Research on all-optical redundancy networks underground coal mines

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Abstract: In view of the serious environmental interference of coal mine underground, the inconvenient power supply of underground equipment and the existence of passive serial series number of existing F5G underground network network, explore a new coal mine underground all-optical network redundancy technology networking scheme, realize the multi-stage series of passive light branches of the mine, Solve the problem of low number of underground optical branches in series and anti-interference of communication. Based on the principle of all-optical network network, this paper expounds the redundancy protection mechanism of all-optical network group, and designs a wide-ranging coverage scheme of fiber optic whole mine through precision calculation and analysis. Through laboratory verification and coal mine roadway simulation experimental data show that the all-optical redundancy technology network scheme can realize the underground passive light multi-stage serialization, while ensuring the priority and reliability of underground gas system. At the same time, the priority and reliability of the underground gas system are guaranteed; the scheme parameter comparison table is suitable for various types of coal mines and can be used as a reference for coal mine users in the construction of underground all-optical networks.

1. Introduction
The further expansion of coal mining and the growing emphasis on mining safety gradually turn China's coal mining industry towards intelligence and informatization, making digital mine construction a new trend[1]. Furthermore, considering the serious interference with underground coal mining, the application of 5G technology to the coal mining industry [2-5] will get all-optical networking for downhole use into the mainstream of the next-generation coal communication. As Wang Guofa, member of the Chinese Academy of Engineering, mentioned recently, "F5G [6-7], an important part of new mining network infrastructure, is a gigabit optical network that provides an information superhighway for intelligent coal mining construction, whereby multi-source information about coal mines can be perceived in real time and the whole man-machine-environment-management digital system can be efficiently enabled, reducing safety control risks and facilitating full automation on the production sites."

2. All-optical networking and its protocol
Time division is currently prevailing in the terrestrial all-optical network [8]. It enables network devices
to connect in divided time slots in a bid to ensure effective and reliable data communication, and employs passive optical splitting for the passive branching of network devices at all levels, by comparison with conventional communication technologies which realize communication branching only when power is available. The protocol of terrestrial all-optical networking was shown in Figure 1.

![Diagram of terrestrial all-optical networking](image)

Figure 1 Schematic diagram of terrestrial all-optical networking

The protocol boasts the following advantages: 1. Passive optical splitters with a 1: N splitting ratio can be distributed in the middle of multiple core areas to facilitate optical cable deployment, rather than having to be placed with a power supply; 2. This is user-friendly for installation and saves the use of optical cables; And 3. The passive optical splitters require fewer electrical network devices and save device cost.

However, the all-optical networking protocol is subject to several problems in underground coal mining: 1. It only makes level 1 splitting possible and suffers huge hidden peril since the connection of the whole network which features distributed splitting will be interrupted by failure at a branch point; 2. With the absence of a protection mechanism between network devices, the communication in each region would be interrupted if the optical cable was broken; And 3. The distributed splitting structure requires each node to deploy optical cable back and forth, which increases the workload and engineering waste.

3. All-optical network in underground coal mining

3.1. Network topology

The network construction for underground coal mining needs to start from communication reliability, communication stability (anti-interference) and construction efficiency. Thus, an all-optical network redundancy protocol suitable for underground coal mining was designed on these key points and the characteristics of all-optical technology, the schematic scheme of which was shown in Figure 2.

![Diagram of all-optical network redundancy](image)

Figure 2 Network topology of all-optical network redundancy in underground coal mining

The corresponding host system features hand-in-hand protection by one host and one standby, and dual-host redundant backup. Each local service maintains contact with both the host and the standby,
but it only communicates data with either of them so that the standby engine would start work if the host failed. When all devices and the cable are working, Local Services 1-4 correspond with Main Host A only. When the cable is disconnected at m, Local Services 3-4 correspond with the standby while Local Services 1-2 correspond with the host. When the cable is disconnected at n, Local Services 1-3 correspond with the host whilst Local Service 4 corresponds with the standby.

The methane monitoring system is of vital importance in the coal mining system, and therefore it should be designed to avoid the sharing of a local service with other systems, so as to reduce the influence of the failure of other systems or equipment maintenance on methane monitoring. Therefore, the methane monitoring system was separated from other systems in the local services.

