OPNT
Optical Positioning, Navigation and Timing

White rabbit time and frequency transfer in the SURFnet8 network for VLBI purposes

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The European VLBI network

Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

The European VLBI network – synchronization

Synchronization of radio telescopes:

- H-masers are currently used at most radio telescopes

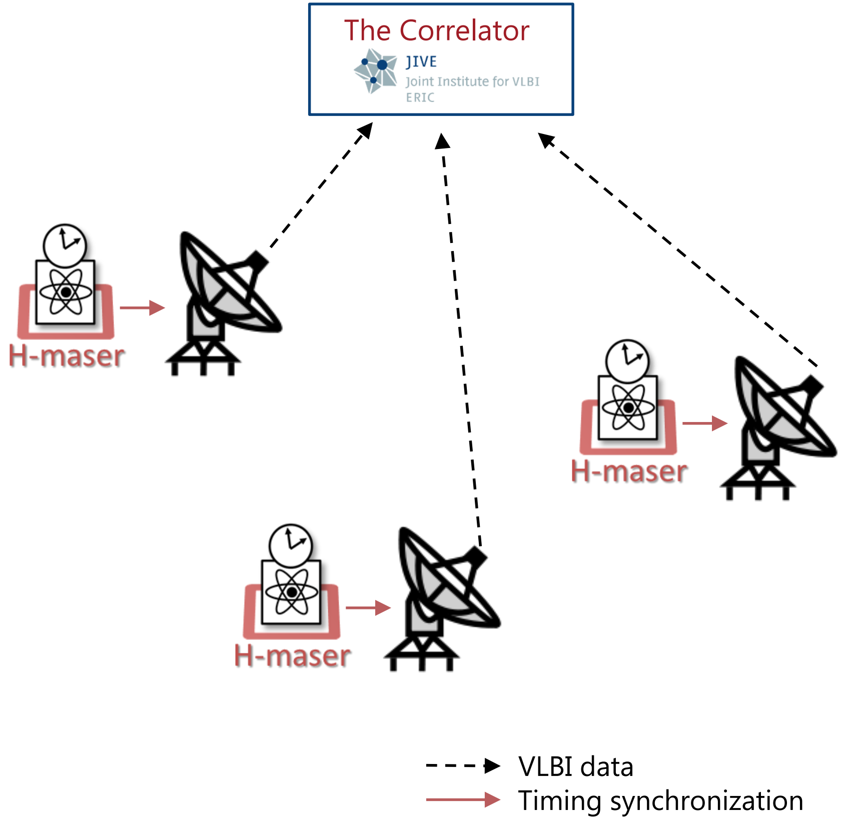
Drawbacks of using H-masers:

- H-masers drift and offset need to be determined before performing VLBI
- H-masers are costly and require service every few decades

Time & frequency requirements:

- Time offset: $< 16\ \mu s$
- Frequency stability:
  $< \sim 9 \times 10^{-12}$ at 1 s for observations at 6 GHz
  $< \sim 4 \times 10^{-11}$ at 1 s for observations at 1.4 GHz

Looking for other solutions that also meet the VLBI time & frequency requirements…

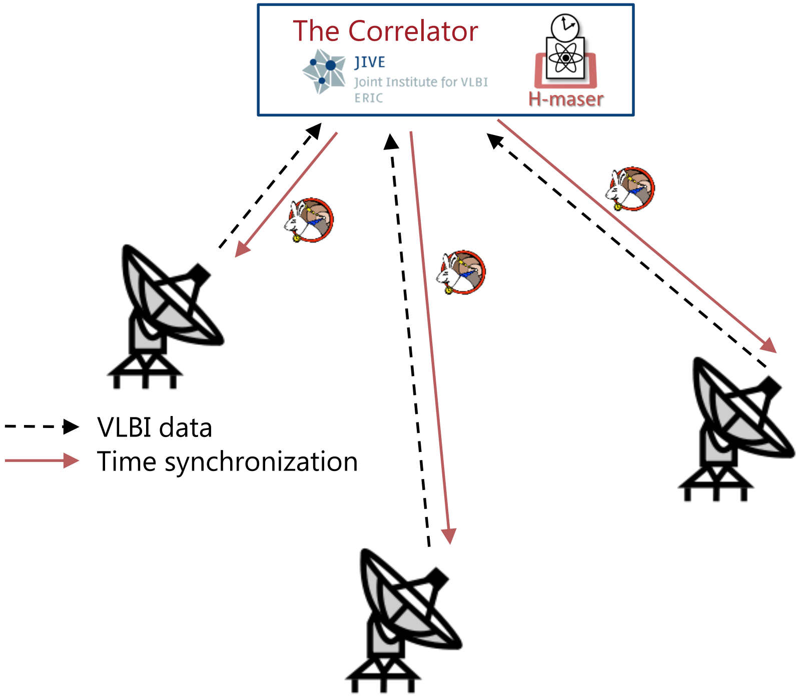


Synchronizing radio telescopes using White Rabbit

Synchronize radio telescopes to one reference clock using the White Rabbit (WR) protocol.

