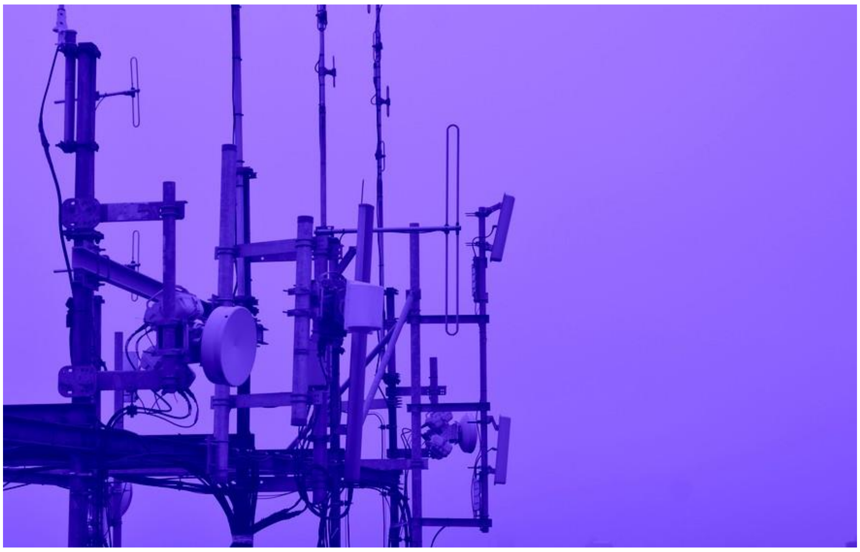
# Total cost of ownership and time to breakeven of last mile data transport for MNOs and ISPs



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This report was commissioned by Cambridge Broadband Networks Ltd. However, it has been prepared by Real Wireless independently and represents our own views based on our experience, primary and secondary market research, analysis and modelling.

# Executive summary

The last few years has seen significant innovation in data transport technologies, driven by MNOs' needs to densify backhaul networks as well as ISPs' needs to deliver better broadband services to cloud enabled enterprises. There is now a range of solutions to choose from, and this paper aims to help MNOs and ISPs understand the cost implications of that choice.

Last mile transport technologies considered:

- Managed fibre
- V-band (57-66GHz) point to point (PTP)
- E-band (71-86GHz) PTP
- Microwave (26-42GHz) PTP and point to multipoint (PMP)
- Sub 6GHz unlicensed PTP and PMP

An analysis of total cost of ownership (TCO) per link finds site rental and rates dominate, accounting for around half of the five year TCO. Operation and maintenance is around a quarter and equipment capex, a fifth. These proportions reveal that TCO is much more sensitive to site related costs than equipment pricing. Comparing technologies, we find:

- Managed fibre has significantly higher TCO than the wireless solutions in our global figures, although we do note there are regional variations.
- Through savings in capex and opex, PMP can have as little as 50% TCO of PTP in high density deployments carrying bursty traffic with lower mean bit rates.
- PTP has lower TCO than PMP for low density deployments carrying constant bit rate type traffic – typical of 'middle mile' transport.

To illustrate the impact of TCO we develop a case study of an ISP building-out a network to supply carrier grade connectivity to enterprise premises. We consider the rate at which the ISP can deploy revenue generating links to their customers, the cost of building out and operating the infrastructure and the resulting return on investment over time. We find:

- Sub 6GHz and microwave PMP solutions result in the fastest time to break even of around 13 months for this case study, relative to 16-19 months for other solutions.
- For the same investment over a five year period, PMP enabled the ISP to connect 67% more customers and generate 1.8x higher return on investment than PTP.
- The higher revenue per link possible with the licensed band 'gold' service generated a 30% higher return on investment than its unlicensed equivalent.

Overall, we identify the key factors which dominate TCO and return on investment for MNOs and ISPs selecting transport technologies, and identify the scenarios where certain technologies are a better choice than others.

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# 1. Introduction

With more and more people and businesses depending on data connectivity, so the importance of the network infrastructure needed to deliver it is elevated. Everyone is now well aware of the Wi-Fi and cellular networks connecting their smartphones and other devices to the nearest access point or base station. There is also an increasing recognition of the role of *data transport* to backhaul that traffic towards core networks and on to the internet beyond. These transport networks are used by both mobile network operators (MNOs) and internet service providers (ISPs) alike. Not only are MNOs densifying their networks with smaller cells in order to keep up with data growth, enterprises too are increasingly embracing cloud services which demand symmetrical carrier grade connectivity for their sites and campuses. These trends have brought to the fore the importance of the data transport networks, demonstrated by the surge in interest in backhaul and transport technologies in recent years.

Much has been written about the different technologies available for small cell backhaul and other similar last mile transport applications[1,2], and the industry has settled on the following broad categorisation:

- Wireline: Categorised into fibre or copper, self-installed or managed service.
- Wireless: Categorised by carrier frequency, spectrum licensing arrangement and whether point to point (PTP) or point to multipoint (PMP) topologies are supported

In this paper we consider the cost implications of the different transport technology choices faced by MNOs and ISPs. We develop a model for total cost of ownership (TCO) which includes not only the initial outlay for the equipment itself, but also the more significant costs of installing and operating it over its lifetime.

We apply our TCO analysis to an example business case of an ISP wishing to provide access services to enterprises. By considering both the revenues and costs over time, we evaluate the time to break even – a positive return on investment - for a range of different technology choices. This case study could also be applied to an MNOs backhaul division.

The purpose of this paper is to provide MNOs and ISPs a framework for comparing the costs and potential return on investment of different transport options to inform technology selection. We have populated our model with data gathered though our own primary and secondary research to represent a general case, but recognise there can be significant variations across different markets and regions as well as dependencies on the asset holdings of the companies concerned. We encourage readers to customise the model to suit their particular conditions, and will be happy to assist them in doing so.

