CEPC wireless control system considerations

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1. the requirement

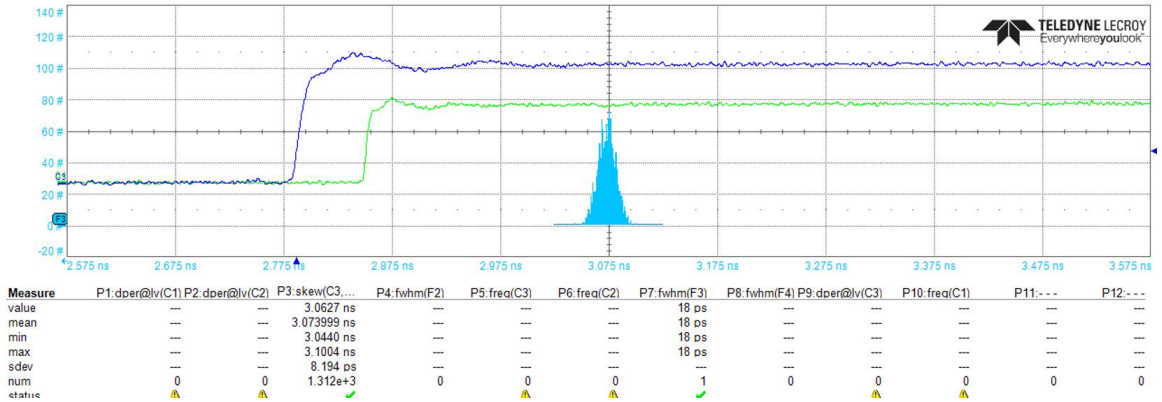
- A tunnel and support tunnel with a circumference of 50 kilometers
- Clock and data bidirectional transmission
- The synchronization of the clock of each point less than 50ps(?), the jitter of clock less than 1ps(?)
- Certain bandwidth for each point, and network protocol for each point
- Radiation tolerance
- Long-term reliable work

2. possible wireless technology

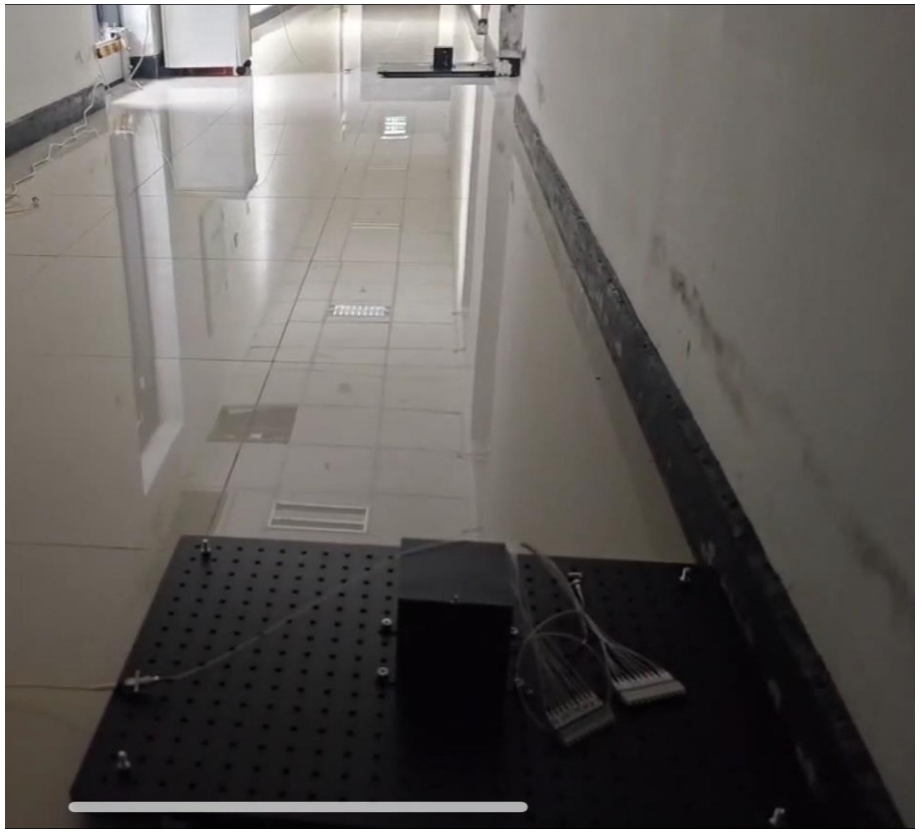
- WIFI6(7), LAN, bandwidth 500Mbps(10Gbps), can't to be used for the precision clock transmission
- NearLink technology, local area network, bandwidth 500Mbps, can fully replace WIFI, supplied by Huawei, uncertain whether can be used for precise clock transmission or not
- Laser, point-to-point transmission, with a bandwidth of 10Gbps, can be used for data and control transmission within short to medium distances (<1 kilometer), and can be used for precision clock transmission. Customizable, ready for various experimental services
- So, Laser is the best wireless transmission technology for the control system of CEPC accelerator

