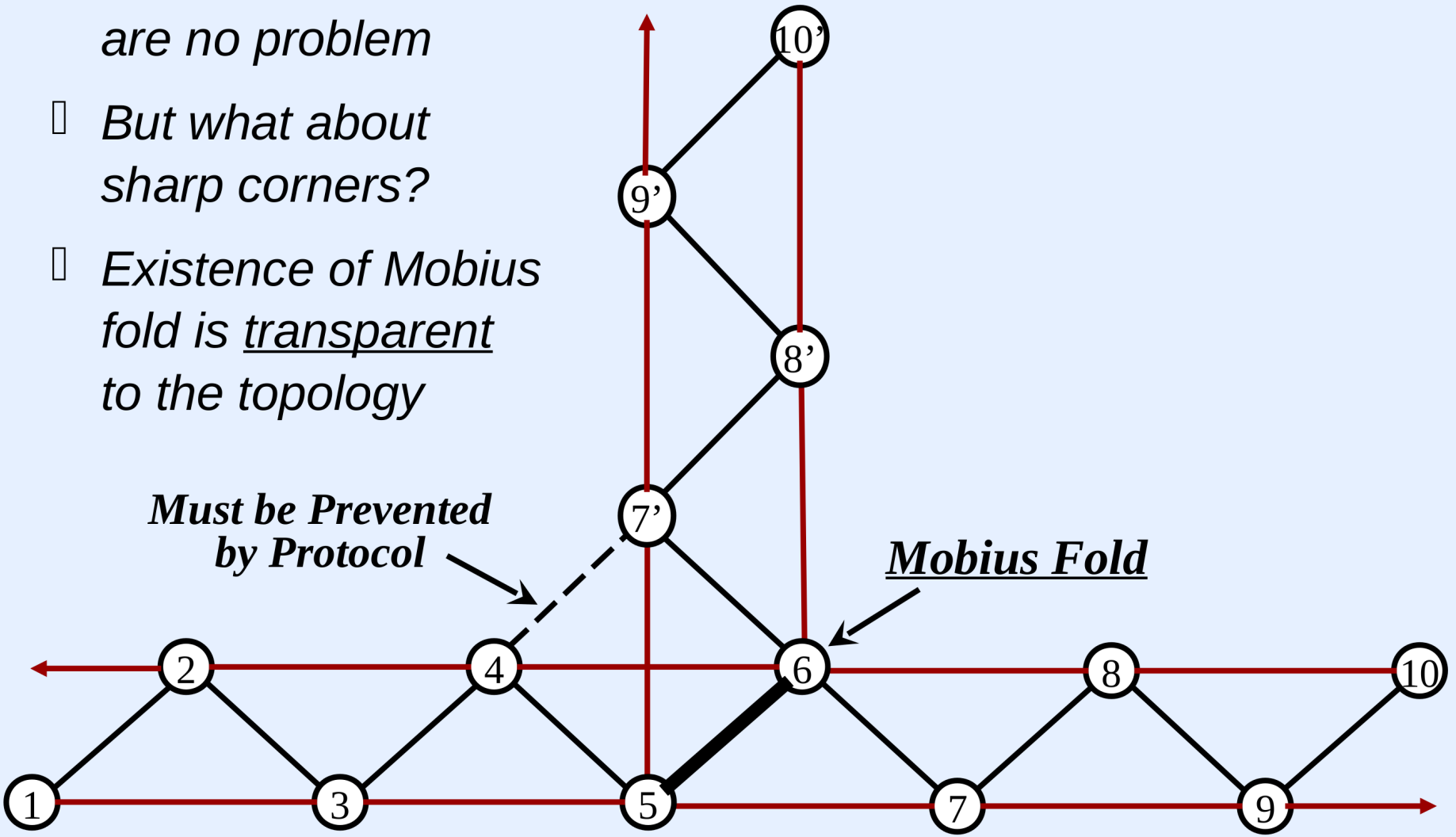


- *Useful Physical Realization = 2D Triangular Mesh*



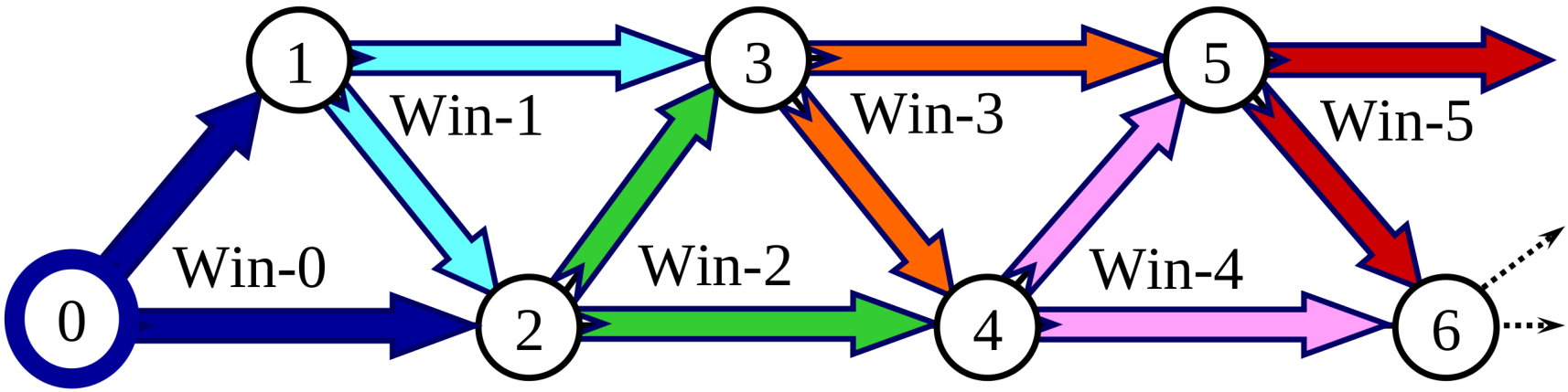
Turning Corners

- *Gentle curves are no problem*
- *But what about sharp corners?*
- *Existence of Mobius fold is transparent to the topology*



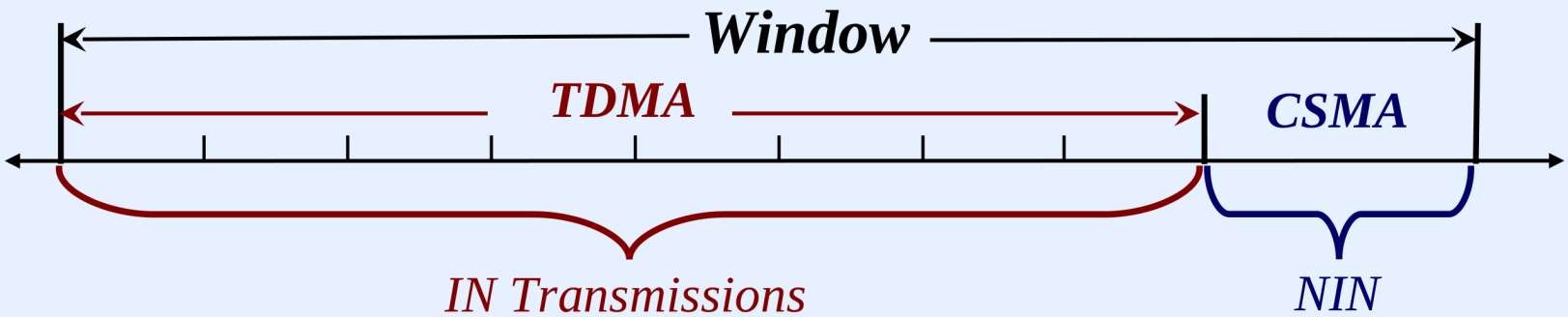
Systolic Broadcast

- **Unidirectional Single-Source Broadcast:**
  - ✦ *Window 0: Node 0 originates a message*
  - ✦ *Window w: Node w forwards node 0's message*
- **Redundancy:** *Node Red = Path Red = Time Red =* ***2***
- **Unidirectional Multi-Source Broadcast**
  - ✦ *Window 0: All nodes originate a message*
  - ✦ *Window w: Node k forwards node (k-w)'s message*