[1] "*Backhaul Technologies for Small Cells: Use Cases, Requirements and Solutions*", Small Cell Forum, Feb 2013, http://scf.io/document/049
[2] "*Small Cell Backhaul Requirements*", NGMN Alliance, Jun 2012, http://goo.gl/17bwI

## 1.1 Our methodology

Figure 1 outlines the various stages of analysis presented in this paper: For a range of wireline and wireless transport solutions, we develop a TCO model comprising capital expenditure (capex) followed by ongoing operation expenditure (opex). We evaluate a five year TCO per connection based on the initial outlay followed by five years of operation. Observing that the TCO of certain technologies can vary considerably according to deployment conditions, we outline qualitatively the factors which may increase or decrease their TCO.

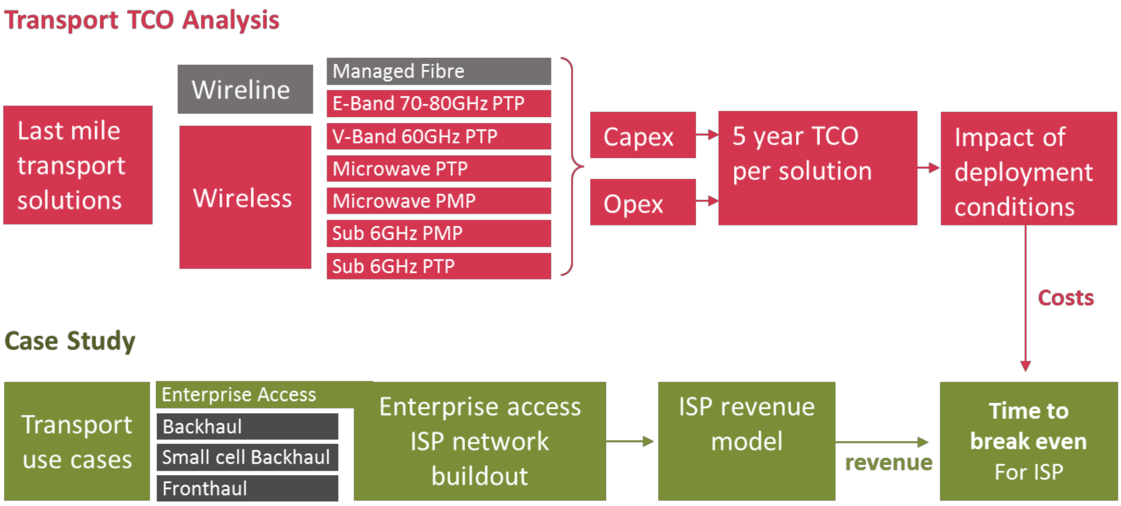


**Figure 1: Analysis of last mile transport TCO and application to enterprise access use case**

The second part of this paper presents a case study for an ISP building out an access network to provide carrier grade connectivity towards enterprises. We consider the ISP's infrastructure investment over time, and the resulting capability to generate revenue from operational access links. Combining the time varying revenue and costs yields their return on investment and time to break even for different transport technology choices. To some extent we see the technology choice depends on the timescale over which the ISP requires a return on investment as well as the extent of investment they are able to make. This case study could also be applied to the last mile backhaul division of an MNO, where increased technology efficiencies would yield a larger network buildout for a given time and budget.

## 1.2 Transport technologies

We consider here a number of technology candidates suitable for mobile network backhaul and enterprise access as described below:

**Wireless**: Table 1 outlines aspects which broadly differentiate between wireless solutions. The carrier frequency is a fundamental choice and has implications for the type of propagation (whether non line of sight is practical), the type of spectrum licensing typically available, and to some extent the types of network topology. Furthermore, the carrier frequency has implications for the amount and cost of spectral bandwidth. In general, there is less bandwidth at lower frequencies, and it is more sought after.

| Wireless Technology Category | Line of Sight? | Spectrum Licensing | Topology |
|---|---|---|---|
| **E-Band 71-86GHz** | LOS | Light licensed | PTP |
| **V-Band 57-66GHz** | LOS | Unlicensed | PTP |
| **Microwave PTP** (26-42GHz) | LOS | Link licensed | PTP |
| **Microwave PMP** (26-42GHz) | LOS | Area licensed | PMP |
| **Sub 6GHz PMP** | Non LOS | Unlicensed | PMP |
| **Sub 6GHz PTP** | Non LOS | Unlicensed | PTP |

**Table 1: Key differentiators of wireless transport technology options**

Of the available wireline solutions, we consider only managed fibre as it is more readily comparable with the wireless options. Operator owned fibre is a viable option, but it represents a considerable investment and a much longer return on investment timespan than the other options considered here.

Performance requirements for backhaul applications are defined by NGMN operators in[2,3,4] and a detailed technical analysis of the various options is provided by Small Cell Forum[1] . The basis for our cost modelling is made in a partner paper analysing the business case for virtualised small cells[5]. In this paper we assume all solutions meet technical performance requirements, and we focus on the commercial differences in cost and time to deploy operational, revenue generating links.

3 "*Guidelines for LTE Backhaul Traffic Estimation*", NGMN, July 2011, http://goo.gl/EWQQg
4 "*Backhaul Provisioning for LTE-Advanced & Small Cells*", NGMN, Oct 2015, https://goo.gl/ZEBXHQ
5 "*Business Case Elements for Small Cell virtualization*", Small Cell Forum, Jun 2015, http://scf.io/document/158

## 2. Total cost of ownership for transport

### 2.1 Costs and association with sites or links

The total cost of ownership (TCO) of the last mile transport network comprises a number of capital outlays and ongoing operation expenditures. Costs can be incurred by terminal sites, hub sites or the links themselves as shown in Figure 2. We define sites and links as:

- **Site:** The physical location where equipment is deployed to terminate one end of a connection. End customer sites are called 'terminals'. MNOs and ISPs also use 'hub' sites to aggregate many terminal connections onto higher capacity trunk links upstream towards their core networks.
- **Link:** The transport connection between two sites