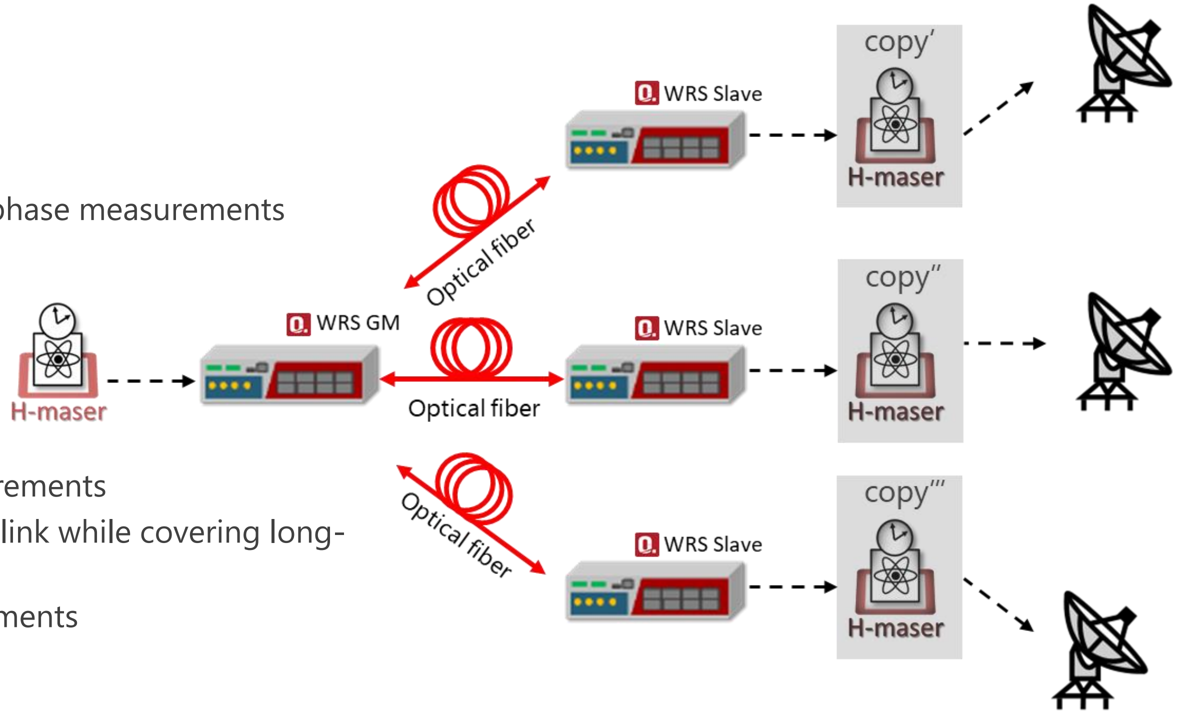
Benefits:

- Only **one H-maser** needed, reduces the costs
- All radio telescopes are continuously synchronized to the same H-maser
- **Same fiber-optic network infrastructure** can be used for the VLBI data transfer as well as for time & frequency distribution



White Rabbit

White Rabbit:
- Developed at CERN*
- Combination of IEEE 1588 (PTPv2) + SyncE + DDMTD phase measurements
- Optical 1 Gigabit Ethernet data transfer
- Sub-nanosecond accuracy



Challenges:
- Increase WR frequency stability to meet the VLBI requirements
- Implement WR in an existing operational data transfer link while covering long-haul distances (>100 km)
- Delay-calibrate the WR link to meet the timing requirements

