Why is a Last Mile network such a complex but also vital issue in Networking and Communications?

Since the goal is to connect end-users to ISPs, it's essential to consider the unique geographical and economic factors that shape different communities and their environments. For example, an approach that works well for an end-user in an Australian metropolitan may not be as effective in India. Take trenching, for instance, while expensive, the process of deploying fibre in Australia is well-structured and widely implemented. In contrast, in India, securing permissions is a major challenge due to dense populations and bureaucratic hurdles. The slow approval process often pushes companies to opt for aerial deployment in many parts of the last-mile network. However, aerial cables are highly vulnerable to environmental factors, with even moderate to heavy rainfall or strong winds frequently causing disruptions and noise interference. Additionally, land acquisition concerns among residents further complicate trenching.

Each geo-economic region comes with its own set of challenges. In rural Australia, end-users are often located far from exchanges, making last-mile deployment significantly more costly due to terrain, distance, and the environment. Maintenance and repairs are equally difficult, which is why many users end up with Fixed Wireless or Satellite services. But these come with limitation of high latency, reduced data rate and poor service. It makes activities like gaming and HD video conferencing impractical. Even when FTTN (Fiber to the Node) is available, performance degrades sharply with distance, and it's common for end-users to be more than 5 km(Copper would be useless around 4km) from the nearest node, severely impacting speed and reliability.

Urban areas, on the other hand, face a different set of challenges. Many networks still rely on aging infrastructure, requiring constant maintenance and upgrades. In some ways, rural areas might have an advantage, as they bypass the trial-and-error phase of determining feasible solutions. They usually get what is proven to work in the city or their options are predefined by geographical and technological constraints. Network congestion is another major issue unique to urban settings, with data transfer rates slowing down significantly during peak hours, impacting overall connectivity and user experience.

Developing the last mile network would require an understanding of all of these factors. A team well versed with the geographical, economical and even cultural challenges unique to each deployment site is the bare minimum in my opinion. And even then, it might not be enough and a lot of work would end up happening on a "trial and error" basis.

What are the main, typical, options for delivering Last Mile networks in Australia, NBN or otherwise? [4 marks]

The National Broadband Network (NBN) is a government owned broadband provider to improve internet access across Australia. It is responsible for majority of the last mile infrastructure that is and that will be. There are other players, private fibre network providers, Fixed wireless and satellite providers.

The last mile approach of NBN can roughly be broken down in the following way:

1. **Fibre to the Home (FTTH)**
   Direct fibre to the user.

2. **Fibre to the Node (FTTN)**
   Fibre from exchange to a node in a reasonably urban area. The node then connects to end user via existing copper(telephone) lines.

3. **Fibre to the Kerb/Curb(FTTK/C)**
   Fibre from exchange to some device on the street, typically the user is responsible to run the copper from the device to their house to access the network.

4. **Hybrid Fibre Coax(HFC)**
   Fibre from exchange to an optical node, from there, a shared coax copper cable runs across the entire neighbourhood/street making it a shared medium. This is less common but still worth a mention as NBN, and private companies like Telstra bet heavily on this approach because it could leverage existing cable infrastructure.

5. **Fixed Wireless**
   When fibre deployment is not possible. For rural, remote or difficult terrain areas.

6. **Sky Muster Satellite**
   For properly remote locations. Customers from Tasmania and from remote islands (Norfolk, Christmas). Two satellites are used to provide internet to the end user.

The notable alternative players provide a privatised service for the same carriers mentioned above.

1. **Private FTTP Networks**
   companies like TPG, Opticom and Aussie broadband provide direct fibre to the user.

2. **5G Broadband(Wireless)**
   Alternative to fixed wireless from NBN. Telstra, Optus, etc are major providers.

3. **Satellite Internet**
   Currently, Starlink uses low orbit satellites for the service with latency lower than sky muster satellite from NBN.

What are the actual technical (physical) limitations on data-rates across the various Last Mile network technologies? [3 marks]

1. **FTTP**
   Fibre does not allow multiple users to tap into the same line, unlike copper. Point to point deployments from exchange to every possible the end user would amount to millions of kilometres of fibre. And that fibre needs to be laid underground and would also require maintenance and repair. This is why it is financially and practically impossible to only use FTTP for last mile.
   BANDWIDTH 1 GHz – 10 THz
   Max Data Rate 1 GB/s – 10 GB/s

2. **FTTN**
   The existing copper lines that it relies on lose signal strength over distance. Copper also resists higher frequency signals, limiting the range of frequencies that can be reliably transmitted without significant attenuation. Copper is also an antenna, so it is going to pick up noise from other cables and surroundings.