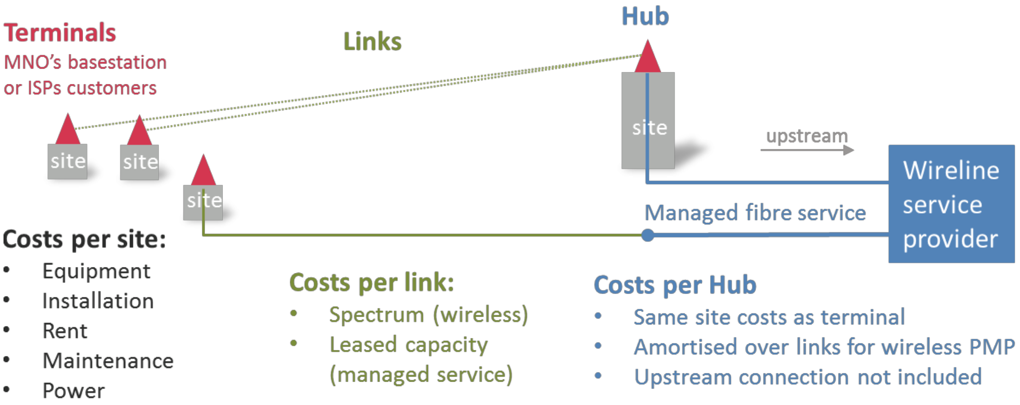


**Figure 2: Apportioning costs to customer terminal sites, hub sites or the links in between**

Transport technologies differ in the makeup of equipment and sites needed to deliver each operational link to a customer. Our TCO is evaluated based on the average *link* deployed by the ISP or MNO providing connectivity to a single terminal. Each wireless link has costs incurred at both ends, although in the case of PMP, the costs of the hub site are amortised over all of the links it supports. We consider here only the last mile costs and not those upstream of the hub site.

TCO comprises the range of capital and operational expenses shown in Figure 3. The TCO evaluation in this paper is based on an initial capital outlay in 2015 followed by five years of operational costs, increasing with an assumed compound annual growth rate (CAGR) of 3.3%. Further assumptions on each item are given in Figure 3.

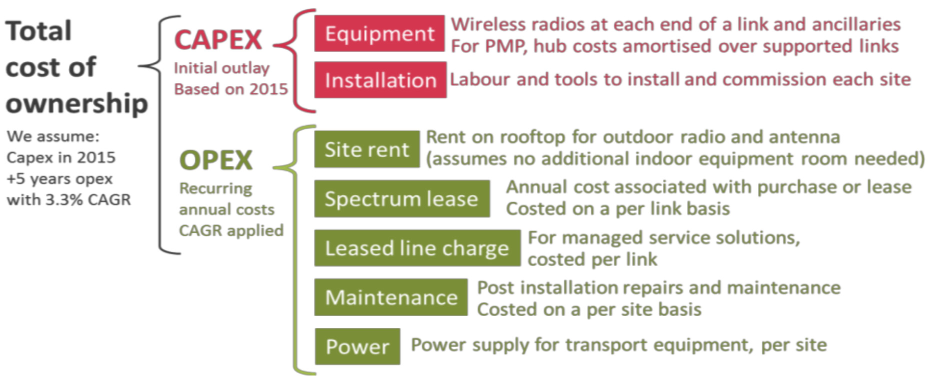


**Figure 3: Components and assumptions for the TCO calculations**

## 2.2 Relative sizes of TCO components

Before delving into the detail of how the various cost components were derived, it is informative to understand their relative contribution to overall five year TCO, which we show below in Figure 4. This overall distribution is based on an average over all wireless technologies, and is the *result* of our bottom-up analysis rather than the input to a top-down one.

|  | RW | Ericsson |
|---|---|---|
| Equipment | 19% | 20% |
| Installation | 3% | 9% |
| Operation | 26% | 27% |
| Site rent/cost | 52% | 44% |

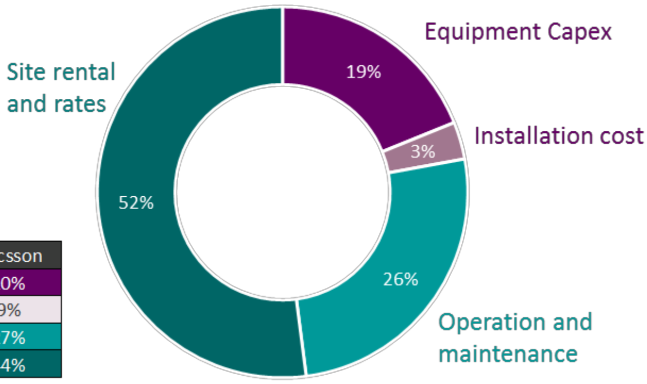


**Figure 4: Distribution of five year TCO for wireless backhaul and comparison with Ericsson's 'Microwave towards 2020' report[6]**

By way of a sanity check, we compare our distribution with similar figures given by Ericsson in their "*Microwave towards 2020*" paper[6], and are reassured to find broad agreement with one explainable exception on installation cost.

***Site costs dominate TCO, comprising around 50%. Transport technologies requiring fewer sites will have cost advantages.***

The largest component of around half the five year TCO is for site rental and business rates, revealing that the main benefactors of network build-out are landlords and local authorities rather than equipment vendors. The other half of TCO is broadly split between capex and ongoing operation and maintenance costs. Equipment capex (comprising transport hardware, software and ancillaries) is around 20% of total TCO. This means that buyers should not place too much weighting on equipment pricing itself, but rather consider the knock-on implications of that choice on the more dominant costs of site rental and operation and maintenance.

The one inconsistency between our and Ericsson's analysis is in installation costs. We observe a lower proportion here of only 3% of TCO, which is attributed to the site visits needed to install the link. Ericsson's analysis additionally factors in project management and design costs which explains why it is larger proportion. Whilst we accept that this omission may make our overall cost figures slightly lower, we do not expect it to vary significantly across wireless solutions favouring one more than others. Furthermore, since this is the smallest component of cost, overall TCO will not be sensitive to our assumptions here.

[6] "*Microwave towards 2020*", Ericsson, 2014, http://www.ericsson.com/jm/res/docs/2014/microwave-towards-2020.pdf

The key takeaway here is that site costs are dominant, so technologies which require fewer sites will have cost advantages.

