Network Design: Last-Mile Connectivity in Rural Australia

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Abstract

The last mile in networking refers to the final segment of the telecommunications infrastructure that connects end-users to the broader network and remains to be one of the most persistent issue in modern connectivity systems. This report examines the challenges of implementing a last-mile network infrastructure with a focus on rural Australian communities. Beginning with an analysis of why last mile connectivity represents one of the most complex but essential components of modern network architecture, the report identifies the technical, geographical, and economic factors that contribute to this complexity. It then evaluates the primary options available for last-mile network delivery in Australia, including NBN technologies such as Fiber to the Premises (FTTP), Fiber to the Node (FTTN), Fixed Wireless and Satellite, as well as emerging alternatives. The report provides a detailed technical assessment of the physical limitations affecting data rates across these various technologies, examining factors such as signal attenuation, interference, distance constraints, and environmental considerations. The final section presents a comprehensive network design recommendation for a rural community, balancing practical implementation considerations with the specific connectivity needs of remote populations. The design incorporates appropriate technology selections, topology considerations, and scalability planning to address the unique challenges of rural last-mile connectivity while ensuring sustainable and effective service delivery.

Contents

1 Complexity and Problems of Last Mile in Networking and Communications

1.1 Infrastructure challenges

Infrastructure challenges in last-mile deployment are particularly pronounced due to the varied geographical landscapes that must be traversed, ranging from dense urban environments to sparsely populated rural areas[27]. The cost-benefit analysis often fails to justify comprehensive deployment due to the extensive physical infrastructure requirement and the scarce populations in rural areas, resulting in a limited customer base. This physical deployment complexity is further compounded by the need to integrate with legacy systems while simultaneously preparing for future technological advancements[17][41].

1.2 Performance issues

Performance issues in last-mile connectivity primarily manifest through bandwidth limitations, latency variations, and reliability concerns. There is also the frequent signal degradation over copper-based systems, interference in wireless implementations, and environmental vulnerabilities that can precipitate service disruptions during adverse weather conditions. These performance challenges are worsened by the asymmetric nature of many last-mile technologies, where download speeds significantly outpace upload capabilities, creating an imbalance that becomes increasingly problematic as cloud-based applications and remote work requirements increase.[53]

1.3 User diversity

User diversity introduces additional complexity through the wide range of requirements. Residential users demand high-bandwidth entertainment services, business customers require reliable and symmetrical connections, and specialized industries require tailored quality-of-service guarantees. This diversity of expectations creates a challenging environment for standardization and necessitates sophisticated traffic management protocols to ensure equal resource allocation across varying users.[41][31]

1.4 Technical constraints

Technical constraints further complicate last-mile implementations through physical limitations imposed by transmission media. Copper-based systems suffer from distance-dependent signal attenuation, wireless solutions contend with spectrum scarcity and interference, and even fiber optic deployments face installation complexity and physical vulnerability challenges. These technical barriers are often magnified by regulatory frameworks that may restrict certain technological implementations or impose specific performance requirements that influence architectural decisions.

1.5 Economic factors

Ultimately, economic factors represent perhaps the most significant barrier to comprehensive last-mile connectivity. The high capital expenditure required for infrastructure deployment, particularly in areas with low population density, creates a market failure.[10] The long-term return on ongoing maintenance costs, technological obsolescence risks, and evolving consumer expectations results in complex financial models that frequently deter investment in marginalized communities.

2 Options for delivering Last Mile networks in Australia or NBN

The National Broadband Network (NBN) in Australia has implemented a multi-technology mix approach to address the diverse last-mile connectivity challenges across the continent. Various technological solutions are deployed based on geographical constraints, population density, and economic considerations.[44]