   Copper wires also cannot cater to high speed 2 way data transmission. The VDSL2 lines were designed for voice calls rather than data. So we get decent download speeds and much worse upload speeds due to the way copper carries electric signals. It is actually really convenient that we are able to get decent download speed from them because they were originally used for a different purpose.

   Adding to what was mentioned above, due to signal loss over time, a copper wire can only reliably carry a signal for about 4km. The degradation over distance is as follows:
   - **Up to 1 km** → ~100 Mbps
   - **1–1.5 km** → ~50 Mbps
   - **Beyond 1.5 km** → 25 Mbps or lower
   - **Beyond 3 km** → ~5-10 Mbps

   BANDWIDTH 17 MHz – 35 MHz
   Max Data Rate 0.1 GB/s – 0.3 GB/s

3. **FTTK/C**
   Not as good as FTTP because it still uses copper lines to connect from the kerb to the user's device.
   BANDWIDTH 106 MHz – 212 MHz
   Max Data Rate 0.5 GB/s – 1.0 GB/s

4. **HFC**
   The upload speed is lesser than download speed because the optical node is connected to the users via a shared coax cable. And because coax cables are better suited for downstream signal flow anyway, that combined with congestion causes the upload speed to suffer. Download speeds might also suffer noticeably during peak hours.
   BANDWIDTH 1 GHZ – 1.2GHZ

5. **Fixed Wireless**
   Fixed wireless actually has many caveats.

   It requires a clear Line of Sight from source to destination. So a huge mountain, hills, buildings or even trees might in between a user and a source tower might affect the signal.

   The signal loses strength over distance. Towers typically cover up devices within a 14-15 km radius under NBN. But latency and connectivity issues at distances more than 8km are extremely noticeable.

   Since all users are sharing the same bandwidth, there is high potential for network congestion. One must be wary of the difference between the bandwidth of the tower and the bandwidth that they can actually operate under which is much lower.

   It is also extremely susceptible to weather conditions.

   The upload speeds are also much lower because like coax, wireless also prioritises downstream signal flow. So gaming, and high quality video conferencing is still not very feasible on wireless.

6. **Satellite**

   Signals must travel a long distance and back. The major limitation is the latency. NBN sky muster is around 36,000 km away from the earth. The latency on Sky Muster is around 600-700ms. While it provides a great solution for remote users when it comes to essential tasks like email and browsing, the upload speeds are still very low and the video calls and gaming experience would still be very poor. This might change with more and more companies deploying lower earth orbit satellites. The latency of Starlink is much lower than NBN Sky muster.

   The bandwidth available for use of satellite for the last mile is also quite limited. Only a fixed amount of frequency bands are available for satellite signal. There is also potential for congestion because the bandwidth is shared.

   Extreme weather will also negatively impact satellite signal strength.

LAST MILE DESIGN

a. Wired approaches

1. FTTN Simple: I am going to give a detailed explanation of this **FTTN Simple** approach.

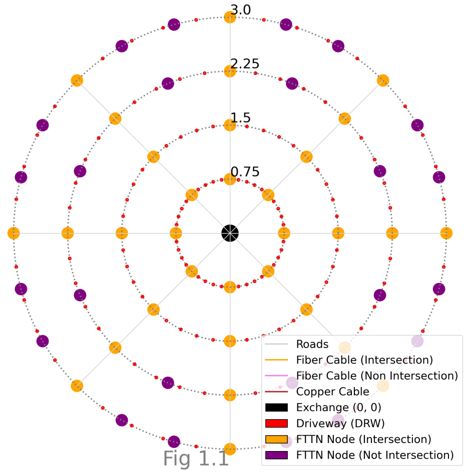


Fig 1.1

As you can see in the graph(Fig1.1), The exchange is represented by the black node. The FTTN nodes at the intersection of the roads are represented by the orange. The purple nodes are FTTN nodes equidistantly placed across each segment. (one per segment in 3rd ring and 2 per segment in 4th ring)