3. the consideration of the system

- Test result
  - Basement of main building
  - About 6 meters distance
  - The transmission of clock and the data at the same time
  - Jitter of clock : 5.8ps(RMS)

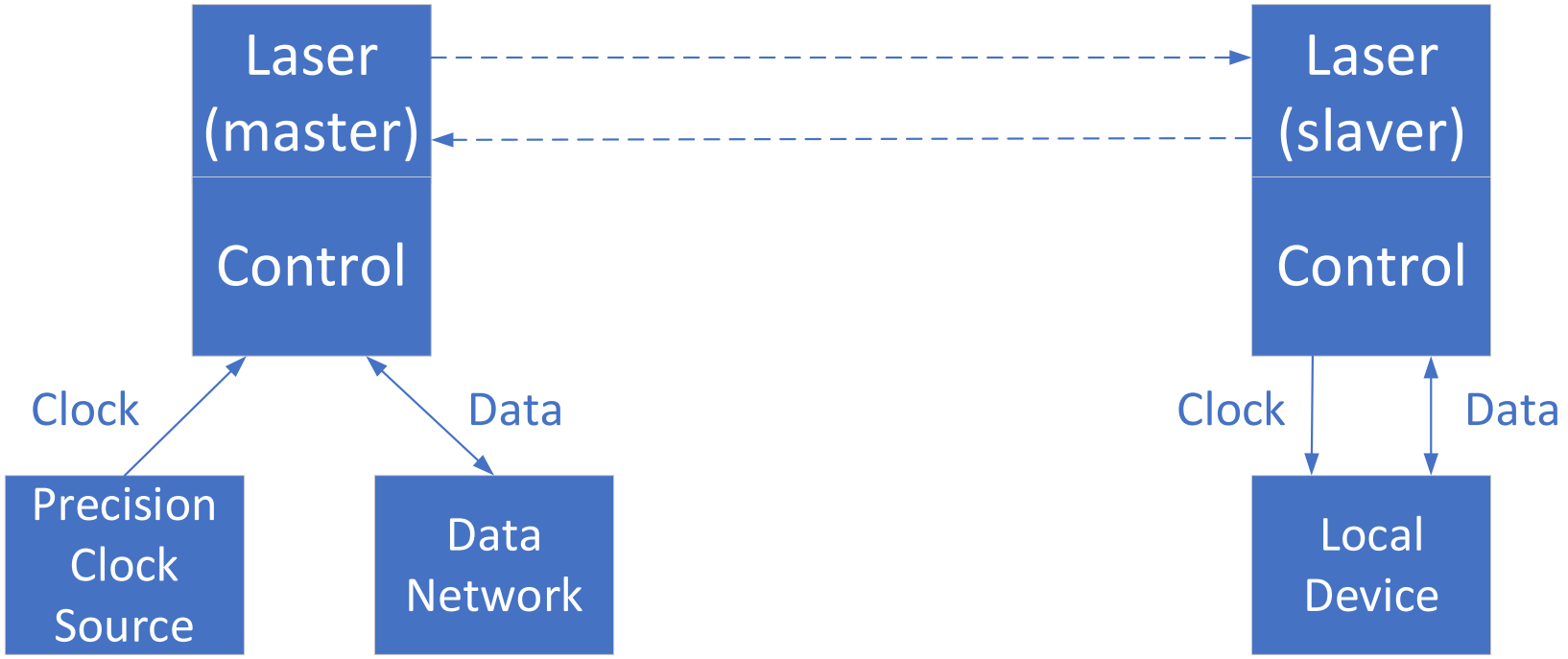


Measure	P1:dper@lv(C1)	P2:dper@lv(C2)	P3:skew(C3,...	P4:fwhm(F2)	P5:freq(C3)	P6:freq(C2)	P7:fwhm(F3)	P8:fwhm(F4)	P9:dper@lv(C3)	P10:freq(C1)	P11:- - -	P12:- - -
value	---	---	3.0627 ns	---	---	---	18 ps	---	---	---	---	---
mean	---	---	3.073999 ns	---	---	---	18 ps	---	---	---	---	---
min	---	---	3.0440 ns	---	---	---	18 ps	---	---	---	---	---
max	---	---	3.1004 ns	---	---	---	18 ps	---	---	---	---	---
sdev	---	---	8.194 ps	---	---	---	---	---	---	---	---	---
num	0	0	1.312e+3	0	0	0	1	0	0	0	0	0