2.1 Fiber optics

Fiber optic technologies are the premium solution for last mile connectivity, with theoretical capacity measured in terabits per second through wavelength division multiplexing. Fiber optics deliver exceptional bandwidth, enabling symmetrical upload and download speeds using modern Passive Optical Network (PON) implementations[29] [59]. They offer unparalleled bandwidth potential with minimal signal degradation over long distances as well as low latency and consistent signal quality, making fiber ideal for applications requiring real-time responsiveness, such as online gaming. Fiber to the Premises (FTTP) offers symmetrical gigabit-capable connections directly to end-user locations through dedicated fibre strands that provide unparalleled bandwidth capacity and future-proofing capabilities. FTTP deployments were envisioned as the cornerstone of Australia's broadband strategy, however economic considerations led to the adoption of alternative approaches, such as Fiber to the Node (FTTN) and Fiber to the Curb (FTTC), which leverage existing copper infrastructure for the final connection segment while still benefiting from fiber back-haul capacity, resulting in a compromise between performance capabilities, deployment cost and faster roll-out[38] [14]. As for operational savings, all fiber networks save **$54-$91** annually per home compared to copper, primarily from fewer truck rolls and lower churn and frees 50% duct space, reducing pole attachment fees by up to 50%[26]. Fiber optic cables are highly durable, resistant to electromagnetic interference (EMI) and less susceptible to environmental factors, resulting in fewer service disruptions and lower maintenance costs over time[13].

2.2 Satellite internet

The NBN Sky Muster II offers broadband connectivity to around 400,000 premises in remote locations[45]. But satellite communications represent the most severely constrained last-mile technology from a data-rate perspective, with traditional geostationary satellite systems limited by extreme latency (since the signal has to travel through the Earth's atmosphere) and relatively modest bandwidth allocations[58] [23]. Still modern high-throughput satellites have substantially improved capacity through frequency reuse, spot beam technology, and more efficient modulation schemes[37], enabling higher downstream rates to individual users, though practical implementations typically offer significantly lower speeds due to oversubscription ratios[58]. Emerging low-earth orbit (LEO) constellations like Starlink promises substantial improvements in both latency and capacity[47] while still facing fundamental constraints related to atmospheric interference, limited spectrum availability, and the technical challenges of maintaining connectivity with rapidly moving satellites[23].

2.3 Fixed wireless

Fixed wireless technology is a critical middle-ground solution for regional and outer suburban areas where fibre deployment costs are prohibitive, yet population density exceeds satellite service capabilities. The NBN fixed wireless network utilizes LTE technology operating primarily in the 2.3 GHz and 3.4 GHz spectrum bands to deliver connections with theoretical maximum download speeds of 75 Mbps. However, actual performance is highly dependent on distance from transmission towers, topographical features, and network congestion factors, with service typically available to premises within a 14 km radius of transmission infrastructure, according to the Regional Telecommunications Review[43] [50] [49] [25].

2.4 Copper-based technologies

Copper-based technologies continue to form a significant component of Australia's last-mile network architecture, such as DSL, including asymmetric digital subscriber line (ADSL) which uses copper access network to provide an internet service but the primary method is by re-purposing existing telecommunications infrastructure using technologies such as Very-high-bit-rate Digital Subscriber Line (VDSL) in FTTN deployments[60]. These copper-dependent solutions present substantial performance variations based on line quality and distance from nodes, with connections exceeding certain distance thresholds from distribution points experiencing significant speed degradation due to signal attenuation and electromagnetic interference, resulting in a diversified service quality landscape[21] that has prompted ongoing discussion regarding the long-term viability of copper-dependent solutions as documented in the Australian Infrastructure Audit 2019 by Infrastructure Australia[12].

3 Limitations on data-rates across the various Last Mile network technologies

Last-mile network technologies' theoretical and practical data-rate limitations vary substantially across different implementation methods. Each approach is constrained by distinct physical properties, environmental factors, and technical parameters that collectively determine performance ceilings.

3.1 Fiber optics

Modern Passive Optical Network (PON) implementations, including XGS-PON and NG-PON2, can deliver symmetrical 10 Gbps connections to individual premises, with next-generation standards promising even greater capacities. However, practical implementations typically offer lower capacities due to economic considerations rather than technical limitations, with the primary constraints relating to installation complexity, deployment costs, and the specialized equipment required for fiber termination and management[18]. High-quality fiber exhibits **0.1 dB/km loss**, enabling long-haul transmission without repeaters. However, last-mile segments often suffer **0.2-0.4 dB** loss per bend due to tight coiling[57]. When it comes to infrastructure, there are many economic constraints involving deployment costs, repeaters, and labor. Urban trenching costs **$18 per foot**, while rural deployments face **$4 per foot** for aerial fiber and specialized splicing technicians cost **$70-$120/hour**, with fusion splicing machines priced at **$14,000** and upwards[22] [35] [56]. Environmental factors must also be considered when installing in rural areas as moisture and temperature shifts can affect the cables if water penetrates inside due to poor installation or physical damage, causing attenuation.

