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AI-Powered Smart School Connectivity

An AI-driven solution that classifies schools based on connectivity needs and optimizes network expansion using mathematical modelling, reducing costs and ensuring scalable, reliable internet access with minimal investment

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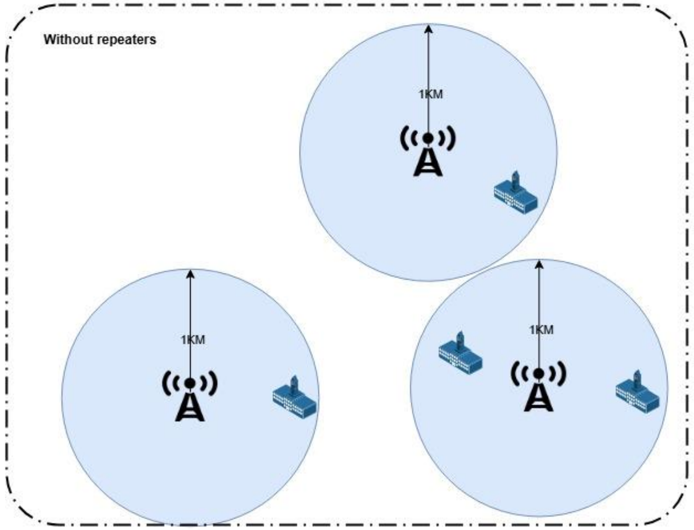
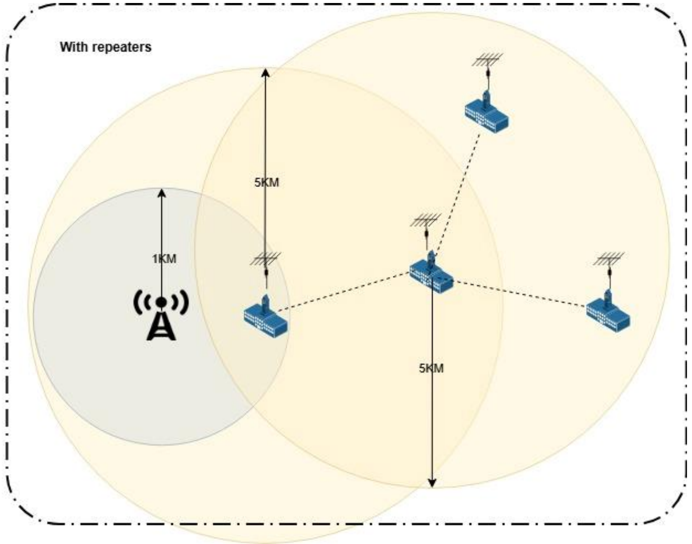
Maximizing Connectivity by Leveraging Existing Infrastructure

Expanding internet access to schools doesn’t always require costly new infrastructure. A **single 5G microcell** can cost over **€10,000**, making large-scale deployment financially challenging. However, **AI-driven optimization** enables us to find **more cost-effective** solutions.
Our goal is to provide **universal school connectivity** at **minimal cost** by strategically leveraging **existing infrastructure** and deploying the most **efficient mix of technologies**. The key part of this approach is **using already connected schools as network hubs**, extending coverage through **Point-to-Point (PtP) WiFi** to bridge connectivity gaps with **minimal additional investment**.

Not optimized approach:
3 5G towers
4 5G modems





AI-optimized approach:
1 5G tower
4 PtP repeaters

Assumptions and Key Conditions

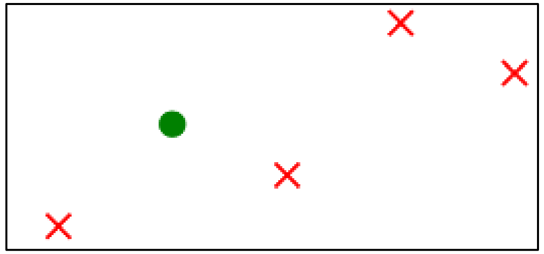
To maximize cost-efficiency, we assume that an **existing school's internet connection can be extended** to nearby schools. However, several **technical limitations** must be considered:

- ✓ **Range Constraints** – A **maximum distance of 5 km** is set for establishing a high-speed connection between two schools, ensuring **reliable performance using PtP WiFi connection**.
- ✓ **Bandwidth & Network Hops** – To prevent network congestion, we limit the number of **hops from the nearest mobile network tower to 2**. This prevents excessive signal degradation and ensures stable bandwidth.
- ✓ **Defining a Connected School** – A school is considered **"connected"** if it has direct **mobile network coverage** (e.g., within range of a 5G tower, requiring only a modem). If it falls outside direct coverage but can be reached via a **network extension**, the same **5 km distance rule** applies for feasibility.

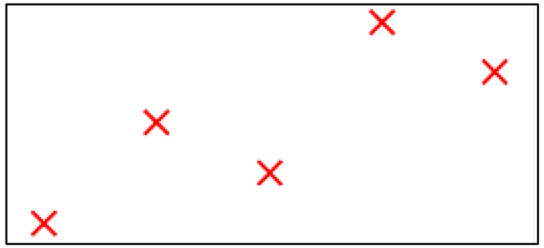
By **factoring in these constraints**, our AI-driven model **optimizes school connectivity while maintaining network performance and cost-efficiency**.

Different cases, different solutions

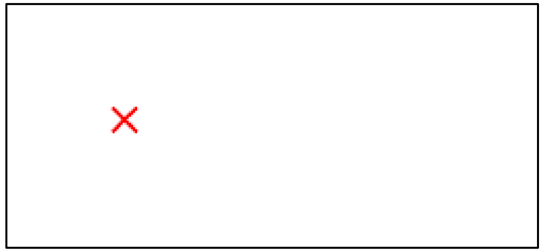
A) "Partially Connected Cluster" – A group of schools where at least one has internet access, but others do not.



B) "Isolated Cluster" – A group of schools with no existing internet connections.



C) "Remote Standalone School" – A single school without any internet connection.



Not shown: a trivial case when all schools in a cluster are already connected

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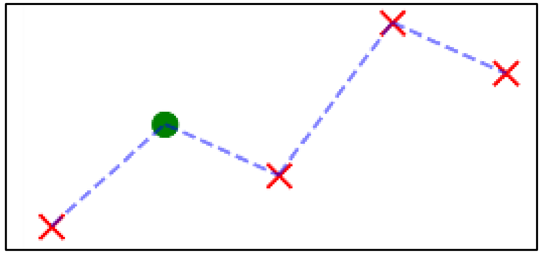
Different cases, different solutions

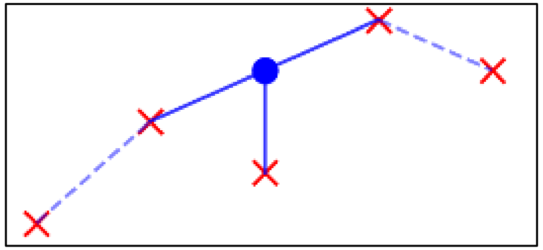
A) "Partially Connected Cluster" – A group of schools where at least one has internet access, but others do not.

Leverage the already connected school(s) to extend access to others in the cluster through optimized linking.



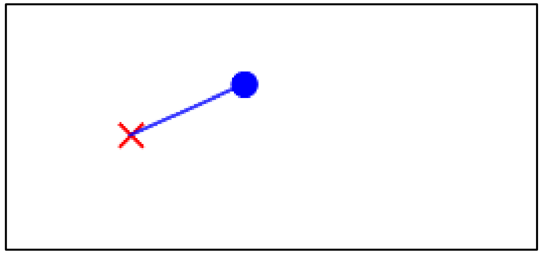
B) "Isolated Cluster" – A group of schools with no existing internet connections.

Identify the best central point for connectivity and optimize links to surrounding schools.



C) "Remote Standalone School" – A single school without any internet connection.

Provide a dedicated tower or landline for a single isolated school.



