IT. 3502 - High-Rate Networks

Project 2

Definition of an FTTA loop for the backhaul of equipment in an urban area

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1 **Overview** (GUO Xiaofan & YIN Chenghao)

This report focuses on the fiber optic line design for a specific area, incorporating different station roles (radio sites, fixed network and anchor stations). It considers factors such as network reliability, cost control, redundancy requirements, and terrain limitations to propose a series of design solutions and select the optimal strategy for implementation. The report covers design principles, topology structure, specific line designs, cost estimation and optimization recommendations.

2 **Loop Design** (GUO Xiaofan & YIN Chenghao)

2.1 Design Principles

1. Network Reliability Priority:
   - Key nodes (such as orange NRA/O nodes and green wireless stations) should be connected to anchor stations using dual physically separated return paths to ensure high reliability.
2. Cost Control:
   - Avoid unnecessary dual-path setups by selecting suitable topology structures and optimizing fiber length to reduce construction costs.
3. Avoid Using Black Main Roads:
   - In fiber optic line design, black main roads should be avoided to minimize and bottleneck latency and construction restrictions.
4. Layered Topology Optimization:
   - Based on the importance of station roles, adopt a layered design with dual-path connections for key nodes and single-path connections for regular nodes.
5. Future Scalability:
   - Reserve space in the fiber layout to facilitate the addition of new nodes or bandwidth upgrades in the future.

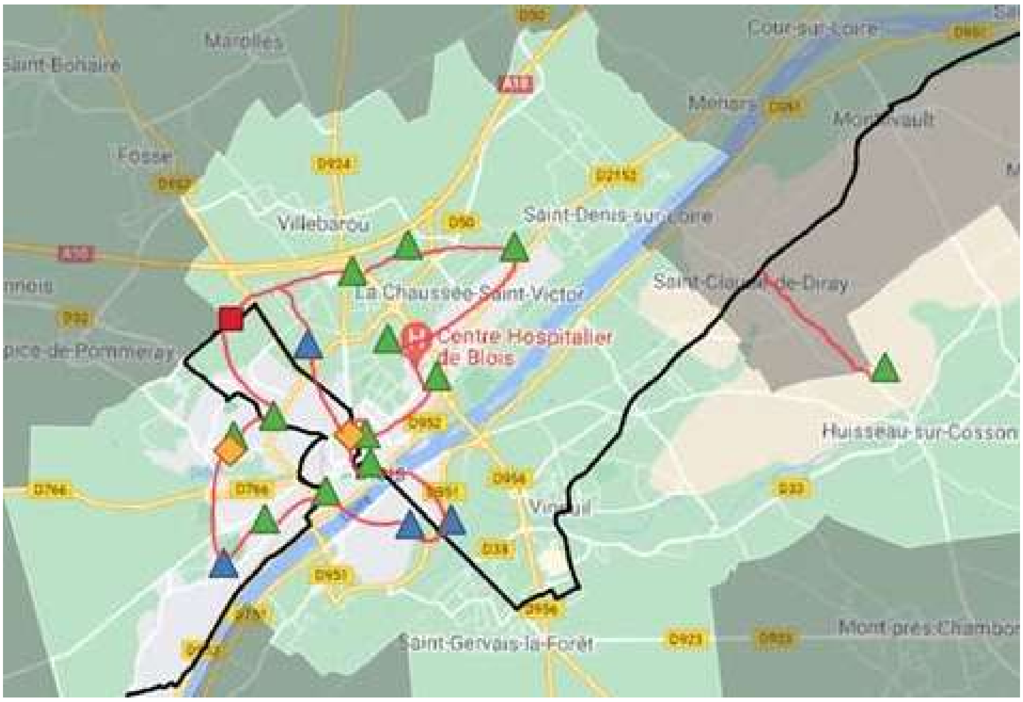
2.2 Line Design Details

2.2.1 Station Classification and Roles

1. **Wireless Stations (Green Stations):**
   - Primary Function: Provide wireless communication services (5G/4G base stations).
   - Design Requirements: High bandwidth and low latency; suitable for dual-path or ring designs.
2. **NRA/O Fixed Network Nodes (Orange Stations) :**
   - Primary Function: Aggregate traffic from fixed network users (e.g., residential and enterprise broadband) and handle return paths.
   - Design Requirements: Dual-path connections to anchor stations for high reliability.
3. **Anchor Stations (Red Stations):**
   - Primary Function: Serve as the core aggregation point, connecting to the upstream network.
   - Design Requirements: High reliability with dual-path inputs supporting large volumes of traffic.