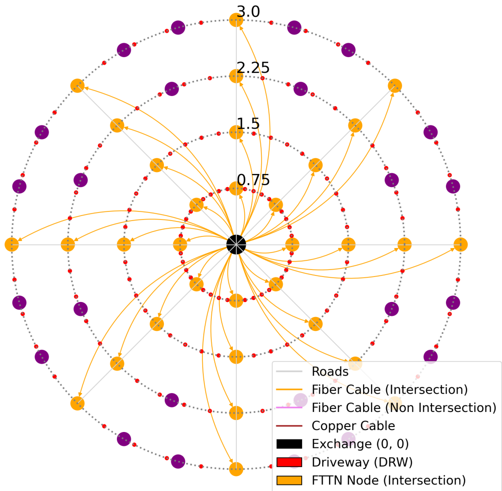


Fig 1.2

There is a p2p Fiber cable from exchange to every single FTTN Node(Intersection and Non Intersection). (The connections are along the road, but curved for the sake of display).
(As many Fiber cables as FTTN intersection nodes)

```
def add_extra_intersections_on_ring(self, ring: int, per_segment: int):
    radius = self.radii_km[ring - 1]
    for seg in range(self.segments_per_ring):
        angle_start = (seg / self.segments_per_ring) * 2 * np.pi
        angle_end = ((seg + 1) / self.segments_per_ring) * 2 * np.pi
        for i in range(1, per_segment + 1):
            frac = i / (per_segment + 1)  # e. (variable) angle_end: float ent
            mid_angle = angle_start + frac * (angle_end - angle_start)
            x = radius * np.cos(mid_angle) + self.origin_x
            y = radius * np.sin(mid_angle) + self.origin_y
            name = f"I_R{ring}_M{seg}_{i}"
            self.pos[name] = (x, y)
            self.G.add_node(
                name,
                pos=(x, y),
                colour='purple',
                size=self.size_intersection_node
            )
```

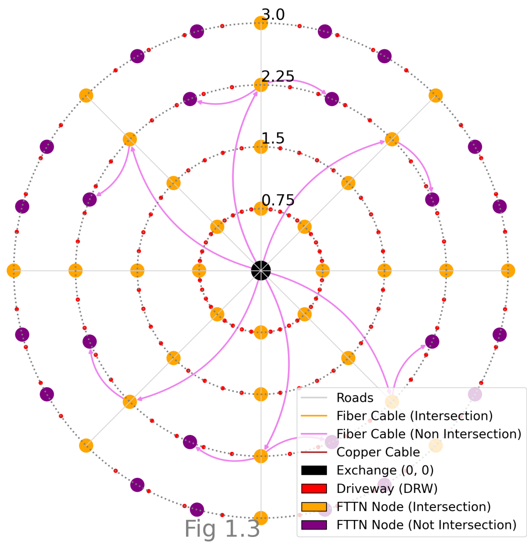


Fig 1.3

Let's observe Fig 1.3. Shows Fiber connections from exchange to non-intersection FTTN nodes(purple) in the 3rd ring. The Fiber cable goes through the intersection(orange) and then connects to the closes non intersection FTTN node.

(As many Fiber cables as FTTN non intersection nodes on the third ring)

The purple Fiber cable does not connect to the orange node, just goes through that location.

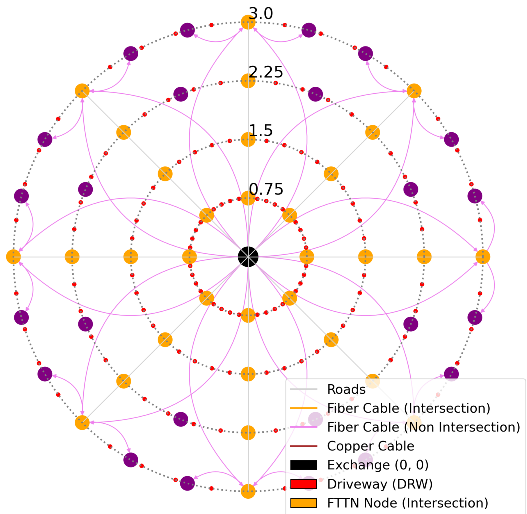


Fig 1.4

Fig 1.4 shows Fiber connections from the exchange to the 4th ring's non-intersection FTTN nodes(purple). For each non-intersection FTTN node, the Fiber goes through the orange node and then the closest non-intersection node that is not connected to the exchange.

As many Fiber cables as FTTN non intersection nodes on the 4th ring.