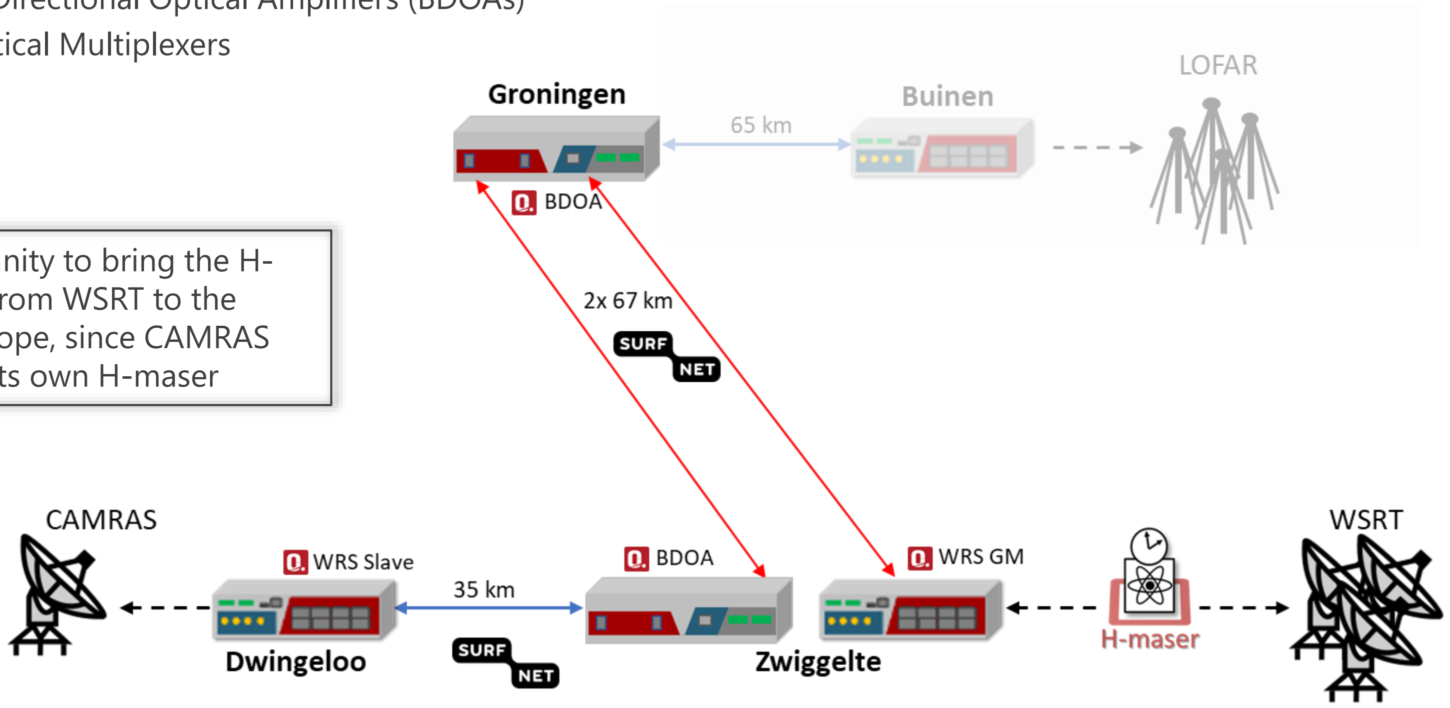
Performance upgrades:
- Low-jitter daughterboard for better long-term stability
- Clean-up oscillator for better short-term stability (< 1 s)

*https://white-rabbit.web.cern.ch/

Integration into the SURFnet8 network (1)

- 169 km fiber over the operational SURFnet8 optical network
- Grand master White Rabbit switch with low-jitter daughterboard
- Slave White Rabbit switch with low-Jitter daughterboard + clean-up oscillator
- 2 x OPNT Bi-Directional Optical Amplifiers (BDOAs)
- 2 x OPNT Optical Multiplexers

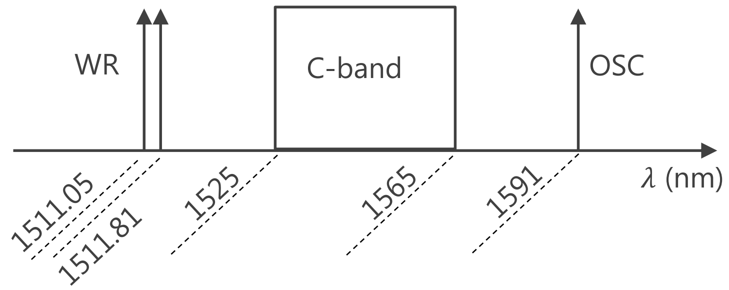
Perfect opportunity to bring the H-maser's signal from WSRT to the CAMRAS telescope, since CAMRAS does not have its own H-maser