2.2.2 Specific Line Design Solutions

1. Design 1



Description:

- **Compact and Centralized Layout**

  The red line focuses on critical urban core areas, starting from the central anchor station and primarily connecting nearby radio stations in the northwest. It avoids extending into suburban zones, maintaining a dense and efficient coverage.

- **Path Optimization and Cost Efficiency**

  The short, direct path minimizes fiber deployment length, reducing construction costs while ensuring optimized connectivity for high-demand stations.

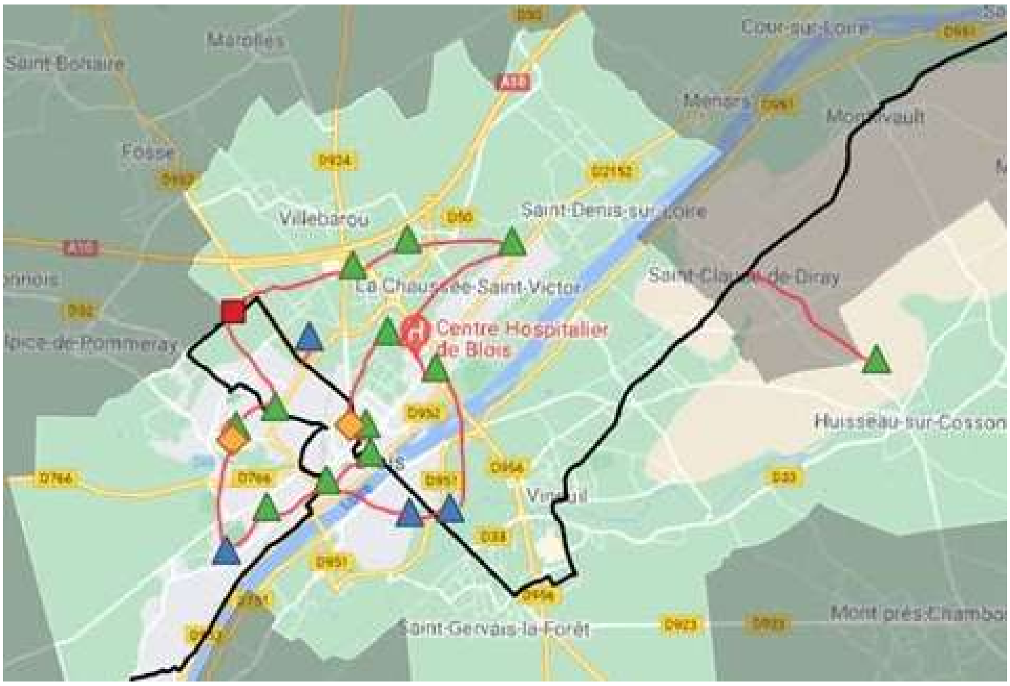
- **Risk Mitigation**

  By bypassing the black main road, the design reduces construction coordination challenges and potential risks associated with congestion and road-related failures.

- **Simple and Effective Deployment**

The straightforward layout, with minimal intersections or branching, ensures a quick and cost-effective deployment process.

2. Design 2



Description:

- **Balanced and Expanded Layout**

  The red line adopts a balanced design, connecting both northern and southern radio stations while originating from the central anchor station. By extending beyond the city core, it provides coverage for outlying urban zones and achieves better geographic balance.

- **Two-Branch Structure for Medium-Range Connectivity**

  The layout forms two distinct branches: one extending northward toward suburban stations and the other southward for additional coverage. This design optimizes connectivity for dispersed stations without compromising simplicity.