The purple Fiber cable does not connect to the orange node, just goes through that location

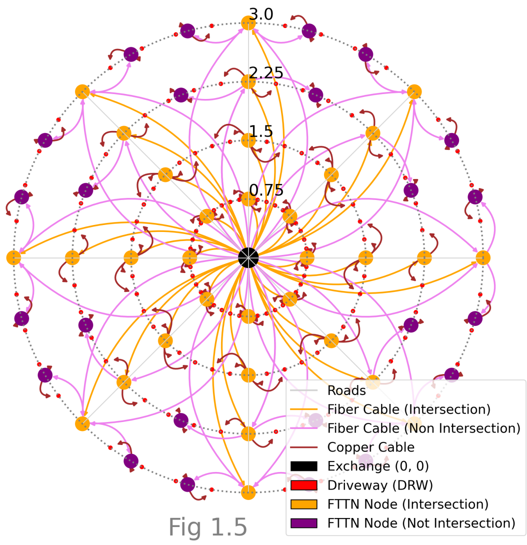
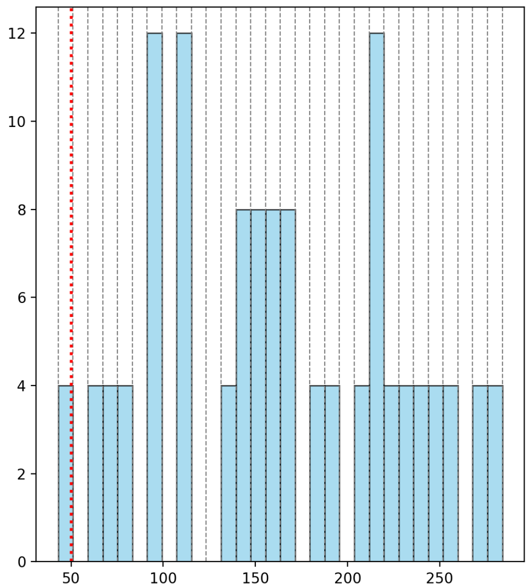


Fig 1.5

Finally, copper cables are used to connect the driveways to the exchange.
For each driveway node(red), A copper cable is connected from the closest FTTN node.

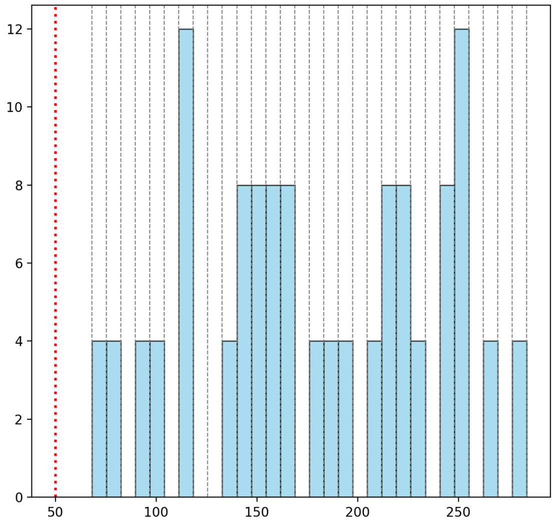
```
def check_if_all_driveways_connected(s: Self):
    return all([nx.has_path(s.G, s.exchange, n) for n in s.drw_nodes])
```

```
if __name__ == '__main__':
    c = Circle()
    c.add_intersection_nodes()
    c.add_fiber_from_exchange_to_default_ir()
    c.add_extra_intersections_on_ring(ring=3, per_segment=1)
    c.add_extra_intersections_on_ring(ring=4, per_segment=2)
    c.add_fiber_from_exchange_to_extra_ir_in_third_ring()
    c.add_fiber_from_exchange_to_extra_ir_in_fourth_ring()
    c.add_driveway_nodes()
    c.add_copper_to_each_drw_from_closest_ir()
    if c.check_if_all_driveways_connected():
        print('Congratulations !!!!', 'All driveways have connection to excha
```



There are 4 drive way nodes with download speed less than 50 Mb/s.

This happens because of the second ring, the distance between copper cable and FTTN nodes is as more than 600m in some cases.



After adding one extra FTTN node per segment, all download speeds are above 50Mb/s.

```
if __name__ == '__main__':
    c = Circle()
    c.add_intersection_nodes()
    c.add_fiber_from_exchange_to_default_ir()
    c.add_extra_intersections_on_ring(ring=2, per_segment=1)
    c.add_extra_intersections_on_ring(ring=3, per_segment=1)
    c.add_extra_intersections_on_ring(ring=4, per_segment=2)
    c.add_fiber_from_exchange_to_extra_ir_in_third_ring()
    c.add_fiber_from_exchange_to_extra_ir_in_fourth_ring()
    c.add_driveway_nodes()
    c.add_copper_to_each_drw_from_closest_ir()
    if c.check_if_all_driveways_connected():
        print('Congratulations !!!!', 'All driveways have connection to exchange')

    print('total fiber in km: ', c.compute_total_fiber_in_km())
    print('total copper in km: ', c.compute_total_copper_in_km())
    # c.plot()
    c.estimate_speed_per_drw()
    c.plot_speeds_histogram()
```