3.2 Satellite

Satellite Internet services are pivotal in Australia's connectivity landscape, especially for remote and rural areas where deploying terrestrial infrastructure is economically impractical. However, this technology has many constraints and vulnerabilities such as to DDoS attacks, which can cause more than a simple inconvenience, especially in rural areas with limited alternative connectivity options. These attacks can disrupt critical services such as emergency communications, telemedicine, and disaster response efforts. The technology also has inherent limitations, particularly in latency (usually exceeding 500ms) and capacity constraints that result in more restrictive data allowances compared to terrestrial alternatives[20] [16]. Bandwidth is limited per satellite due to fixed Ku-band spectrum allocations, with shared transponder resources often reducing practical per-user speeds during periods of network congestion[37]. These limitations are compounded by spectrum scarcity, as geostationary orbital slots remain restricted to 2° spacing above the equator to minimize interference, effectively capping the total number of operational satellites[33]. Many other persistent challenges remain of an environmental nature, including atmospheric interference where mm wave signals experience loss during heavy precipitation, space debris concerns with Starlink satellites facing close encounters with other objects and spectrum overlap issues causing radio astronomy to face interferences from loud downlink signals[48].

3.3 Fixed Wireless systems

Wireless systems encompass various technologies with widely divergent performance characteristics, ranging from 4G LTE networks capable of theoretical peaks around 100-300 Mbps to 5G implementations potentially reaching multi-gigabit speeds under ideal conditions with the latency ranging from 30-50 ms[54] [34]. These wireless technologies face distinctive limitations related to spectrum availability, signal propagation characteristics, and environmental factors, with performance degrading significantly due to obstacles, distance from transmission sites, atmospheric conditions, and network congestion[9]. In contrast, spectrum allocation constraints create fundamental capacity ceilings that can be partially addressed through advanced techniques like massive MIMO, beamforming, and carrier aggregation[42]. When it comes to Signal propagation challenges, mmWave signals are blocked by buildings, foliage, and even rain, reducing effective range by $\tilde{3}$0% in urban environments[61], ultimately reducing signal strength for 5G mmWave at 1 km to be less than 10% while 4G can maintain approximately 70% signal strength at 5 km[61] [34].

3.4 Copper-based systems

Copper-based systems, primarily represented by Digital Subscriber Line (DSL) technologies, face bandwidth constraints dictated by the physical properties of twisted-pair copper wiring, with signal attenuation increasing dramatically over distance and frequency. Modern Very-High-speed Digital Subscriber Line (VDSL2) implementations can theoretically achieve downstream rates of up to **100 Mbps** over short distances[6]. Still, performance degrades exponentially as distance increases, with signals beyond 1.5 kilometres typically limited to under 25 Mbps regardless of the line quality[1] [2]. The physics of copper transmission presents unavoidable challenges, as frequency-dependent attenuation follows a logarithmic pattern where every 3 dB loss effectively halves signal power[52]. A standard 0.4 mm copper cable exhibits approximately 20 dB/km attenuation at 1 MHz, with this degradation worsening significantly at the higher frequencies necessary for broadband data transmission.

4 A basic network design to meet the needs of a rural community

4.1 Hypothetical Scenario

The goal is to build a comprehensive network design to meet the connectivity needs of the rural community of Bungenwood. The community presents a symmetrical deployment scenario with farms arranged along eight circular roads, four in each of two concentric regions. These roads form rings at radii of 0.75 km, 1.5 km, 2.25 km and 3 km from the central point, intersected by four cross-roads at 45° intervals. Each segment of road between intersections contains four equally spaced residences, creating a distribution of 256 properties across the area. Each property connects to the nearest ring road via a 50 meter driveway, providing convenient access point for last-mile connectivity implementation. This regular arrangement facilitates systematic network planning, though the increasing distances in outer rings present challenges for the technologies' sensitivity to distance limitations.

The design will consider various technological approaches, evaluating their technical feasibility, performance characteristics, deployment logistics, and provides a detailed cost analysis for both short and long-term implementation scenarios while adhering to the minimum connectivity requirement of 50 Mbps downstream for each property.