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Data Sources and Analytical Tools

To ensure an **accurate and data-driven** connectivity strategy, we utilized the following datasets and tools:

- **School Data** – Obtained from the **Giga School Mapping Data** dataset, providing precise school locations and connectivity status. (*Giga is a global initiative focused on connecting schools to the internet.*)
- **Cell Tower Data** – Sourced from **OpenCellID**, which provides **3G/4G tower locations**. These were used as a **proxy** to simulate potential **5G tower placements** for connectivity analysis.
- **Analytical & Computational Tools** – All **data processing, clustering, and network optimization** were conducted in **Jupyter Notebook**, leveraging **AI-driven models** to determine **feasible connections** and optimal network expansion strategies.

Solution Approach

Our methodology follows a structured, **data-driven** process to **maximize connectivity at minimal cost**:

1) **Identifying Existing & Low-Cost Connections** – We first integrated **mobile coverage data** with school locations to determine which schools are already **connected** or can be linked with **minimal infrastructure investment** (i.e., within a cell tower's range).
2) **Clustering Schools for Efficient Expansion** – Using **AI-driven cluster analysis**, we grouped schools that are **close enough** to be efficiently connected within a shared network. Calculation for large clusters is optimized by splitting them into smaller units and calculating the solution for each one separately.
3) **Optimizing Non-Connected Clusters** – For clusters without existing connectivity, we **calculated the optimal central points** to **minimize network hops** while ensuring **the lowest possible number of new infrastructure deployments** (e.g., additional towers or relay points).

Wireless vs. Landline

In many cases, deploying a **landline connection is unnecessary. Point-to-Point (PtP) WiFi** with **high-gain directional antennas** can deliver **high-speed internet** without the high costs of fiber installation.
This technology is also effective for **bridging connectivity gaps**—for example, when a school is **just outside mobile coverage range**, a **PtP WiFi link** can extend the connection **up to 5 km** from the nearest **cell tower**, ensuring reliable access without major infrastructure expansion.

Feature	PtP WiFi	Optical Fiber Landline
Speed	100 Mbps – 1 Gbps (can reach 10 Gbps with advanced setups)	1 Gbps – 100 Gbps, scalable
Reliability	Affected by **interference, weather, and line of sight (LOS)**	**Highly stable**, unaffected by weather
Cost	**Low to moderate** (500 – 1.000 EUR per link)	**High** (10.000 – 100.000 EUR per km)
Maintenance	**Low**, occasional alignment and interference management	**Moderate to high**, repairs can be costly (fiber cuts)
Geographical Limitations	Needs **Line of Sight (LOS)**, limited by terrain	Can be **buried or aerial**, no LOS needed

Panama

We selected **Panama** as our case study due to its **relatively small area, a significant number of non-connected schools, and the availability of sufficient data for analysis**. Below are the results from our model:

Initial Data Overview

- Total schools analyzed: 3,171
- Connected schools that cannot connect any unconnected school (no school within range): 958
- Unconnected schools: 1,312
- Connected schools with the potential to extend connectivity: 901

Clustering Results

- Clusters where all schools are disconnected: 51
- Clusters with a mix of connected and disconnected schools: 73
- Standalone schools (not included in cluster analysis): 94

Network Expansion Analysis

- Schools connected without new towers (leveraging existing connections): 625
- New towers deployed: 169 (75 within clusters, 94 for standalone schools)
- Schools connected through newly created towers: 266