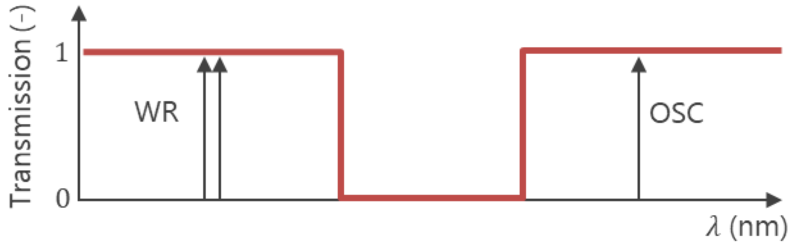


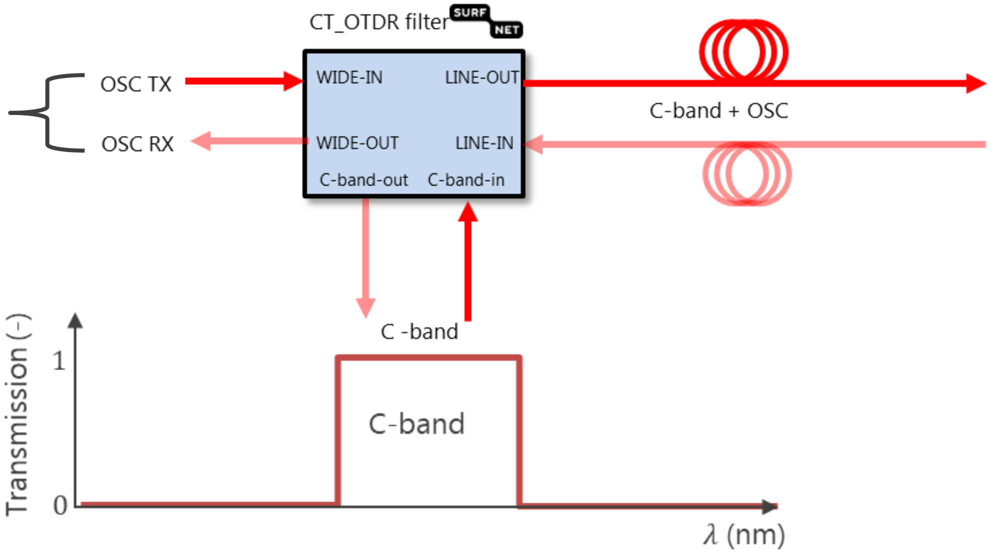
Integration into the SURFnet8 network (2)

- WR needs **bi-directional optical links** for optimum performance
- Telecommunication optical networks are based on **uni-directional links**.
- However, **SURFnet8** supports bi-directional optical links

SURFnet8 channel topology







Integration into the SURFnet8 network (3)

- WR needs **bi-directional optical links** for optimum performance
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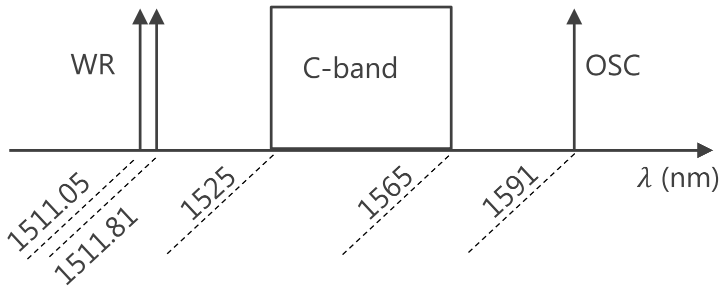
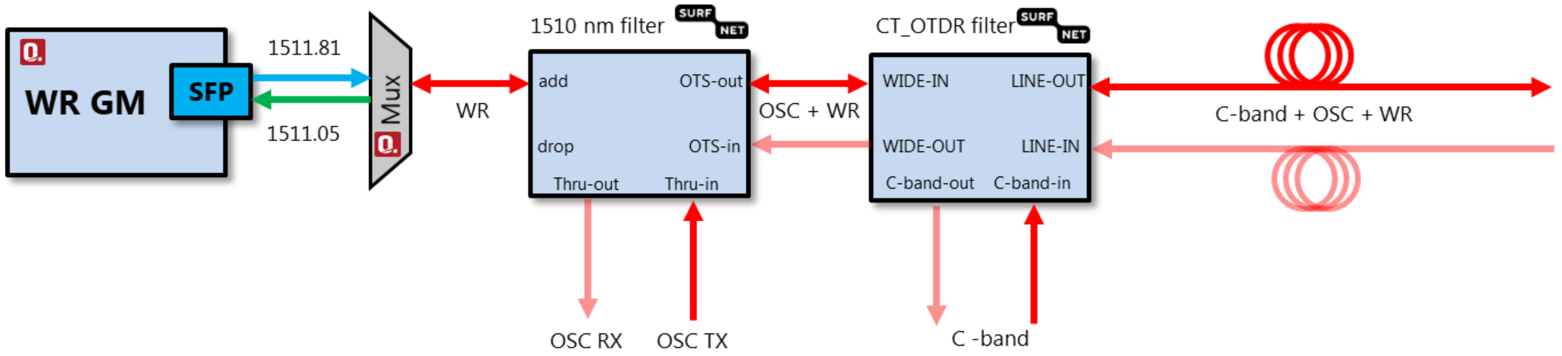
SURFnet8 channel topology