The proposed designs adhere to the stipulated constraints: infrastructure must follow designated roads and driveways, utilize existing exchanges and towers where applicable, and provide uniform connectivity across all properties despite varying geographical locations. Multiple potential solutions will be outlined with detailed analysis of two of the most viable options for both fiber-optic and wireless.

4.1.1 Existing Infrastructure

The community currently possesses limited telecommunications infrastructure:

- 1. Two centrally-located exchanges with copper Plain Old Telephone Service (POTS) connections to each property. These connections follow the road network and provide basic voice services, but are insufficient for broadband delivery at the required 50 Mbps threshold across all distances.
- 2. Two 4G mobile phone towers, one at each exchange, providing cellular connectivity and potential backhaul opportunities for new infrastructure. These towers offer viable mounting locations for additional communications equipment, potentially reducing installation costs and simplifying planning.

4.2 Various Approaches

4.2.1 Fiber to the Premises (FTTP)

A direct fiber to the premise implementation using a star topology would provide dedicated fiber connections from the exchanges to each individual property. This approach would involve deploying fiber cables radiating outward from the exchanges, following the road network to reach each residence[55]. The performance characteristics of this solution are exceptional, offering symmetrical bandwidths of up to 1 Gbps—twenty times the minimum requirement of 50 Mbps. Fiber's low signal attenuation means that performance would remain consistent regardless of a property's distance from the exchange. The passive optical Network (PON) technology typically employed in such deployments could provide a 1:32 or 1:64 split ratio, allowing efficient use of feeder fibers while maintaining ample bandwidth per subscriber[51]. This implementation would require significant fiber deployment when accounting for all road segments and driveways plus termination equipment at both exchanges and each property. While offering the highest performance potential, the star topology represents the most fiber-intensive approach, with consequently higher materials and labor costs.

4.2.2 Fiber to the Node (FTTN)

An alternative approach would leverage the existing copper infrastructure for the final connection to each property, while deploying fiber to intermediate cabinets/nodes positioned at strategic locations throughout the community. This fiber-to-the-node solution would place 16 distribution cabinets, two per quadrant per ring, housing VDSL2 equipment capable of delivering high-speed broadband over the existing copper pairs. Performance under this model would vary based on the distance between each property and its serving cabinet. Properties close to cabinets could expect downstream speeds of **80-100 Mbps** and upstream speeds of **30-40 Mbps**. However, properties at the maximum distance from cabinets might experience reduced speeds due to copper-related signal attenuation. This solution requires less fiber deployment than the FTTP option but necessitates powered cabinets, active electronics, and depends on the quality and viability of the existing copper infrastructure. The performance variability and reliance on ageing copper represents a significant limitation, particularly when considering the 30-year horizon specified for the project.

4.2.3 Fiber ring with Fiber Drops

The fiber ring architecture represents a balanced approach, deploying fiber cables in closed loops following each of the eight circular roads, with additional fiber segments connecting the rings at intersection points. Fiber distribution points would be established at intersections, providing connection points for fiber drops extending to individual properties. This architecture offers the performance advantages of full fiber deployment with symmetrical speeds up to **1 Gbps**, while providing inherent redundancy through its ring structure. In the event of a cable break at any point, traffic can be routed in the opposite direction around the ring, maintaining connectivity for all subscribers. The ring topology also facilitates staged deployment, allowing the network to be built out progressively if budget constraints necessitate a phased approach[24]. The implementation would require approximately 47 km of fiber for the main rings, plus an additional 12.8 km for the 256 property drops (at 50 meters each). Distribution points would be placed at intersection locations, housing passive optical splitters to serve clusters of properties efficiently. This approach represents a middle ground in terms of fiber deployment requirements while offering full fiber performance.

4.3 Wireless approaches

4.3.1 Fixed Wireless access with Central Towers

Utilizing the existing towers at the exchanges, a fixed wireless access solution would deploy high-capacity omnidirectional transmitters to serve the entire community. Each tower would be equipped with sectorial antennas dividing coverage into multiple zones to maximize capacity and minimize interference. This solution could deliver downstream speeds of **75-100 Mbps** and upstream speeds of **10-20 Mbps**[11], dependent on factors including distance from the tower, line-of-sight conditions, atmospheric conditions, and concurrent user demand. Properties in the innermost ring (0.75 km radius) would experience the highest and most consistent performance, while those at the 3 km perimeter might encounter more variable service, particularly during adverse weather or peak usage periods. The wireless implementation would require minimal physical infrastructure beyond the transmitting equipment at the exchanges and receiving equipment at each property. This significantly reduces deployment time and disruption compared to cable-based solutions. However, the achievable bandwidth is more limited, and performance may degrade over time as user demands increase without proportionate increases in spectral efficiency.