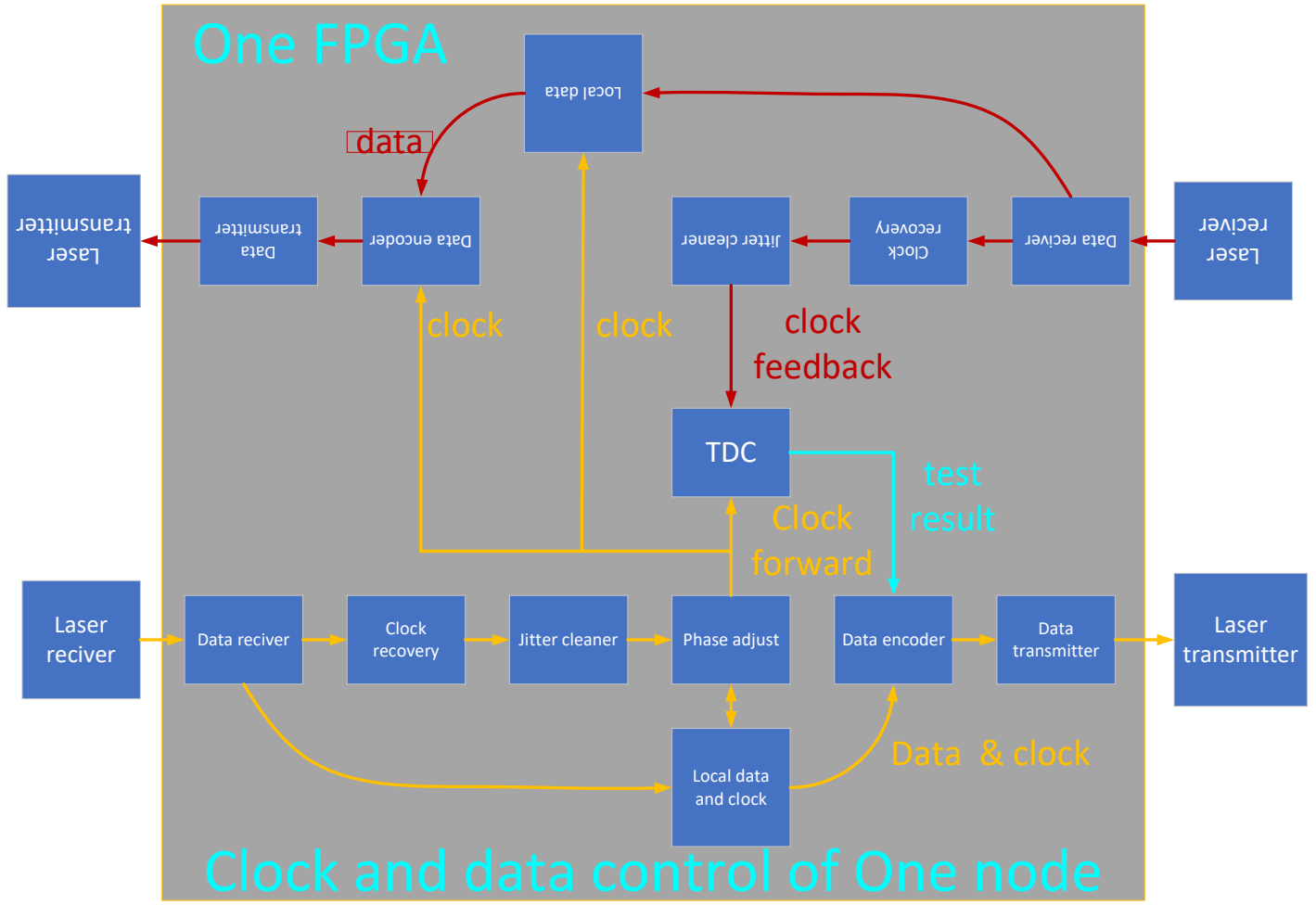
3. the consideration of the system

- Master
  - laser transmission
  - Control part
    - Laser driver
    - Clock control
    - Data switch
    - Position control
    - Status monitor
  - connect to the clock source and outer ethernet
- Slaver
  - Laser transmission
  - Control part
  - connect to local device



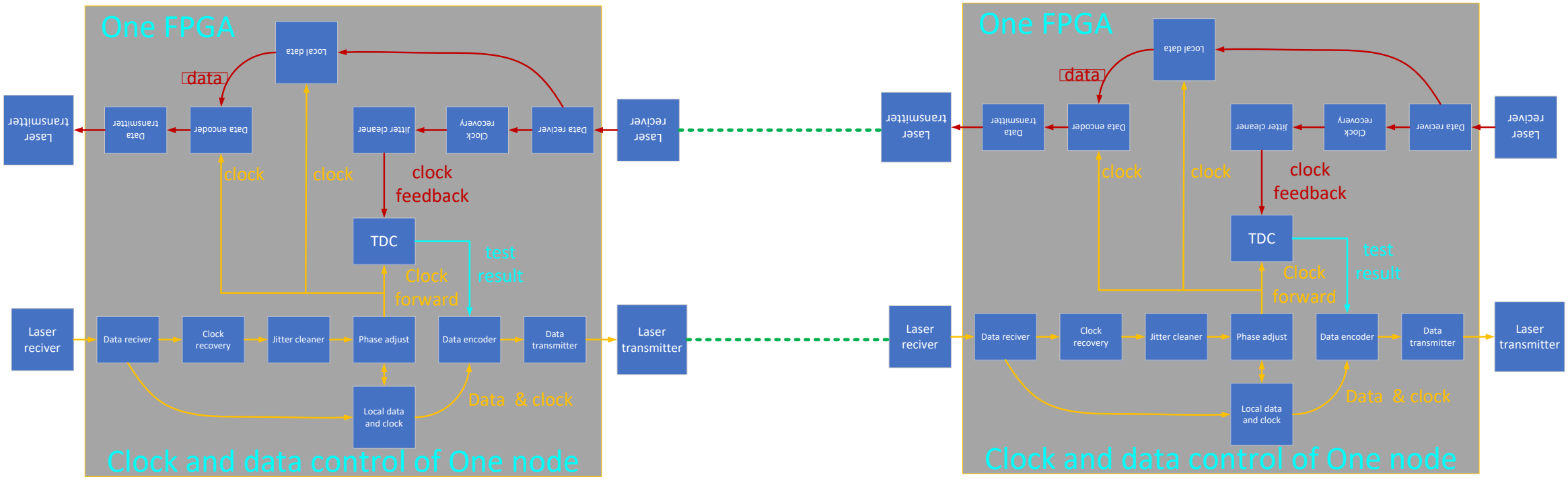
3. the consideration of the system

- Detail of one node
  - The clock will be encoded with data together
  - For the clock of the output of the first jitter cleaner is less than 10ps
  - A TDC will be used to test the delay of the laser and circuit, and the result will be sent to central control unit for calculation
  - The delay can be set to give the suitable phase of the local clock
  - For both direction, 10Gb + 10Gb bandwidth can be provided for data transmission