- At every intermediate site a SURFnet 1510 nm filter is used to multiplex WR with the optical supervisory channel (OSC)

Calibration of delay asymmetry: results (1)

Fixed delay asymmetries:

- WR switch + optical transceivers
- Bi-Directional Optical Amplifiers (BDOA)
- Optical Multiplexers (MUX)

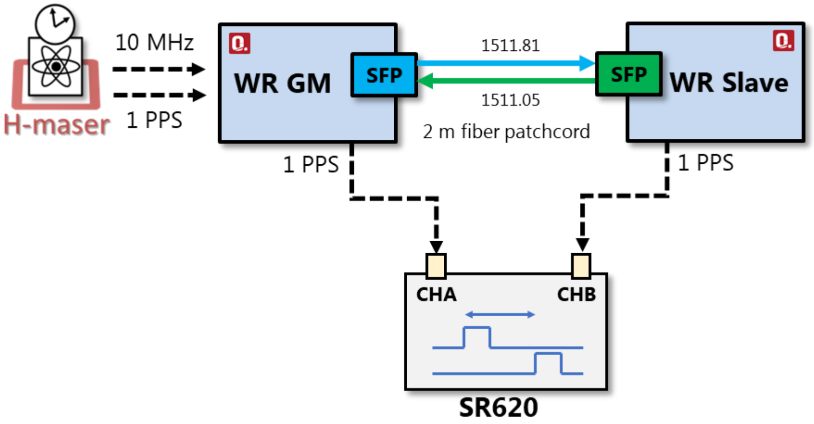
Optical link delay asymmetries:

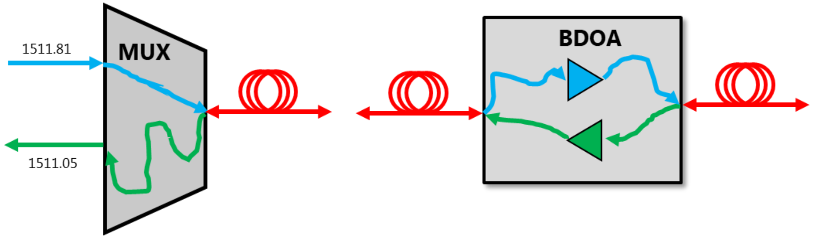
- Caused by chromatic dispersion (CD)
- Variable with the length (L) of the link:

$$\Delta\tau = \delta_{ms} - \delta_{sm} = L\int_{\lambda_2}^{\lambda_1} D(\lambda)d\lambda$$