4.3.2 Mesh Wireless Network

A mesh wireless architecture would distribute connectivity through multiple interconnected nodes positioned at road intersections throughout the community. Each node would communicate with adjacent nodes, creating multiple potential paths for data to traverse the network[55]. This approach would provide downstream speeds of **100 Mbps**, with some variation based on the number of hops between a property and the nearest exchange. The mesh structure provides resilience against individual node failures, rerouting traffic dynamically to maintain connectivity[19]. Implementation would require approximately 16-20 wireless nodes in addition to the base stations at the exchanges, plus equipment at each customer's property. While offering improved coverage reliability compared to the central tower approach, the multi-hop nature of data transmission introduces additional latency and potential throughput bottlenecks at busy nodes.

4.4 Recommended Implementations

4.4.1 Recommended Cabled approach: Fiber Ring with Fiber Drops

The recommended fiber solution would be to use Fiber Ring with Fiber Drops which employs a ring architecture following each of the eight circular roads, with interconnections at the sixteen intersection points where the rings meet the cross-roads. Each intersection would house a fiber distribution point containing passive optical splitters, serving the surrounding properties through individual fiber drops. The Fiber ring would connect to the wider internet through redundant links to both exchanges, providing diverse paths for traffic routing and resilience against single-point failures. The network would utilize Gigabit Passive Optical Network (GPON) or XGS-PON technology, enabling symmetrical bandwidth allocation of up to **10 Gbps** per PON segment, divided among the connected properties, and deliver consistent performance regardless of property location[40]. The round-trip latency should be under 10 ms within the local network, have resiliency against environmental interference and have the capacity to support concurrent high-demand applications including 4K/8K streaming and remote working with negligible packet loss and jitter. The physical infrastructure would consist of:

- 47 km of fiber optic cable following the circular roads
- 16 fiber distribution points at road intersections

- 256 fiber drops (approximately 12.8 km total) connecting properties to distribution points
- Optical Network Terminals (ONTs) at each property.

Unlike copper or wireless alternatives, the fiber implementation experiences no meaningful performance degradation with distance within the community's 3 km radius. This architecture provides optimal performance with inherent redundancy and facilitates future upgrades through equipment changes rather than infrastructure replacement and will ensure uniform service delivery across all properties, fulfilling the consistent connectivity requirement[39].

Some Considerations
Installation process: The fiber ring deployment would involve trenching along road verges to minimum depths of **450-600 mm**, with appropriate conduit installation to protect fiber cables and facilitate future maintenance or upgrades. Road crossings would utilize directional drilling to minimize disruption to traffic flow[28].
Technical expertise: The installation requires specialized fiber splicing expertise, particularly at distribution points where multiple fibers must be accurately terminated. Ongoing maintenance would similarly require access to qualified technicians, though the passive nature of the majority of the infrastructure minimizes routine intervention requirements[36].
Environmental impact: Trenching operations would cause temporary disruption but could be scheduled to minimize impact on agricultural activities.

Cost Analysis
The fiber ring implementation requires significant initial investment in physical infrastructure:

- Fiber cable for main rings: **47 km x $10/m = $470,000**
- Fiber terminations at distribution points: **32** terminations at **$300 each = $9,600**
- Fiber conversion cabinets with splitters: **16 units at $1,000 each = $16,000**
- Fiber drops to homes: **256** homes x **50m** driveways x **$10/m = $128,000**
- Fiber terminations at homes: **256 x $300 = $76,800**
- Fiber terminations at exchanges: **4 at $300 each = $1,200**
- Additional equipment (splitters, splice enclosures, etc.): **$\tilde{\$}$50,000**[46]

These components result in a total estimated capital expenditure of **$751,600**

Long-term Operational Considerations
The fiber solution's operational expenses over the 30-year horizon include[3]:

- Annual maintenance for fiber testing, fault location, and repairs.
- Central and distribution equipment replacement every few years.
- Terminal equipment upgrades every $\tilde{1}$0 years to meet evolving standards and performance requirements.
- Annual power costs for active equipment.
- part-time technical support and administration personnel.