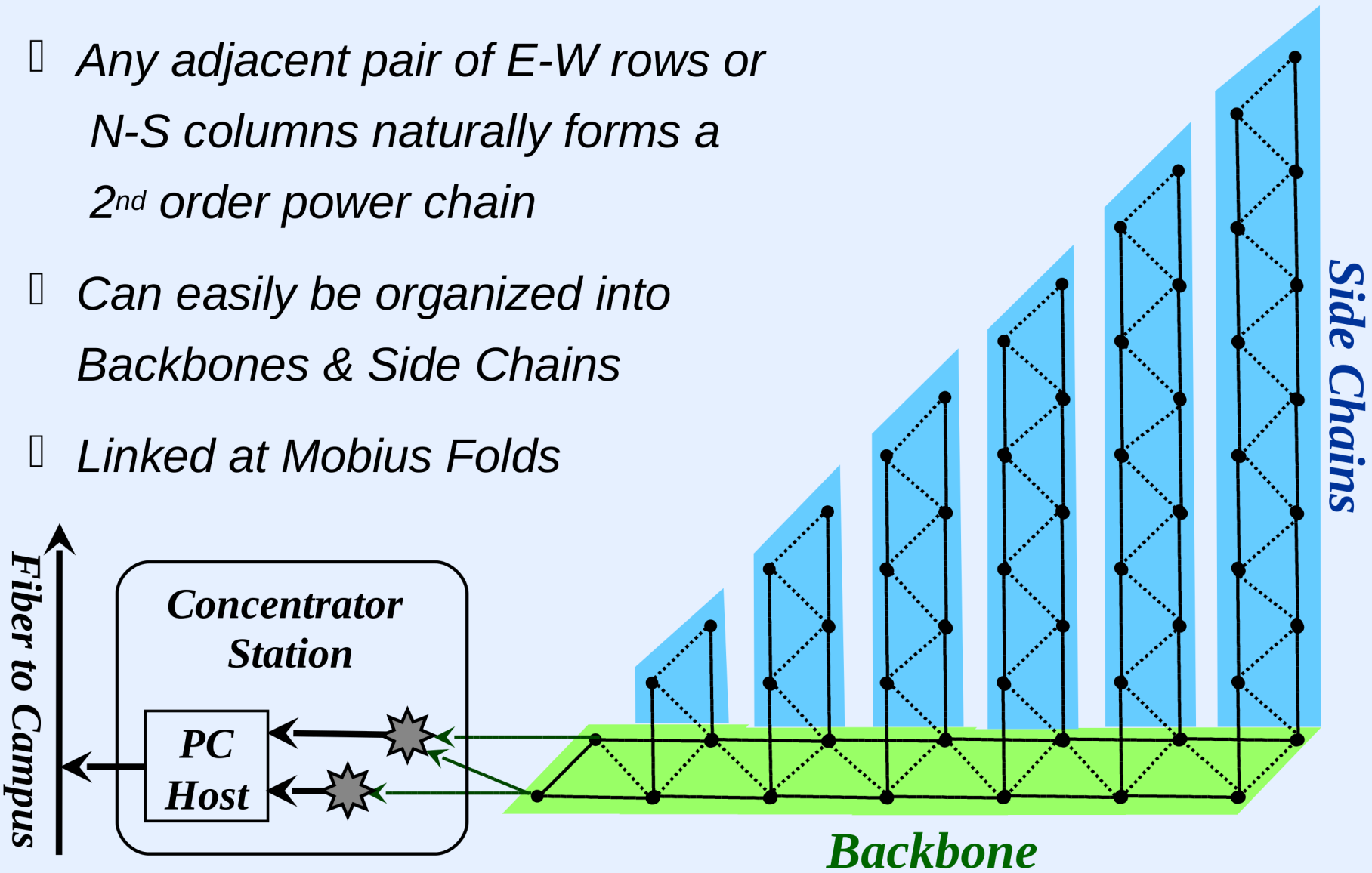
TDMA Frame

- **Hybrid Window Combines TDMA & CSMA slots**
  - *Enough TDMA slots for all INs within interference range*
  - *Enough CSMA slots for expected/desired number of NINs*
- **Auger North-Specific Comm Window**
  - *8 TDMA slots – for neighboring Infrastructure Nodes*
    - Based on predicted interference range, and
    - Alternating use of 2 RF channels
  - *1 CSMA slot – expecting few non-infrastructure nodes*



Covering an Area

- *Any adjacent pair of E-W rows or N-S columns naturally forms a 2nd order power chain*
- *Can easily be organized into Backbones & Side Chains*
- *Linked at Mobius Folds*



WAHREN Status

- After Auger North did not get funding, completion of development left an orphan
- Redundant path communication demonstrated in field tests with a small number of stations
- Development now halted due to lack of funded target project
- Could be picked up as basis of network for a future array

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Final Thoughts

+ Dedicated RF band allocation reduces possibility of outside interference
- Components more difficult to find for dedicated bands
- Dedicated bands more likely available at higher frequencies
+ Custom solutions better suited for real time nature of arrays
- Custom solutions require RF engineering which is hard and therefore expensive
    - The higher the frequency the harder the problem
- Custom solutions exacerbate spares problems