## 2.3 Wireless equipment capex

Equipment pricing can vary dramatically depending on the volumes and timescales involved, as well as who is doing the asking. We present in Figure 5 aggregated results compiled from a range of stakeholder sources, including tier 1 operators, analysts and vendor pricing. We believe that these figures represent low to medium volumes appropriate in 2015. Whilst the absolute prices may vary with volume, we see that relative prices per solution are consistent with the trends seen in individual stakeholder inputs. In this analysis we only consider capex occurring in 2015, and do not consider the impact of price erosion, which may act more strongly on the newer technologies more than the mature ones. Recognising the controversial nature of price comparisons, we re-iterate our earlier finding that equipment capex is less than 20% of the overall TCO, and thus we do not expect the overall outcome to be sensitive to these data.

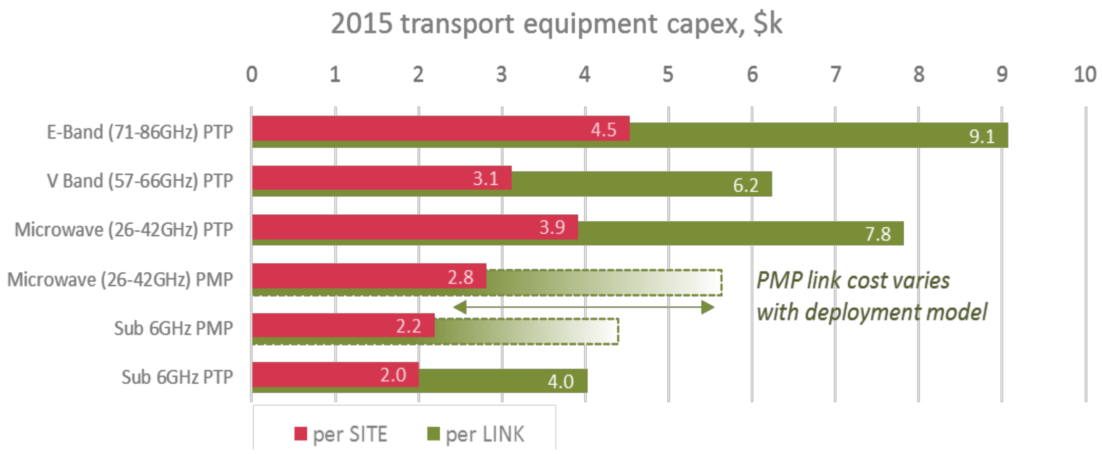


**Figure 5: Wireless equipment pricing averaged per site or per link**

**Assumptions**

- Based on mix of volume and list pricing: represents low-mid volume
- Figures adjusted to purchase in 2015
- Includes radios, antennas and ancillaries

We provide pricing figures per average *site* and per average *link*. For PTP there is a straightforward relationship as each link always requires two sites. For PMP, some of our sources provided combined hub and terminal prices based on typical deployment ratios. Other sources revealed that hub equipment carries a higher price than the customer terminal, and so the average cost per link depends on the ratio of hubs to terminals deployed. We represent this as a variable link cost for PMP which can be as much as 2x the average site cost (when deployed 1 hub per 1 terminal) and as little as 1x the average site cost (when terminals >> hubs). One stakeholder provided shipment volumes of 4:1 terminals:hubs for backhaul markets and 5:1 for enterprise markets. We note that dense networks may exceed these terminal:hub ratios, requiring multiple PMP hub transceivers are deployed at the same site. To be consistent with our PTP cost model, we assume these additional transceivers also incur an additional set of costs as would a new site.

Figure 5 shows that equipment for higher frequencies is generally more expensive, with the exception of V-band which benefits from the higher volumes anticipated with this license exempt band. The wider bandwidths available at higher frequencies also imply a correlation between cost and performance, which one would expect to result from the action of market forces.

## 2.4 Installation capex

Installation cost assumptions are taken from our small cell forum analyses[5,7] and are based on the labour cost of installing a site. Figure 6 provides results from a survey of system integrators with a combined experience of over 10,000 backhaul and access links using both PMP and PTP technologies. They have indicated the typical time to install a 'first' link - which includes a hub site for PMP - and 'subsequent' links, meaning additional terminals attached to the same PMP hub site.

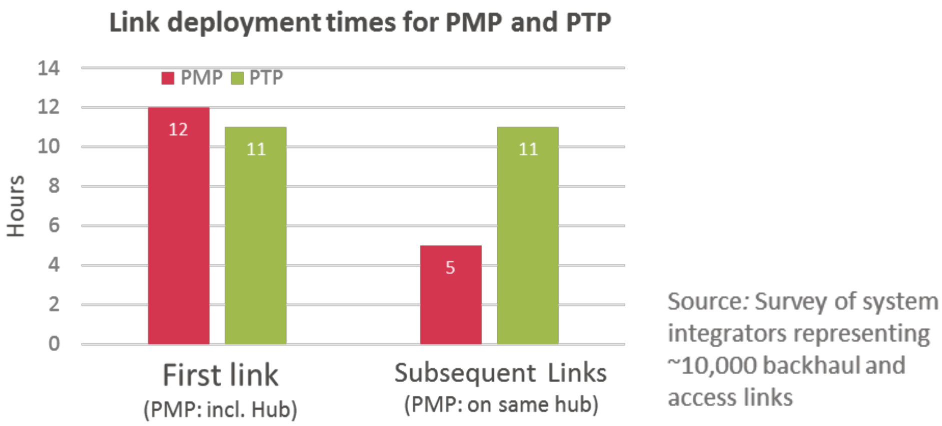


**Figure 6: Survey of wireless link installation times**

These results reveal:

- First link installation times total 11-12 hours for both ends:
  - The PMP hub end takes 7 hours compared to 5 hours for the terminal end
- PTP links averaged 5.5 hours for each end
  - Subsequent PMP links on the same hub take only 5 hours – less than half that of a PTP link as only one site is needed instead of two.

Whilst install times vary slightly, installation cost is likely to be dominated by the overhead of the site visit. The 5-7 hour install times per site suggest one team can do one site per day. These results suggest no material difference between PTP or PMP install costs *per site*, although in deployment conditions requiring fewer sites per link, savings can be made on a *per link* basis. As we have seen in the previous section, site costs dominate TCO, so reducing the number of sites significantly reduces TCO.