The network boasts the following strengths: 1. It allows hot backup of the corresponding host and the standby to avoid the influence on communication by the failure of any device; 2. Each local service maintains two communication modes both having 1+1 protection to ensure that the cable failure will not affect local service communications; 3. All-optical branch nodes do not need a power supply, avoiding the unavailability of power supply during underground coal mining; 4. It makes backbone communication nodes the passive optical branching points, which reduces the electrical device failure of the entire network; And 5. it separates the methane monitoring system from other systems to ensure the priority of methane monitoring.

3.2. Network cascading

Underground coal mining is performed on the roadway, which is extended with the proceeding of mining. Therefore, the all-optical networking should consider the device addition plan; otherwise, the network communication will be in a bottleneck with poor communication in the late production period. Conventional optical splitters are characterized by equilibrium splitting which allows no consideration of the output ratio of the optical splitters during installation. This mode, on the other hand, exposes the optical splitters to huge losses, including decreased cascade series, overloaded local services, a large number of devices that will be subject to communication interruptions when a fault occurs and subsequent enormous implications. Therefore, it is usually not accepted in coal mines.

Given the constant signal sending power and receiving sensitivity of optical devices, the cascade series of optical splitters can be only extended in terms of the splitting ratio. To this end, the optical splitters were designed with disequilibrium splitting, leaving most of the splitting power on the main trunk to guarantee its large power. The topology of disequilibrium splitting network was shown in Figure 3.

![Figure 3 Topology of disequilibrium splitting network](image)

In order to ensure the normal communication of local services, the splitting ratio reserved only needs to ensure the application of the local services, while most of the remaining optical power continues to go down with the main trunk; Similarly, when the optical power on the main trunk can only guarantee local service communication, the network splitting discontinues to split. The optical devices have their signal sending power between -2 and -4 dBm and their receiving sensitivity at -24 dBm. F1, F2 ... F8 in Figure 3 are the local devices.
Optical splitting loss is calculated by the following formula: 
\[ P = -10 \log \left( \frac{P_o}{P_i} \right) \] 
Formula 1

Where P is optical splitting loss, \( P_o \) is the output power of optical splitters, and \( P_i \) is the input power of optical splitters.

4. Experimental testing

4.1. Laboratory splitting series simulation

Theoretical modeling was carried out for passive optical splitting ratio and series in the laboratory, as shown in Figure 3. Given the transmitting power of -2 dBm, the splitting of local services (K) was shown in Table 1 and Table 2, when the disequilibrium splitting ratio is M (throttle splitting on the main trunk) and N (splitting on the main trunk), respectively.

According to Formula 1:
\[ A_n = A(n-1) - 10 \log (M) \] 
Formula 2
\[ B_n = B(n-1) - 10 \log (N) \] 
Formula 3
\[ C_n = A_n - 10 \log (K) \] 
Formula 4

The data in Tables 1 and 2 were calculated by Formulas 2, 3 and 4.

| Table 1 Splitting of local services at a disequilibrium splitting ratio of 20% and 80% |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Local ratio | An     | Bn     | Cn     | An     | Bn     | Cn     | An     | Bn     | Cn     |
| n = 1       | -9     | -3     | -18    | -9     | -3     | -15    | -9     | -3     | -12    |
| n = 2       | -10    | -4     | -19    | -10    | -4     | -16    | -10    | -4     | -13    |
| n = 3       | -11    | -5     | -20    | -11    | -5     | -17    | -11    | -5     | -14    |
| n = 4       | -12    | -6     | -21    | -12    | -6     | -18    | -12    | -6     | -15    |
| n = 5       | -13    | -7     | -19    | -13    | -7     | -16    | -13    | -7     | -15    |
| n = 6       | -14    | -8     | -20    | -14    | -8     | -17    | -14    | -8     | -17    |
| n = 7       | -15    | -9     | -21    | -15    | -9     | -18    | -15    | -9     | -18    |
| n = 8       | -16    | -10    | -19    | -16    | -10    | -19    | -16    | -10    | -19    |
| n = 9       | -17    | -11    | -20    | -17    | -11    | -20    | -17    | -11    | -20    |
| n = 10      | -18    | -12    | -21    | -18    | -12    | -21    | -18    | -12    | -21    |