Case study: Panama

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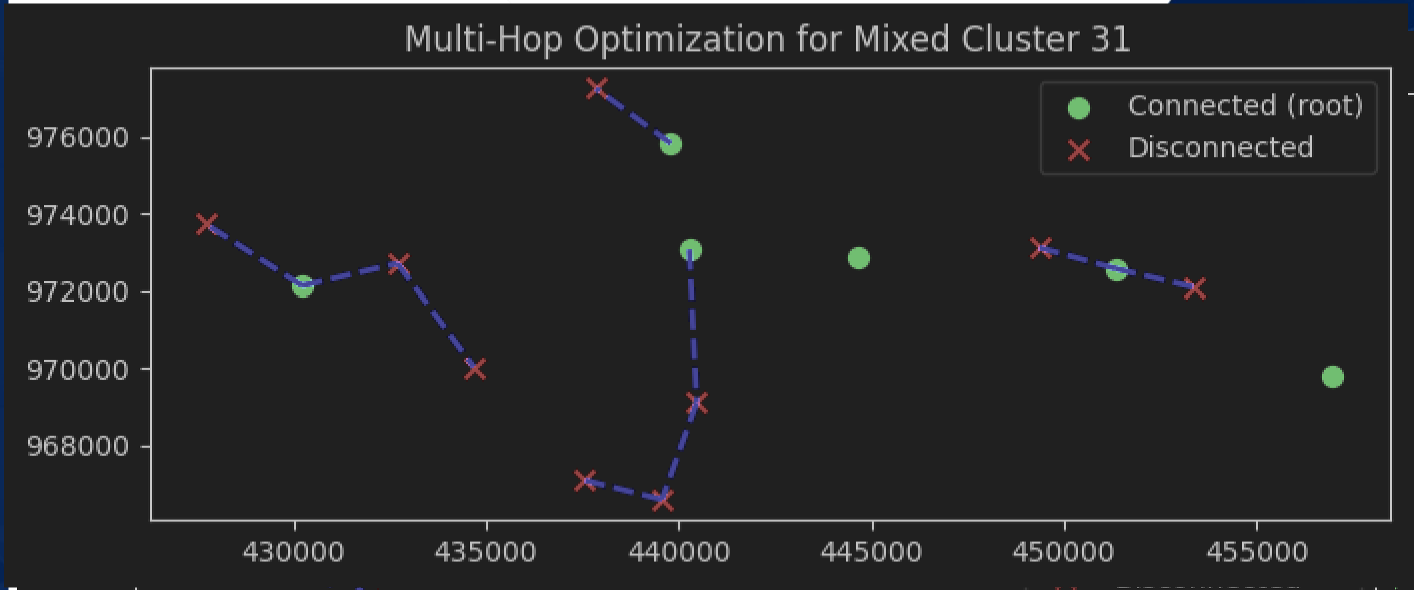