Installation comprises just 3% of overall TCO, which would suggest that on cost grounds alone it should not be a decisive factor in selecting a transport technology. However, the effect on overall speed of network build-out can be very material to the return on investment and time to break even for that network. This effect is analysed in section 3.

[7] "*Business case for Urban Small Cells*", Small Cell Forum, Feb 2014, http://scf.io/document/087

## 2.5 Summary of capex and annual opex

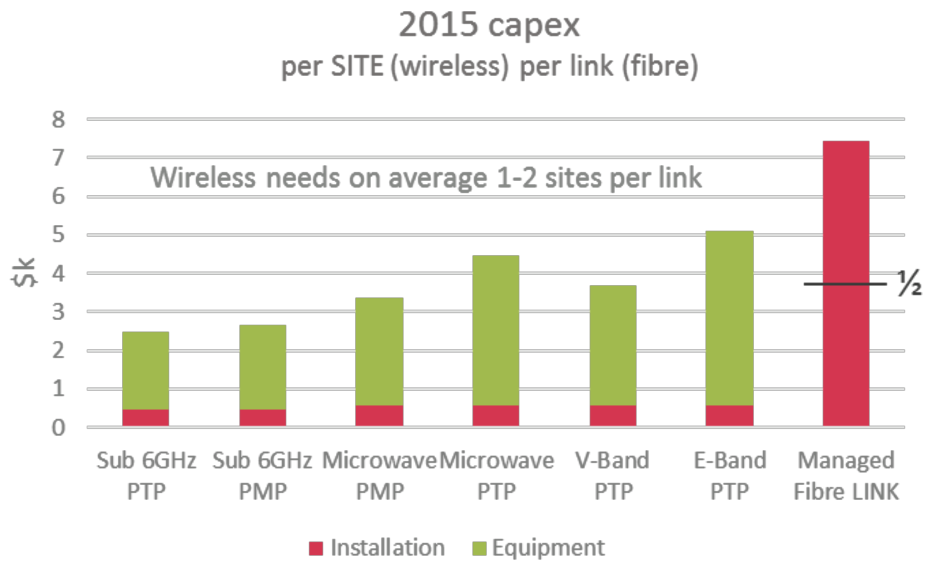


**Figure 7: Summary of 2015 Capex**

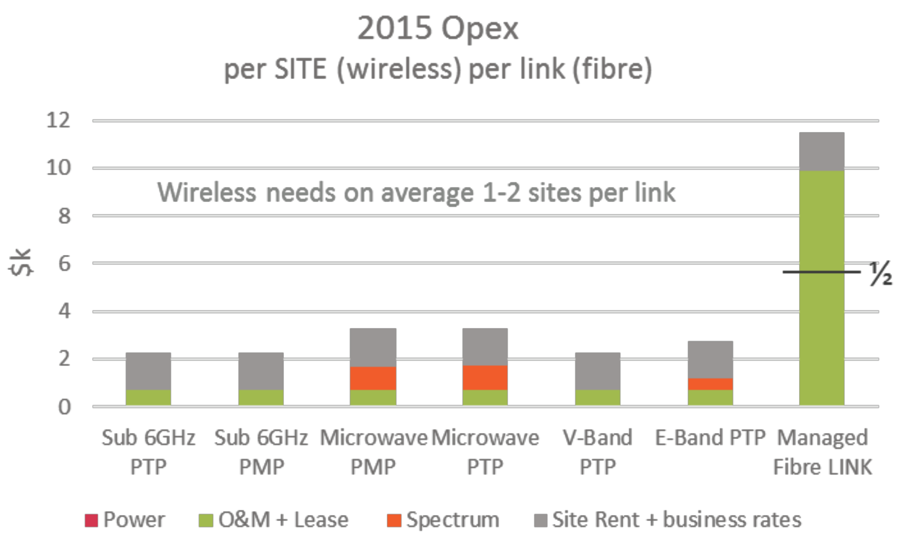


**Figure 8: Summary of 2015 Opex** (subsequent years subject to 3.3% CAGR) source: RW[5]

Figure 7 and Figure 8 show how the capex and opex stack up for the wireless and managed fibre solutions. It should be noted that costs for wireless solutions are presented per site, and each link requires between 1 and 2 sites depending on deployment conditions as described later in section 2.7. In the best case, where only one additional site (link end) is needed to establish an additional PMP link, PMP can save up to 50% capex and opex compared to PTP where two sites are always required. The managed fibre costs are presented per link, and thus are not directly comparable (½ way marks are provided as an approximate guide). Even still, it is apparent that the costs of managed fibre are high compared to wireless. Regional variations in managed fibre costs are discussed further in the source of this figure in[5].

## 2.6 Five year TCO

Figure 9 presents total cost of ownership per link for the different transport technology options, representing purchase and installation in 2015 plus five years of ownership and operation costs, increasing at 3.3% CAGR.