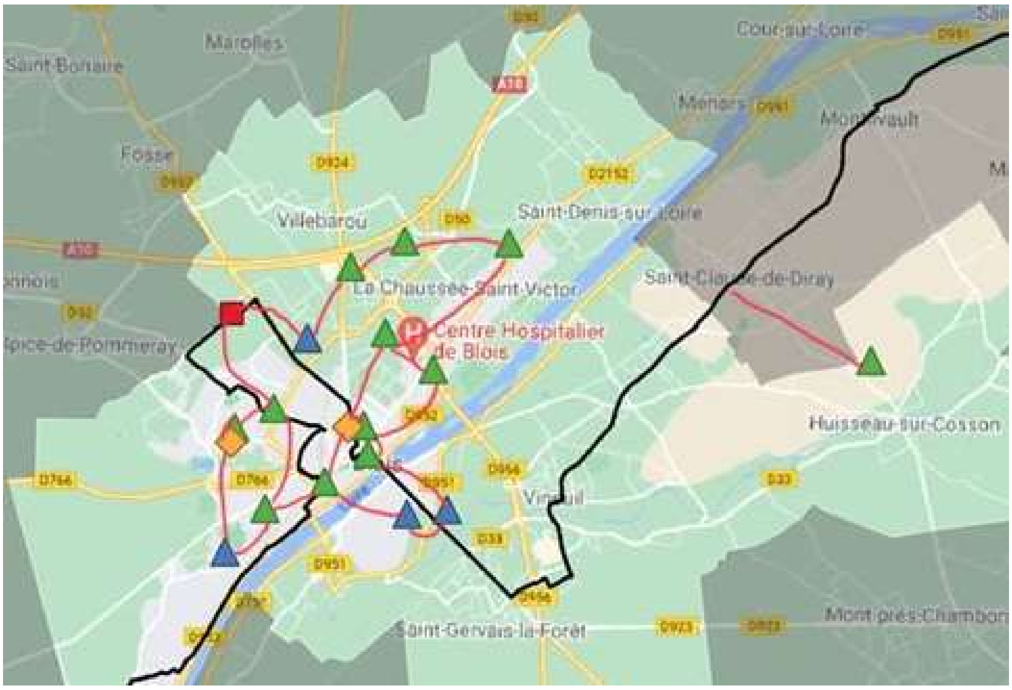
- **Risk Mitigation Through Route Planning**

  The red line avoids the black main road, reducing regulatory constraints and minimizing risks of disruptions.

- **Cost-Efficient Deployment**

By maintaining a relatively linear path and avoiding difficult terrains, the design ensures construction costs remain manageable.

3. Design 3



Description:

- **Comprehensive and Redundant Layout**

  The red line forms a network with multiple intersections and branches, extending from the central anchor station into various directions. A prominent branch reaches far northeastern stations, providing broad coverage for suburban and rural areas while ensuring overlapping connections in the central zone for enhanced redundancy.

- **Wide Area Coverage with Reliability**

  By prioritizing robustness, the design ensures critical infrastructure stability through redundant paths that offer alternative routes, minimizing the risk of network downtime.

- **Optimized for Fail-Safe Operations**

  The overlapping and fail-safe connections improve reliability, ensuring uninterrupted service even during disruptions, making it ideal for areas where network stability is critical.

2.3 Conclusion

By integrating compact, balanced, and redundant fiber connection strategies, the three designs individually have their own advantages.

- The first design focuses on centralized and compact connectivity, optimizing the network for high-demand urban areas with minimal deployment distance and reduced construction costs.
- The second design expands coverage to both northern and southern zones, offering a balanced approach that connects dispersed stations efficiently while maintaining a straightforward layout.
- The third design prioritizes broad coverage and network redundancy, extending connections to remote areas and ensuring reliable data transmission with multiple alternative paths.

By avoiding the existed main road, these designs reduce potential points of failure. The strategic combination of direct paths, extended coverage, and overlapping connections ensures the network remains scalable, flexible, and robust to meet future demands for expansion and increased traffic.

3 Route Deployment and Cost Calculation (Qinyu LIU, Haochao YUAN, Boyang HOU)

Based on the 3 designs above, the cost constraints and evaluation should be considered to compare the advantages in practical deployments. What we have done is using Google Map and the existing deployment of Orange in urban areas to calculate the exact cost of each designed line in practical situations.

3.1 Rules set up

1) For easy calculating, the cost of the optical fiber is set for 10€/m in the cases of sharing the existing route, and 100€/m if there is no existing route that we need to deploy ourselves. The formula we use to calculate the price of a journey is:

$$\boldsymbol{Cost = distance\ travelled \times unit\ price\ per\ meter}$$

(Note: Our calculated prices may fluctuate up or down by 5% to 10% compared to the real price due to force majeure factors.)

2) Put all the radio sites by the main road as possible as we can to reduce the extra cost of the material and avoid private property and public highways being damaged during the construction.

3) Keep all the line as straight as possible to reduce the difficulties of construction and maintenance.