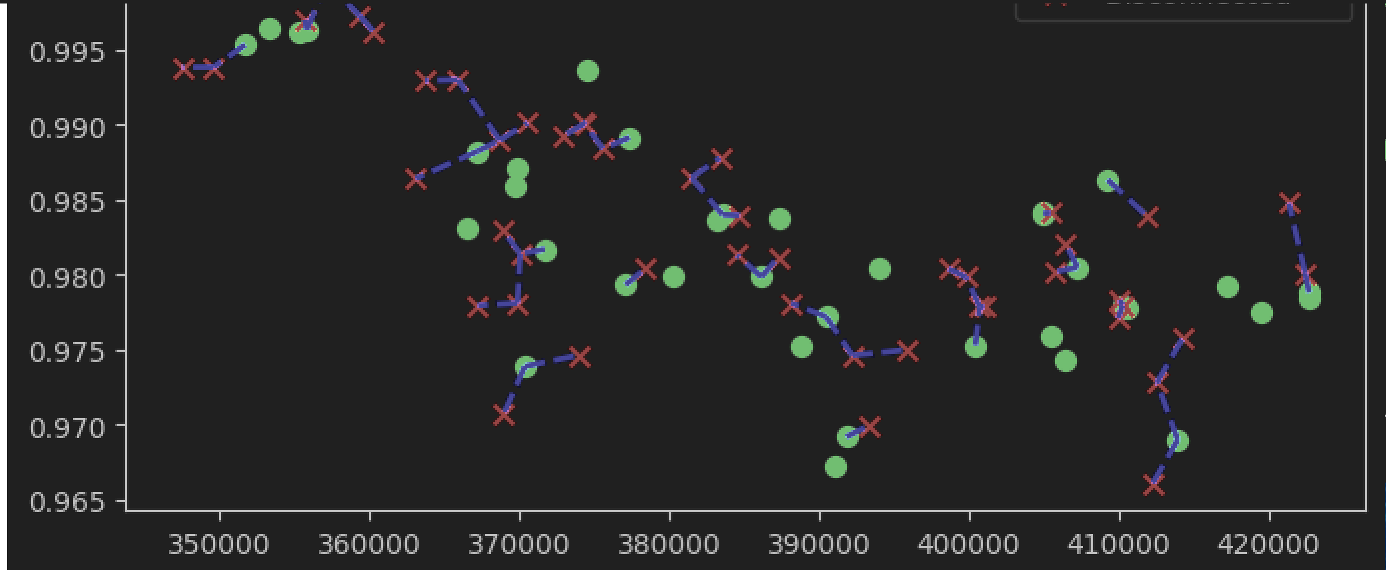
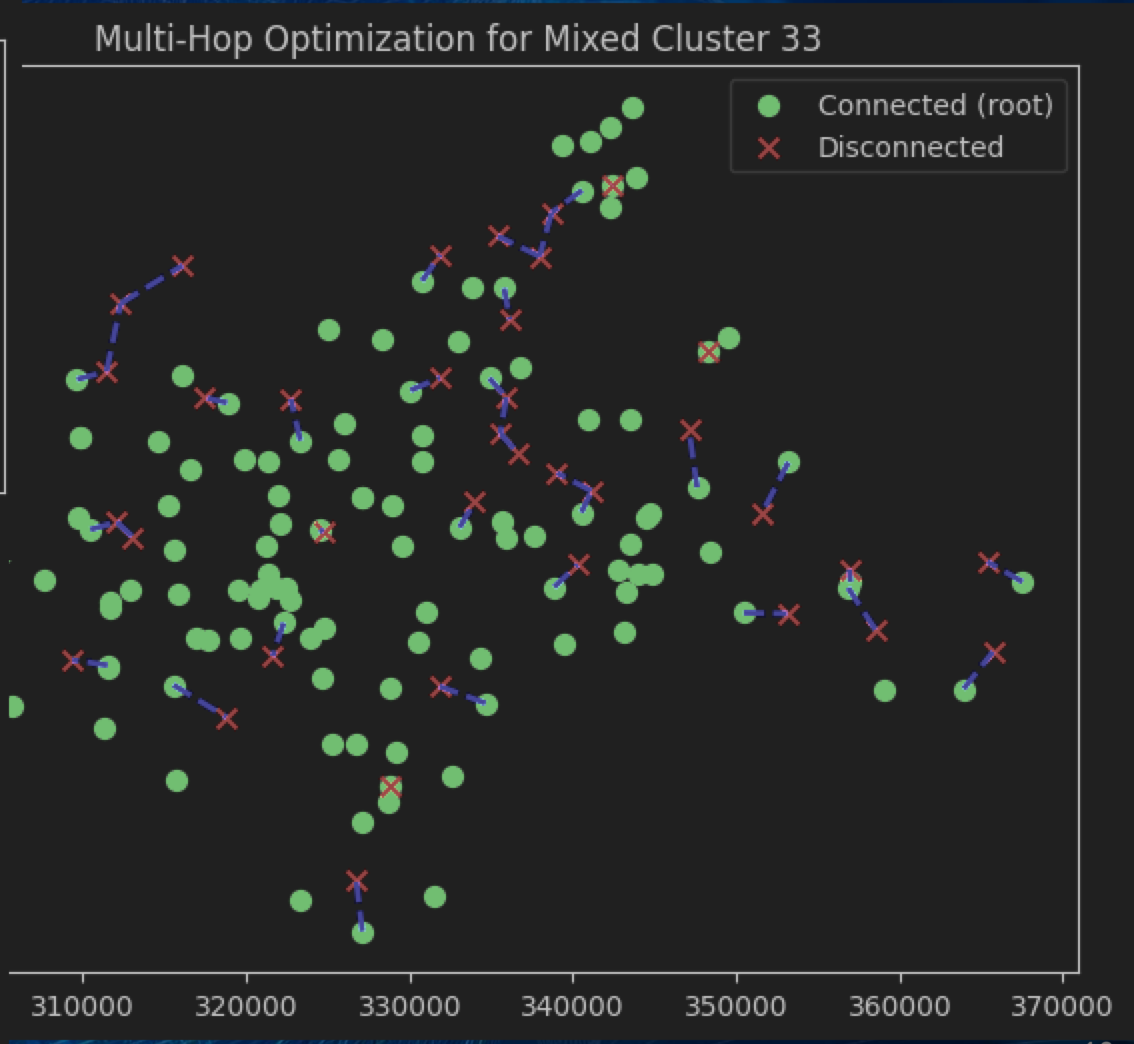