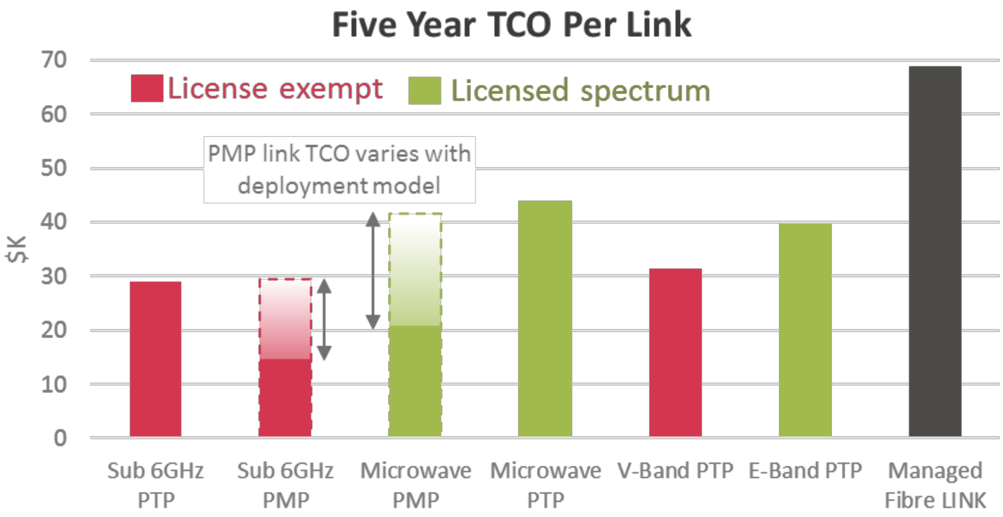


**Figure 9: Comparison of five year TCO per link for different technologies**

The managed fibre solution has higher TCO than all of the wireless options. The premium charged - and paid - for these services can in part be attributed to the higher performance and reliability expected with wireline services. Outsourcing also avoids a longer term commitment for customers having a short term needs such as rental tenants or temporary installations, and avoids the investment and complexity of operating a transport network in-house. We note however that lead times for fibre are reported to be long and unpredictable for new connections away from existing connectivity[8]. At the other end of the scale, MNOs and ISPs with a very long term view of multiple decades may choose to commit to their own fibre build-out. Regional variation in managed fibre service pricing is discussed further in [5].

On the wireless side, the license exempt options tend to have lower TCO than their licensed band equivalents. In our model, license exempt savings are attributed partly to equipment cost but mostly to spectrum which is represented as an ongoing annual charge. Some MNOs may choose to treat spectrum assets as a sunk cost and externalise it from such comparisons. Markets pay a premium for the more expensive licensed band solutions as they are considered to be more reliable, and are free from the uncontrollable interference of other users sharing the band[9]. Proponents of license exempt V-band solutions claim it is immune to the spectrum congestion seen at the sub 6GHz bands where Wi-Fi is active, thanks to transmitter isolation from high atmospheric absorption[10], and narrow beam antennas. We believe this will certainly hold true for the five year timeframe of our analysis. Whether it remains so in the longer term depends on how widely used this band will become and the resulting density of deployed transmitters.

[8] "*Backhaul planning for the two phases of small cell rollout*", Ranplan, Feb 2015, https://goo.gl/LGNARd
[9] "*Licensed versus Unlicensed Spectrum for Utility Communications*", Sensus 2010, http://goo.gl/wmEKJv
[10] "*E-Band and V-Band - Survey on status of worldwide regulation*", ETSI, June 2015, http://goo.gl/juYO5T

Licensed band systems are not immune from interference either, but license holders do at least have control over transmissions. This control goes beyond the simple process of channel selection to determine reuse of frequencies and signal quality: Since licensed band technologies can assume control of the medium, they are able to schedule resources as opposed to contending for them, and thus avoid the efficiency loss due to packet collisions seen at high loads. The current debate around LTE-U and LAA provides further insight into scheduled vs contended spectrum access[11,12]. Whilst this technicality is largely irrelevant in lightly loaded consumer Wi-Fi networks, it may have a more noticeable impact on the guaranteeable performance described in the service level agreement (SLA) of carrier grade transport links.

Although microwave PTP appears as one of the higher cost options, we recognise that it is a mature and established technology that is widely deployed today in fixed transport links. It is possible there is a 'cost' not accounted for in our analysis that represents the risk of change for an organisation or industry: Adoption of new technologies requires re-training and new processes and there is a genuine short term saving in 'sticking to what you know'. In the long run, however, fundamentals will win out and markets will favour those that are able to exploit the benefits of more efficient technology approaches.

## 2.7 Deployment factors influencing TCO in PMP deployments

Figure 9 showed that the TCO per average link is variable and depends on deployment conditions. In their optimum scenario, PMP wireless has the lowest TCO of all solutions, nearly half that of their PTP equivalents. Figure 10 lists deployment factors which increase or decrease PMP link TCO.

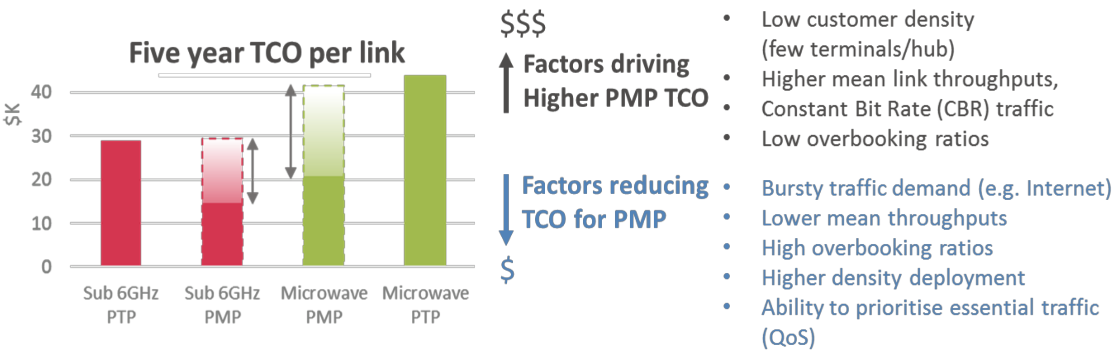


**Figure 10: Deployment factors which increase or decrease TCO for wireless PMP**

Overall, per link TCO with PMP is reduced in deployment scenarios that allow a greater number of terminals per hub: These are where there are high customer densities and where traffic is bursty and is well suited to aggregation. In their paper, Ericsson illustrate an example of how packet aggregation, combined with the ability to prioritise critical traffic

[11] "*Coexistence of Wi-Fi and LTE in Unlicensed Bands*", C.Cano Et al, 2015, https://goo.gl/9sURjC
[12] "*LTE unlicensed and Wi-Fi: moving beyond co-existence*", Senza Fili, http://goo.gl/CHCSvT

types, can bring about a sevenfold increase in link capacity[13]. Here we find that this same principle could alternatively be used to halve TCO.

***In their optimum scenario, PMP wireless has the lowest TCO of all solutions, nearly half that of their PTP equivalents.***

Per link PTP has lower TCO in scenarios where only one terminal is needed or possible for each hub: Low customer densities, higher link throughputs and constant bit rate (CBR) traffic. Although not shown in this cost analysis, PTP equipment with high gain antennas at both ends can achieve longer link ranges than PMP equivalents.  Many of these characteristics are found in 'middle mile' transport connections carrying aggregated traffic for many end-points, making PTP the more appropriate technology here.