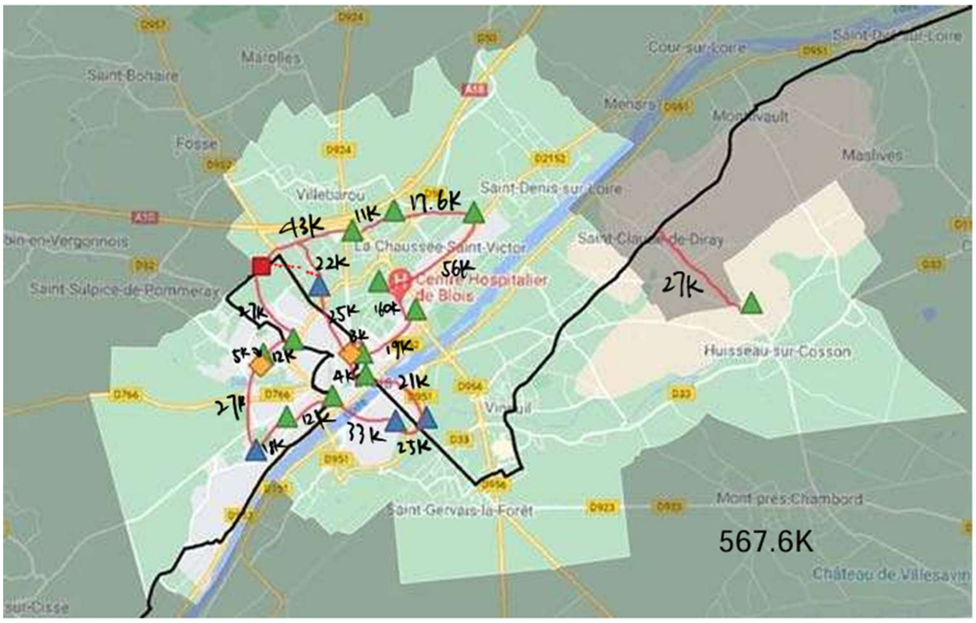
4) Reuse all the existing routes as much as possible to control the cost at a lower level.

5) The plan directly rejected the use of radio, which requires a monthly fee. Although the initial cost of using self-built optical fiber is high, other operators can use our self-built optical fiber to share the cost when laying new optical fiber in the future.

3.2 Calculation

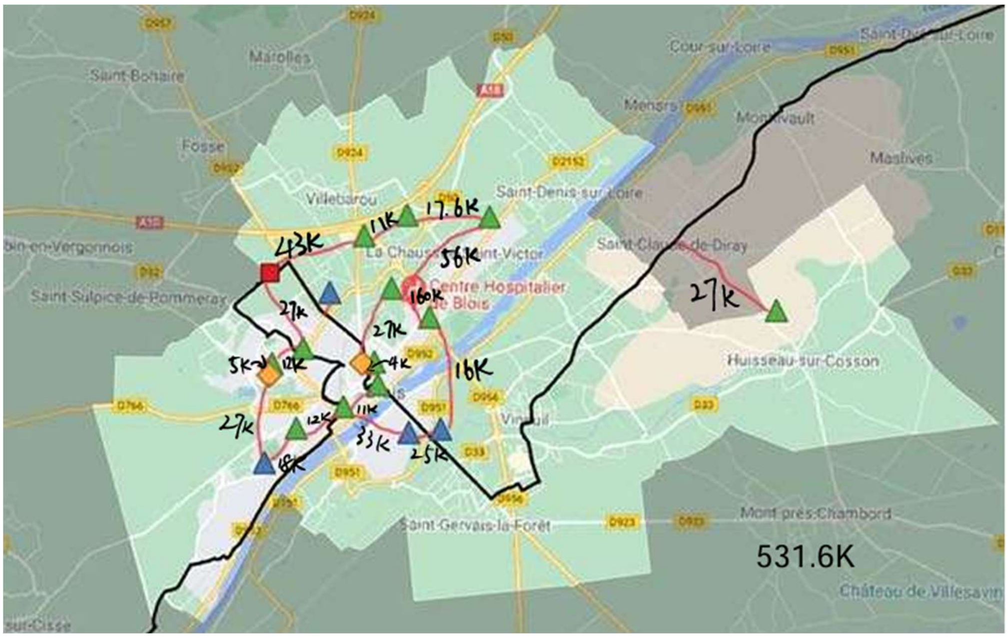
First is to point out each radio site to simplify further calculation directly using Google Map. Then we can calculate the cost by dividing it into 3 different cases corresponding to the 3 different designs above.