Considering the other loss (3dBm), the minimum optical power is 21 dBm.

| Table 2 Splitting of local services at a disequilibrium splitting ratio of 10% and 90% |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Local ratio | An     | Bn     | Cn     | An     | Bn     | Cn     | An     | Bn     | Cn     |
| n = 1       | -12    | -2.5   | -21    | -12    | -2.5   | -18    | -12    | -2.5   | -15    |
| n = 2       | -12.5  | -3     | -18.5  | -12.5  | -3     | -15.5  | -12.5  | -3     | -15.5  |
| n = 3       | -13    | -3.5   | -19    | -13    | -3.5   | -16    | -13    | -3.5   | -16    |
| n = 4       | -13.5  | -4     | -19.5  | -13.5  | -4     | -16.5  | -13.5  | -4     | -16.5  |
| n = 5       | -14    | -4.5   | -20    | -14    | -4.5   | -17    | -14    | -4.5   | -17    |
| n = 6       | -14.5  | -5     | -20.5  | -14.5  | -5     | -17.5  | -14.5  | -5     | -17.5  |
| n = 7       | -15    | -5.5   | -21    | -15    | -5.5   | -18    | -15    | -5.5   | -18    |
| n = 8       | -15.5  | -6     | -18.5  | -15.5  | -6     | -19    | -15.5  | -6     | -19    |
| n = 9       | -16    | -6.5   | -19    | -16    | -6.5   | -19    | -16    | -6.5   | -19    |
| n = 10      | -16.5  | -7     | -19.5  | -16.5  | -7     | -20.5  | -16.5  | -7     | -20.5  |
| n = 11      | -17    | -7.5   | -20    | -17    | -7.5   | -20    | -17    | -7.5   | -20    |
| n = 12      | -17.5  | -8     | -20.5  | -17.5  | -8     | -21    | -17.5  | -8     | -21    |
| n = 13      | -18    | -8.5   | -21    | -18    | -8.5   | -21    | -18    | -8.5   | -21    |

Considering the other loss (3dBm), the minimum optical power is 21 dBm.
4.2 Field test
The system was built and tested in Qingshuixi Coal Mine in Zhongliangshan according to the topology in Figure 3. A comparison between the measured and simulated data was shown in Table 3.

| Disequilibrium (M:N) | Local | Actual series | Actual local services | Theoretical series | Theoretical mount points |
|----------------------|-------|---------------|-----------------------|-------------------|------------------------|
| 2:8                  | 1:8   | 3             | 8                     | 4                 | 8                      |
|                      | 1:4   | 6             | 4                     | 7                 | 4                      |
|                      | 1:2   | 10            | 2                     | 11                | 2                      |
| 1:9                  | 1:8   | 0             | 0                     | 1                 | 8                      |
|                      | 1:4   | 6             | 4                     | 7                 | 4                      |
|                      | 1:2   | 12            | 2                     | 13                | 2                      |

1+1 protection: less than 300 ms

Based on the model and experimental data, it can be concluded that: 1. Passive splitting series of the local service with a splitting ratio at 1:2 are significantly more than those at other splitting ratios; 2. No matter how much the splitting ratio is, the actual cascade series is less than the theoretical figure in that the optical connector suffers a huge loss during device connection. 3. According to Table 1 and Table 2, the appropriate reduction of the splitting ratio in the local services may contribute to the increase of the passive splitting series; And 4. 1+1 redundancy protection will take less than 300 ms.

5. Conclusion
Modeling and testing suggested that all-optical network redundancy can enable passive optical branching in underground coal mining, untrammeled by the conventional mode where network branching can only be realized when a power supply is available. The passive branching technology avoids the electromagnetic interference of electromagnetic signal to communication devices and thus reduces their communication failure. Also, it has the function of hand-in-hand protection, allowing optical redundancy protection and securing communication safety in coal mines.

The series of passive optical branching in this experiment were limited by the optical power of the experimental devices. If the power was appropriately increased and the receiving sensitivity is appropriately adjusted, the series should be increased, as should the network size.

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