[13] "*new* Microwave in 2020", Ericsson, Sept 2015, http://goo.gl/f0t6oO

# 3. Case Study: Time to breakeven for an enterprise ISP

Here we model revenue generation from an ISP network buildout and combine with our TCO model to calculate return on investment over time. This reveals the *time to breakeven*: how long before the ISP will have a positive net return on their infrastructure investment.

## 3.1 Method and assumptions

The ISP in this case study is setup to sell carrier grade connectivity services to enterprises. It invests in network infrastructure and receives revenue for operational links. We make the following assumptions:

**Assumptions**

- The ISP owns or leases core network infrastructure out to fibre points of presence, and requires a last mile wireless transport technology to extend connectivity out to business premises.
- Demand for services is insatiable, and customer acquisition is limited only by the speed of network build-out.
- Build-out is limited by deployment teams to a fixed number of 80 site installs per month.
- Point to point (PTP) wireless links require two sites to be installed. Point to multipoint (PMP) assumes a deployment with five customers connected to each hub transceiver[14] equivalent to 1.2 sites per link.
- Revenue is received per month for every link in operation delivering a service:
    - Silver service using license exempt Sub 6GHz: $180 per customer, per month
    - Gold service using licensed and V-band solutions: $250 per customer, per month
- Customers are tied in to a 12 month minimum contract, after which we assume 10% churn per month.

This case study represents the ISP's technology selection process for their last mile transport, and externalises other costs considered to be independent of this. The resulting return on investment therefore does not represent the ISP as a whole, but that of the department responsible for the last mile transport. These other costs would delay the time to breakeven compared to figures given here – but we believe this will not impact the ranking of technology options.

This ISP case study could equally apply to an MNO's backhaul department, where cost efficiencies here enable competitive advantage through larger network for a given time and budget.

[14] Based on shipment volumes of terminals:hubs for an stakeholder supplying PMP to enterprise markets.

## 3.2 Rate of revenue generation

The ISP's sales revenue depends on the number of links they have in operation. Figure 11 shows that with a fixed rate of site installs per month, the use of PMP wireless enables more links to be operational at any given time. Viewed another way, a given number of links can be operational in a shorter time. The degree of saving depends on the terminals to hubs ratio set by the deployment conditions as described earlier. In the case of five terminals per hub shown here, PMP supports 67% more links than PTP at any given time.

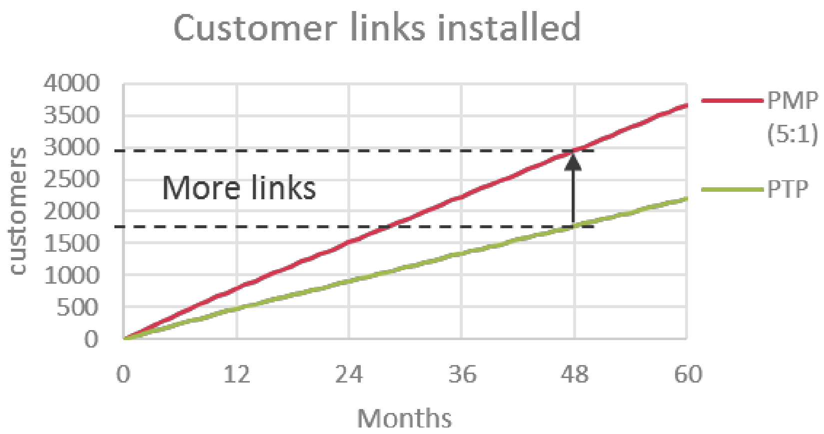


**Figure 11: Installed *links* over time for a fixed installation rate of 80 *sites* per month**

Figure 12 shows the resulting cumulative revenue over time for the gold and silver services with PTP or PMP technology choices. Clearly the gold service brings in more revenue over time since we have assumed insatiable demand. However, revenue alone does not factor in the higher cost of ownership for the licensed or V-band solutions required. PMP results in a faster rate of revenue generation since there are more operational links at any given time.

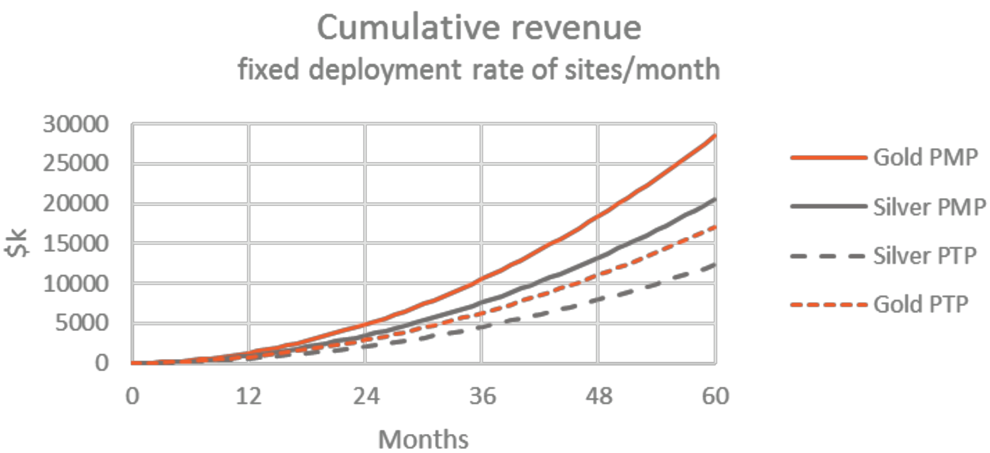


**Figure 12: Cumulative revenue over time for different service offerings and technologies**

## 3.3 Return on investment and time to breakeven

Return on investment is evaluated by subtracting from the revenue the costs for every site installed and operated by the ISP. Each site's capex and first year of opex is incurred at the time of installation, with subsequent years' opex occurring on the site's anniversary, with a 3.3% CAGR applied. Figure 13 reveals the how the technology choice impacts the depth of investment and time to breakeven in the first two years.