3.2.1 Design 1



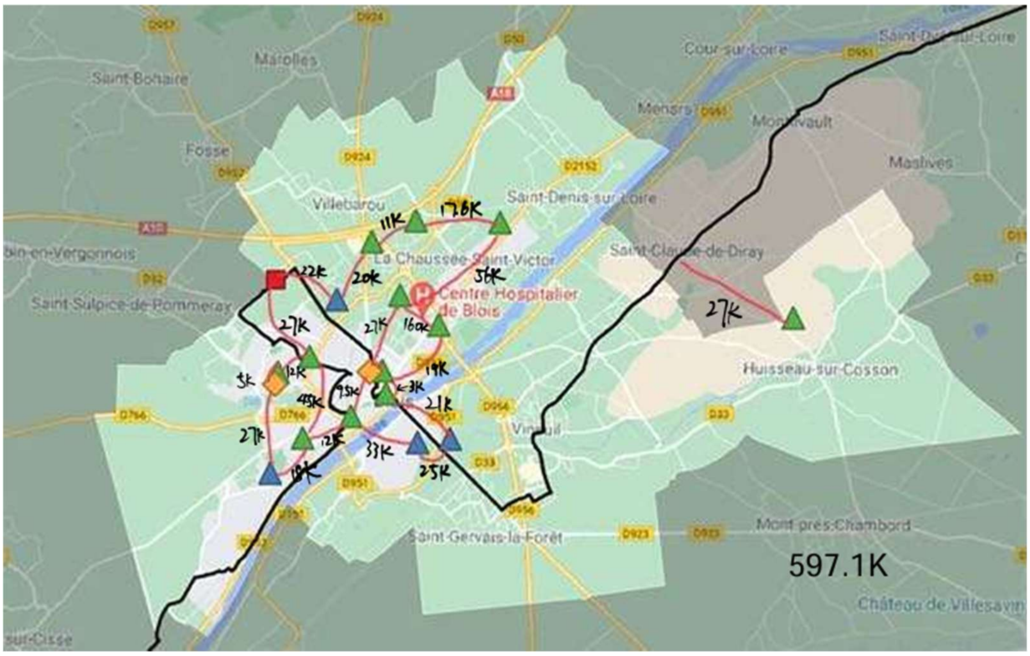
- The total cost of Design 1 ≈ 567.6K.
- The black line is the main bus connected only to the red base station in the city center area.
- For the isolated point, it’s directly connected to the black line.

3.2.2 Design 2



- The total cost of Design 2 ≈ 531.6K, which is the least expensive
- There are two radio stations connected to the main black bus, one is in the city center, and another is far away.
- Most of the deployment is similar to Design 1 in a practical situation.

3.2.3 Design 3



- The total cost of Design 3 ≈ 597.1K, which is the most expensive one.
- No station connected to the main bus except the non-city-center one.

3.3 Conclusion and Problems

1) The 3 cases are similar to each other when it comes to the practical situation on the map.

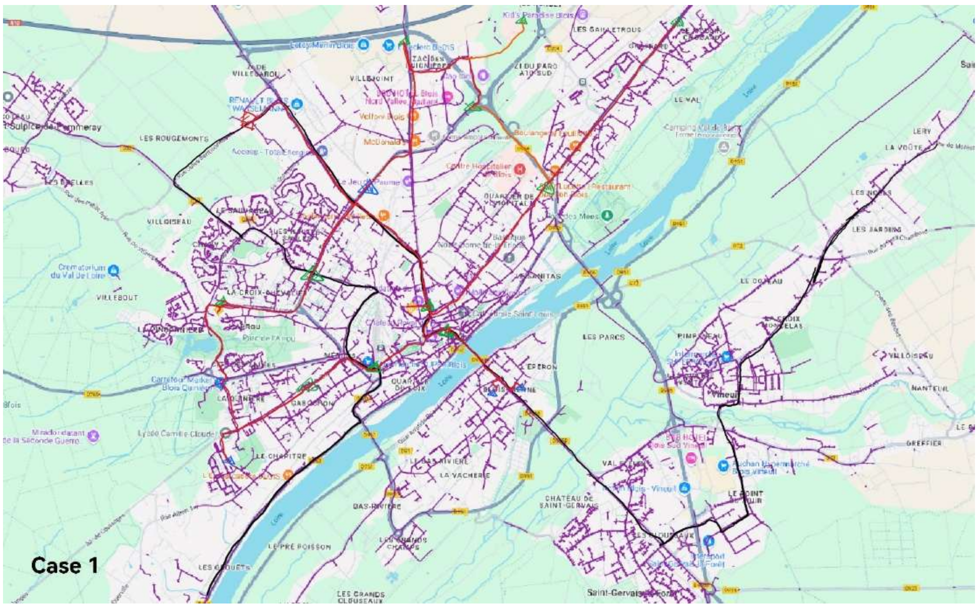
2) The total cost between one and another is around 30K, and they all follow the Backhaul principles.