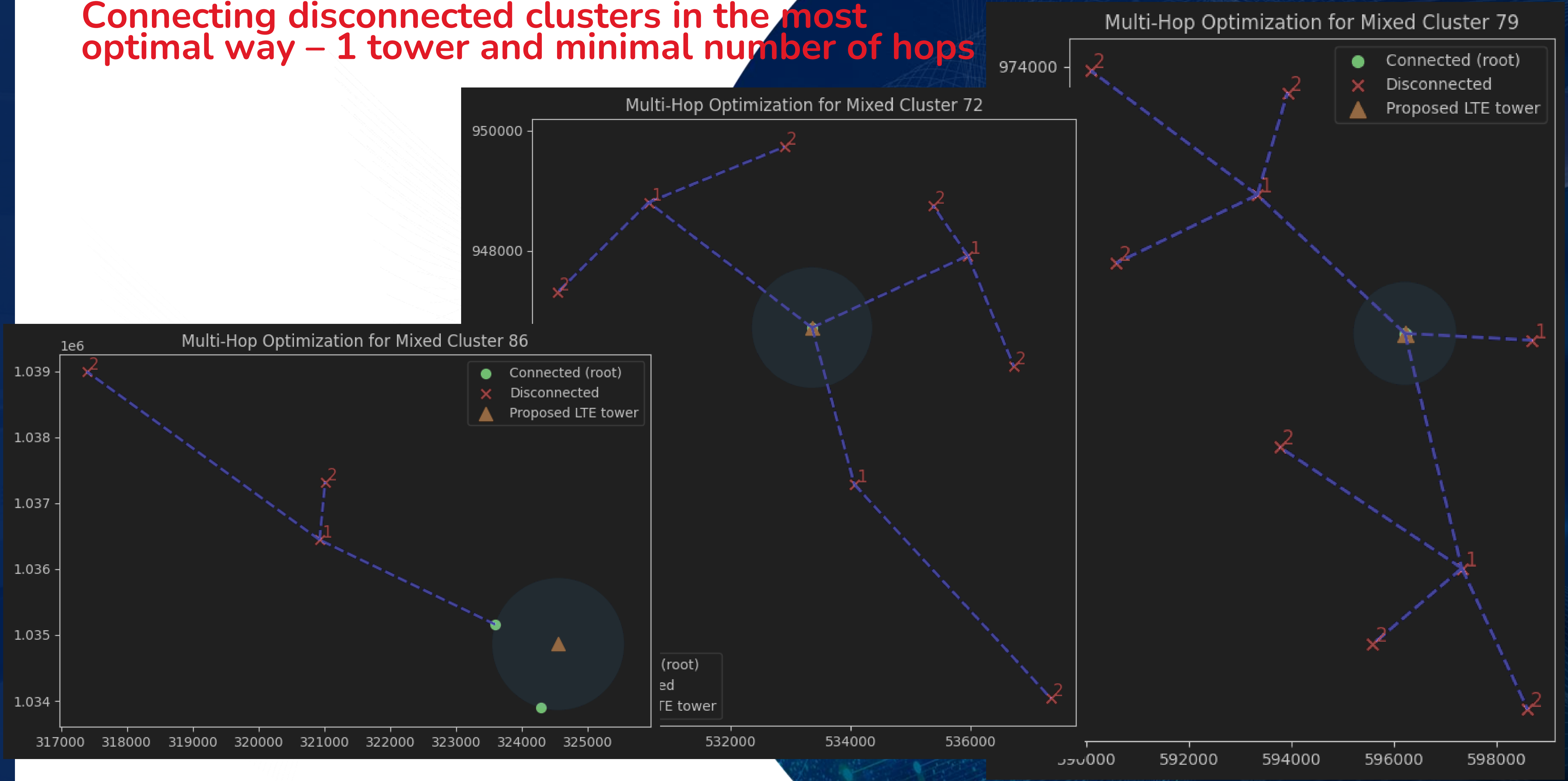
Connecting partially connected clusters