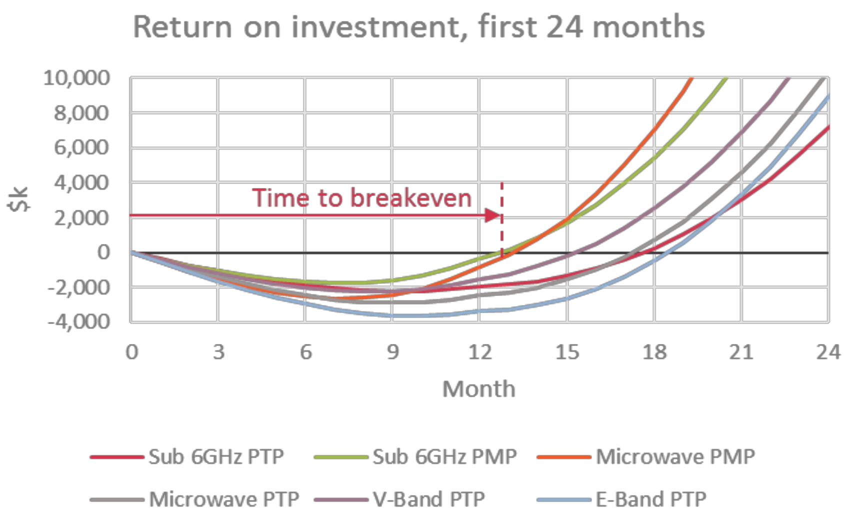


**Figure 13: Return on investment for the ISP – short term**

Figure 13 reveals that the unlicensed band sub 6GHz PMP solution requires the least up-front investment and results in the fastest time to breakeven of around 13 months. This can be attributed to it having the lowest TCO of all options. In this short term view we see that the microwave PMP solution is not far behind. Although spectrum and equipment costs are higher, this is compensated for by the increased revenue from the gold service offering. As described earlier, this relies on the market's willingness to pay a premium for higher reliability links. We believe this would indeed be the case for business grade services in areas experiencing congestion in the 5GHz and 2.4GHz license exempt bands. Figure 14 shows that at 60 months, the licensed band PMP option generated 30% more return on investment than its unlicensed equivalent.

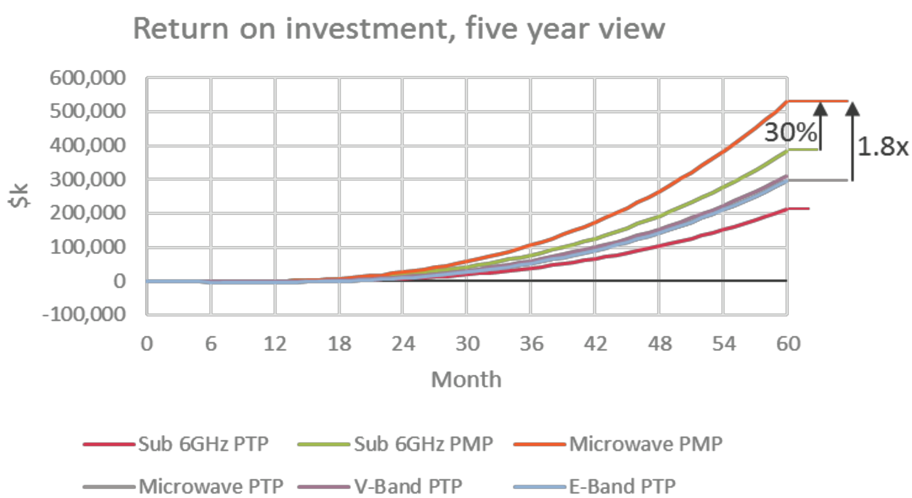


**Figure 14: Return on investment for the ISP – long term**

The five year view in Figure 14 hides the initial investment and reveals the longer term trends. Both PMP solutions gave 1.8x more return on investment than their PTP equivalents due to the greater number of revenue generating links possible from the given installed base of sites. If demand had not been insatiable, this would instead translate into a lower TCO for the given number of operational links. V-band, E-band and microwave PTP choices all result in similar returns, showing that differences in equipment pricing do not significantly impact the overall return on investment of using them. V-band's lower cost gives it the edge on other PTP solutions in the long run.

## 4. Conclusions

We have analysed total cost of ownership (TCO) for a number of last mile data transport solutions suitable for use by mobile network operators (MNOs) as backhaul or internet service providers (ISPs) for broadband access. The technology options are represented by the following categories: Sub 6GHz PTP and PMP, Microwave PMP and PTP, V-band and E-band PTP and managed fibre.

Site costs are dominant, accounting for around half of the five year TCO. Operation and maintenance is around a quarter and equipment capex, a fifth. These proportions reveal that TCO is much more sensitive to site rental and rates than equipment pricing.

PMP solutions can reduce capex, opex and TCO significantly compared to PTP where the total number of sites can be reduced to support a given number of endpoint connections. This is possible where deployment conditions lend themselves to sharing of hub sites and bandwidth between customer terminals. In optimum conditions, TCO can be reduced by as much as 50%. PTP links are the more appropriate choice for 'middle mile' type scenarios, with longer links, lower site density and for aggregated traffic with constant bit rate characteristics and higher mean throughputs.

***In our Enterprise ISP case study, PMP solutions gave 1.8x greater return on investment compared to their PTP counterparts largely because they supported more revenue generating links sooner.***

Our case study for an Enterprise ISP finds Sub 6GHz and microwave PMP solutions result in the fastest time to breakeven of around 13 months, relative to 16-19 months for other solutions. After five years, PMP solutions generated 1.8x greater return on investment compared to their PTP counterparts largely because it supported more revenue generating links sooner. The higher revenue per link possible with the 'gold' licensed band service generated a 30% higher return on investment than its unlicensed equivalent.

Overall, our TCO and return on investment evaluation framework has revealed the deployment factors which should be considered when selecting a last mile transport technology. A well-chosen solution may reduce TCO by as much as 50%, or alternatively, increase return on investment by up to 1.8x.

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