$$\Delta\tau \approx L\widetilde{D} \times (\lambda_1 - \lambda_2)$$

- Ways to measure the CD effect:
  - Round-trip
  - Swapping wavelengths





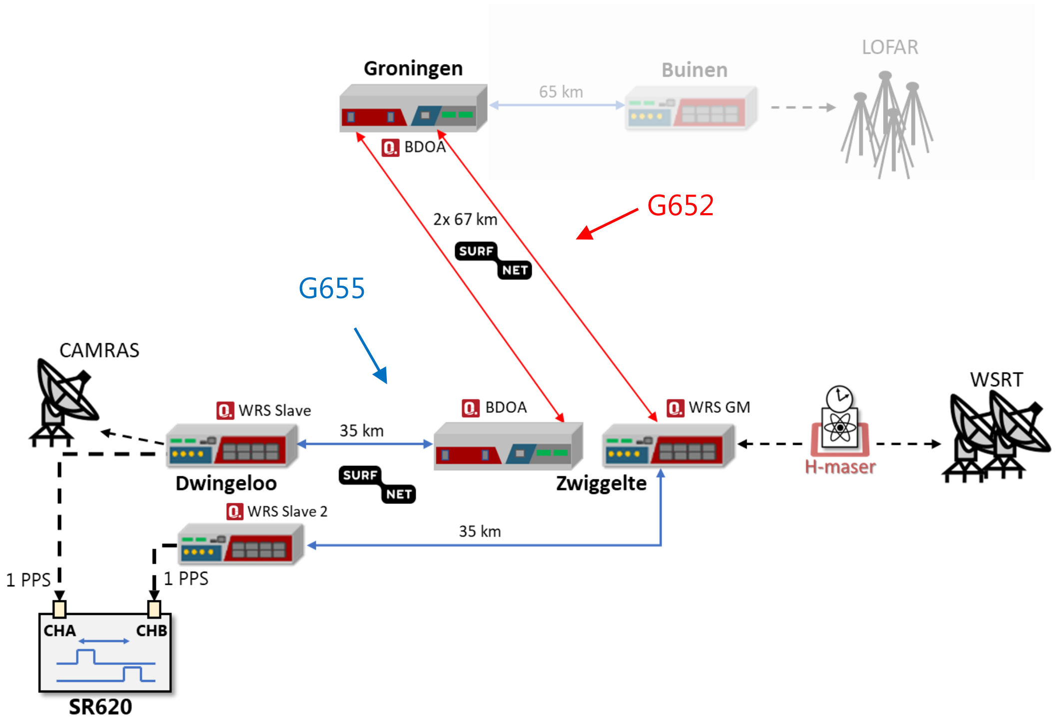
https://www.ohwr.org/project/white-rabbit/wikis/Documents/White-Rabbit-calibration-procedure

Calibration of delay asymmetry: results (2)

Optical link-delay asymmetries:

- 2 x 67 km G652 non dispersion shifted fiber:
  Measured dispersion: (11 ± 2) ps/nm/km
  SURFnet data dispersion: 12.5 ps/nm/km

- 35 km G655 dispersion shifted fiber:
  Measured dispersion: (4 ± 3) ps/nm/km
  In agreement with G655 characteristics



Final result:

- Correction for all fixed-delay asymmetries and optical link-delay asymmetries
- Using one extra calibrated WR link for the final check
- (-370 ± 130) ps offset measured between the two slave switches

Conclusions & Outlook

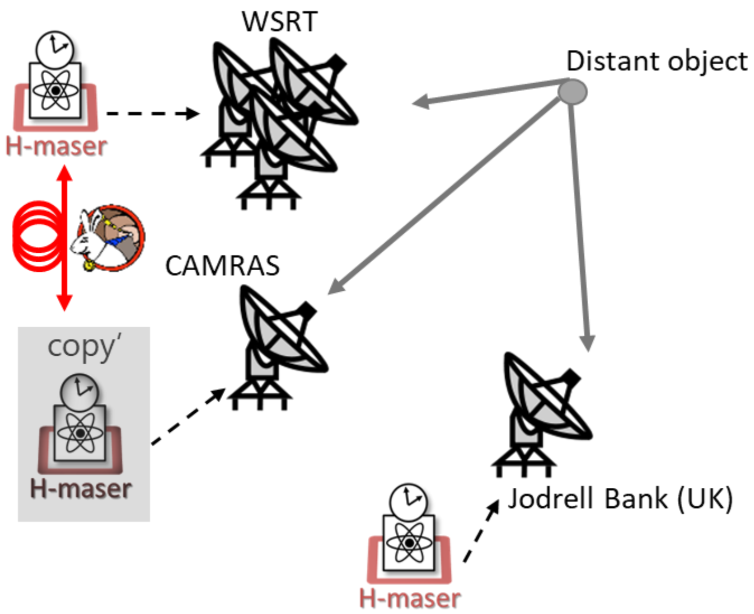
Deployment in the SURFnet8 network:

- 169 km long bi-directional amplified WR timing network successfully deployed by SURFnet, using alien wavelengths
- Production network data traffic not influenced by the WR connection

Time synchronization performance:

- After correction, an offset of (-370 ± 130) ps offset was measured between the two slave switches at WSRT

So, now the CAMRAS telescope has time & frequency through the SURFnet/WR network – but does it work for VLBI?



More details: Deliverables 5.7 and 5.14 (to be submitted at the end of April 2019)