3) Two of the stations are near to each other but there is no existing route for connection, so we have to spend more for construction. However, we can reuse this route for other radio stations

4 Exact Route Deployment (Qinyu LIU, Haochao YUAN, Boyang HOU)

The main purpose of this part is to draw a conclusion of the exact route in real map, which can be more practical as an instruction for the construction, and some detail can be seen in the map.

4.1 Exact Graph



- The red line exists for deployment and the orange line is the route that needs to be built.
- Some of the lines share the same road as the main bus but they are not deployed together.
- Some of the red lines are repeated in the same city road but they have to be deployed repeatedly in order to achieve the backhaul and they are also connected to different nodes between each other.
- The non-city-center radio station is not pointed out on the map due to the lack of coverage.

5 **Conclusion** (GUO Xiaofan & YIN Chenghao)

This report evaluates three fiber optic line designs based on network reliability, cost, and geographic coverage. Design 1 focuses on compact and centralized connectivity in high-demand urban areas, minimizing fiber deployment length and costs while avoiding major roads to reduce risks. Design 2 offers a balanced approach, expanding coverage to both urban and suburban areas through a simple two-branch layout, achieving the lowest cost. Design 3 prioritizes comprehensive coverage and network redundancy, extending connections to remote areas and ensuring fail-safe operations with multiple alternative paths, though at a higher cost. The analysis highlights the trade-offs between cost, coverage, and reliability, with Design 2 emerging as the most cost-effective solution, while Design 3 provides superior robustness for critical infrastructure.

Figure 1 Final Task Table

Distribution of work	members	duration
Task Evaluation	GUO Xiaofan YIN Chenghao	3h
Circuits Designs and Solutions	GUO Xiaofan YIN Chenghao	8h
Cost Calculation and Analysis	YUAN Haochao LIU Qinyu HOU Boyang	7h
Deployment Route Map	YUAN Haochao LIU Qinyu HOU Boyang GUO Xiaofan YIN Chenghao	4h

6 Summary of Issues and Resolutions (GUO Xiaofan, YIN Chenghao)

6.1 Focusing on Actual User Numbers

1) **Problem Description:**

To ensure adequate network redundancy, it is essential to accurately assess the number of actual users in the project area. Special attention should be given to regions without residential users but with significant company presence. Medium and large companies, in particular, require priority consideration due to their substantial data transmission needs.

2) **Theoretical Resolution:**

Conduct thorough surveys to identify key areas with corporate users. Collaborate with local business associations or government databases to map out medium and large company locations. Use predictive analytics to estimate data usage patterns and ensure network capacity aligns with actual demand.

6.2 Risks of Using Existing Network Lines

1) **Problem Description:**

Utilizing existing network lines entails specific risks. Permission must be obtained from the line-owning companies, and fees must be paid for their use. Key concerns include whether these fees are fixed and whether there is a possibility of negotiation failures that could prevent access to these lines.

2) **Theoretical Resolution:**

Develop early-stage partnerships with network infrastructure companies to secure access agreements. Engage legal and financial experts to negotiate favorable terms and ensure fee transparency. Establish contingency plans to deploy alternative solutions if access negotiations fail.

6.3 Cost Estimation: Avoiding Over-Precision

1) **Problem Description:**

For large-scale projects, cost estimation should focus on major expense categories rather than precise figures. Excessive emphasis on detailed calculations could hinder effective planning and resource allocation during project execution.

2) **Theoretical Resolution:**

Adopt a high-level budgeting approach that categorizes costs into broad areas such as infrastructure, labor, and contingency reserves. Use historical data from similar projects to estimate ranges rather than exact values. Update detailed budgeting iteratively as the project progresses to maintain flexibility and adaptability.