The fiber infrastructure has an expected lifespan exceeding the 30-year horizon, with most components remaining viable throughout this period. The primary maintenance expenditure relate to active electronics at endpoints rather than the physical network.

4.4.2 Recommended Wireless approach: Fixed Wireless Access with Central Towers

The recommended wireless solution leverages the existing towers at the exchanges to deliver fixed wireless access to all properties within the community. Each tower would be equipped with high-capacity omnidirectional transmitters, supplemented with sectorial antennas to divide coverage into eight distinct zones, improving capacity allocation and minimizing interference[4]. The implementation would utilize advanced LTE or 5G fixed wireless technology operating in appropriate frequency bands to deliver the required performance[32]. Customer premises equipment would consist of directional antennas mounted on external walls or rooftops, oriented toward the nearest tower, connected to indoor modems/routers for distribution within each property. The fixed wireless solution offers reputable performance with downstream speeds of **40-50 Mbps**[30], round-trip latency of **10-50 ms** within the local network[8] and typical packet loss under **1%** in clear weather conditions. Performance would be optimized through careful frequency planning, appropriate antenna selection, and precise alignment of customer equipment[7]. Properties closer to the towers would experience higher average speeds and more consistent performance than those at the furthest 3 km distance, though all should meet the minimum **50 Mbps** downstream requirement under normal conditions. A significant advantage of the wireless approach is rapid deployment, potentially enabling full community connectivity within a few months or less.

Some Considerations

The wireless deployment presents unique considerations compared to cabled alternatives:

- **Spectrum Management:** Careful frequency planning is essential to minimize interference and maximize capacity. The design would incorporate appropriate channel selection, power control, and antenna patterns to optimize spectrum utilization while ensuring regulatory compliance[5].

- **Environmental Factors:** Signal propagation would be affected by atmospheric conditions, vegetation, and structural obstacles. Seasonal variations in foliage density may impact performance for some homes, particularly those with significant tree cover between their location and the nearest tower.

- **Capacity Planning:** As a shared medium, wireless connectivity requires careful capacity management to maintain performance during peak usage periods. The sectorial approach helps address this by limiting the number of properties competing for resources within each sector, but monitoring and potential equipment upgrades would be necessary to maintain performance standards as usage patterns evolve[15].

Cost Analysis

The wireless implementation presents lower initial investment:

- Omnidirectional transmission systems at exchanges: **2 x $100,000 = $200,000**

- Customer premises equipment: **256 x $500 = $128,000**

- Additional equipment (power systems, mounting hardware, etc.) for fixed wireless would cost much less compared to fiber, let's say around **~$20,000**.

These components result in a total estimated expenditure of **$348,000**. This represents approximately **46%** of the fiber solution's initial cost, offering **significant upfront savings**. The modular nature of wireless deployment also facilitates staged implementation if desired, with progressive expansion of coverage as resources permit.

Long-term Operational Considerations The wireless solution's operational expenses over 30 years include:

- Annual maintenance for equipment inspection, alignment, and repairs.
- More frequent replacement of electronics on a **5-7-year cycle** due to technological obsolescence and environmental exposures.
- System upgrades every $\tilde{5}$ years or so to maintain pace with wireless standards.
- Annual power costs for active equipment with higher power requirements, resulting in more expenditure over 30 years.
- part-time technical support and admin personnel

The wireless solution requires more frequent refresh cycles due to both the evolving nature of wireless standards and the environmental exposure of equipment. This results in significantly higher lifetime costs despite the lower initial investment.

4.5 Final Recommendation

Based on a thorough analysis of performance, deployment considerations, and total costs spanning over three decades, the recommended solution for the Bungenwood community is the Fibre Ring with Fibre Drops.

The fibre implementation offers significantly more bandwidth capacity than the minimum requirements, providing symmetrical gigabit connectivity potential.

Fibre connectivity ensures consistent performance regardless of the location or environmental conditions of the properties, eliminating the inherent variability present in wireless solutions.

Although there is a higher initial investment, the total cost over 30 years will be significantly lower for fiber compared to wireless due to reduced operational expenses and less frequent equipment replacement cycles.

The fibre infrastructure provides ample room for future bandwidth growth without necessitating physical infrastructure replacement, safeguarding the community's investment against evolving requirements.

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