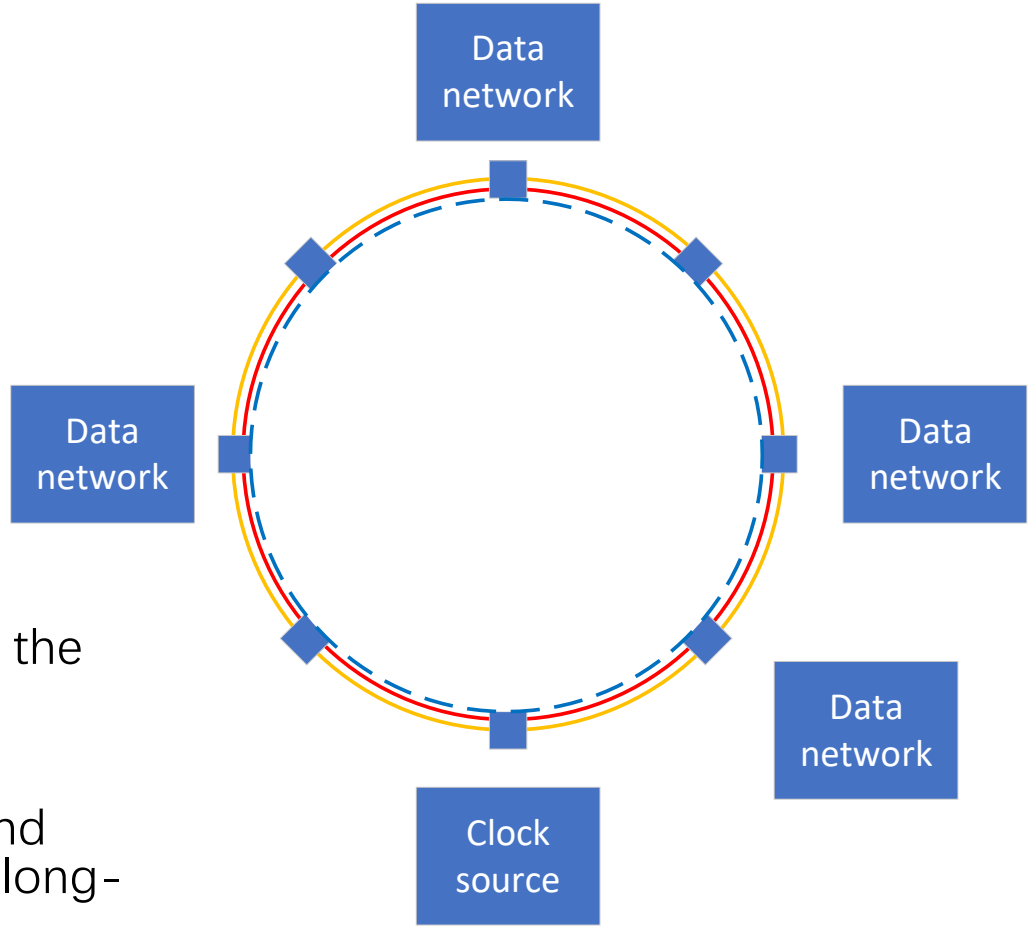
3. the consideration of the system

- For two cascaded nodes

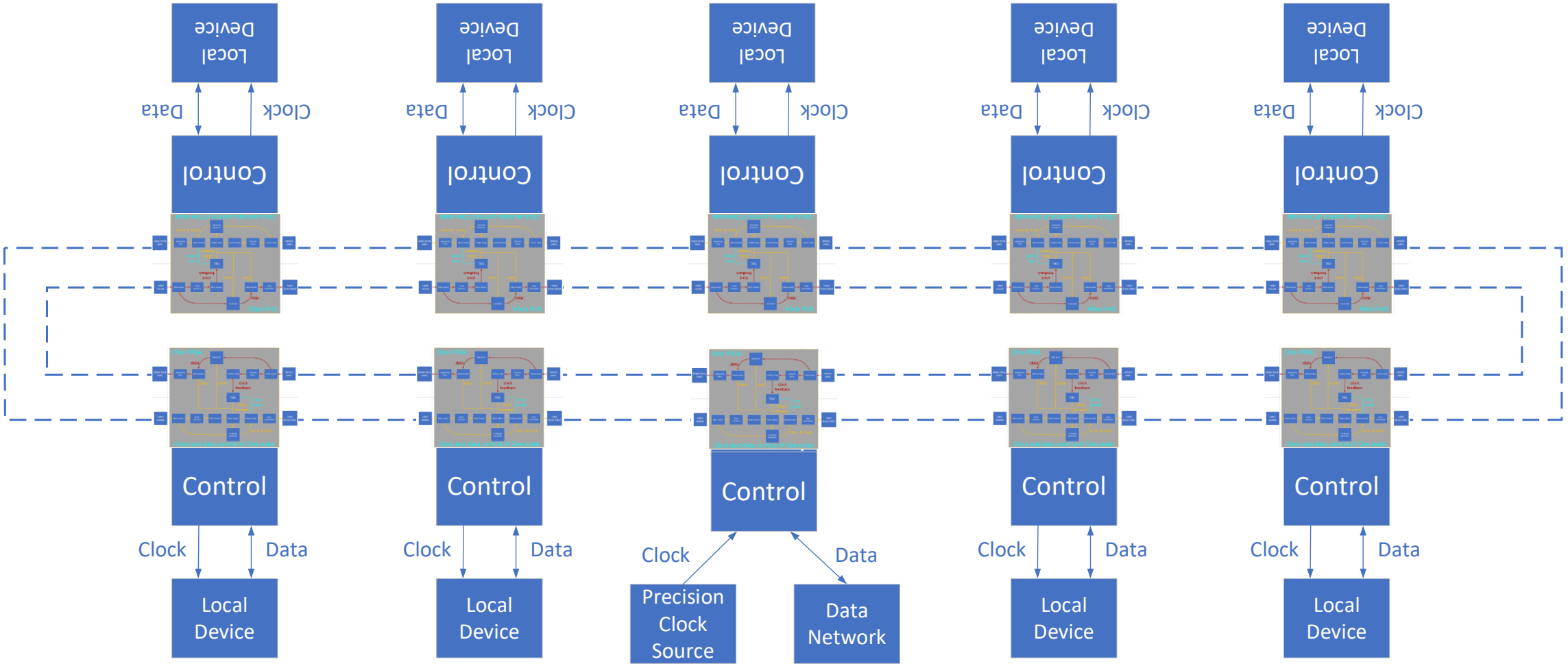


3. the consideration of the system

- For the 50 kilometers system
  - 100 nodes, 500meters each
  - Close loop daisy chain topology structure
  - The clock have one root node
  - The data can have multiple access nodes
- Some issues of the clock control
  - Cycle by Cycle jitter transfer
    - Using jitter cleaner at each node to break down the transferring of the cycle-by-cycle jitter
  - Long-term jitter and Phase skew transfer
    - Using real-time adjust, close loop daisy chain and automatic study algorithm to let the phase and long-term jitter of each node of the system



3. the consideration of the system



3. the consideration of the system

- For traditional clock system, such as “white rabbit” based system, the control is done by point-to-point clock transferring algorithm, so, 3 to 4 levels maybe the limitation of fan-out.
  - $\Delta T_{low-frequence,total} = \sum(\Delta t_{long-term,i} + \Delta t_{phase,i})$
- Different from WR system, for the cascade laser system, the global control algorithm will be used. Except the point-to-point long-term jitter and phase error of each node, an additional delay control unit will be used to compensate the total phase difference. And the close loop phase measurement will be controlled in 15ps.
  - $\Delta T_{low-frequence,total} = \sum(\Delta t_{long-term,i} + \Delta t_{phase,i} + \Delta t_{delay-control,i})$

Summary

- 1. laser transfer technology is mature enough to be used for clock transfer, which can prove sub 10ps resolution of clock jitter and phase synchronization now, and certainly will be improved in the future
- 2. the laser-based system also can prove 10G network
- 3. laser is radiation tolerance, so after the main equipment are shield, then total system will be radiation tolerance
- 4. the laser should be very stable in the environment of CEPC tunnel, because the air is very stable
- 5. machine learning based automatic control system can be used for the jitter, phase and position control

Thanks!