Connecting disconnected clusters in the most optimal way – 1 tower and minimal number of hops



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Final Output & Deliverables

The result of our work is a **Jupyter-based Python model** that performs **parametric interconnectivity analysis**, leveraging **AI-driven clustering** and **network optimization** to establish the most **cost-effective school connectivity strategy** while **minimizing additional infrastructure requirements**.
The model generates an **optimized network expansion plan**, outputting an **Excel report** detailing the **recommended school-to-school connections**, ensuring that schools are linked **efficiently and within feasible distances**.

C	D	E
distance_meter	from_school_name	to_school_name
2290.123104	ESC. RIO TUQUEZA	ESC. BAJO CHIQUITO
3674.390343	ESC. RIO TUQUEZA	ESC. LA CALETA
3595.741458	C.E.B.G. OCTAVIO CEBALLOS	ESC. ARMILA
1092.226583	ESC. BUENA VISTA	ESC. SALTO TRES PIEDRAS
3557.114283	ESC. BUENA VISTA	ESC. RIO BONITO
2753.188924	ESC. PLATANILLO	ESC. ARENAL
4471.635897	ESC. PLATANILLO	ESC. RIO PAVO
2761.920763	ESC. RIO PAVO	ESC. BUENA VISTA
1476.108056	ESC. RIO PAVO	ESC. NUEVO PARAISO
2839.662236	ESC. PLAYA CHUZO ADENTRO	ESC. PLAYA CHUZO CENTRO
851.7050358	ESC. NUEVO PANAMA	ESC. HIGUERONAL ARRIBA
4319.179075	ESC. VIRGEN DEL CARMEN	ESC. HIGUERONAL CABECERA
3912.605138	ESC. SAN JOSE DE CAÃ‘AZAS	ESC. LA OCHO
3608.565827	ESC. VALLE DE BIJAGUAL	ESC. BIJAGUAL
4320.311999	ESC. RIO IGLESIA	ESC. AGUA CALIENTE
4622.824244	ESC. SANSONCITO	ESC. PORTUCHADA
4522.177183	ESC. SANSONCITO	ESC. ARUZA ARRIBA
4332.55905	ESC. ARUZA ARRIBA	ESC. SANSON ARRIBA
4099.065842	ESC. LA PEÃ‘ITA	C.E.B.G. NUEVO VIGIA
4350.276847	ESC. CANGLON	ESC. LA PEÃ‘ITA
2318.853092	ESC. LAJAS BLANCAS	ESC. SANSON ABAJO

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Next Steps & Future Improvements

- **Integrating Geographical Data for Feasibility Analysis** – To enhance accuracy, the next step is incorporating **elevation data** to determine whether **PtP WiFi** – a **more cost-effective** solution – can be deployed in each scenario. This can be achieved by combining **OpenMap elevation data** with school and cell tower locations.

- **Cost Prediction & Budget Estimation** – Further improvements include **developing a cost prediction model** using **procurement data**. This would allow us to **estimate deployment costs for specific areas** and factor in **regional cost variations**, improving **budget planning** and **scalability**.

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Conclusions

By leveraging a **data-driven, AI-optimized approach**, we can achieve **100% school connectivity** with **minimal cost and infrastructure requirements**.

Through **strategic network expansion**, we:

- ✓ **Minimize the need for new cell towers**, reducing deployment costs.
- ✓ **Maximize the use of existing infrastructure**, ensuring efficiency.
- ✓ **Apply flexible, technology-driven solutions**, adapting to diverse geographical and economic conditions.

This approach enables us to build a **sustainable, scalable, and affordable** solution—**empowering underserved regions** and bringing **modern education to children worldwide**.

We don’t chase dreams
We set the standard

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