Crucial economics for mobile data backhaul

An analysis of the total cost of ownership of point-to-point, point-to-multipoint, and fibre options

By Monica Paolini

Executive summary

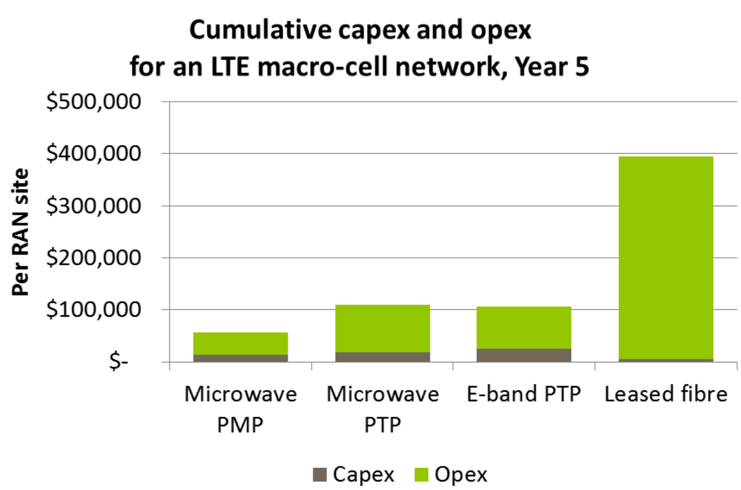
Point-to-multipoint mobile data backhaul can deliver a 49% cost saving over point-to-point backhaul, thanks to a more efficient use of spectrum equipment that lowers capex and opex at the same time

Backhaul is a crucial enabler for mobile operators deploying new high-capacity technologies like Long Term Evolution (LTE), as they look for a solution that meets their performance requirements *and* minimizes costs – in particular opex, the largest contributor to backhaul costs. Backhaul prominence will rise further with the deployment of small cells, and with the associated increase in the number of cell sites, mostly in challenging urban locations and requiring a wireless backhaul link. How can operators choose from a wide range of backhaul choices, ranging from fibre to microwave and E-band point-to-point (PTP), and to microwave point-to-multipoint (PMP)? This paper presents a financial analysis based on a total cost of ownership (TCO) model that compares capex and opex of fibre, microwave and E-band PTP, and microwave PMP backhaul within Long Term Evolution (LTE), third-generation (3G), and small-cell networks over a period of five years.

For operators that do not own a fibre network or lack affordable access to leased circuits, wireless solutions provide the capacity, performance, flexibility, and cost-effectiveness that they need to backhaul 3G and 4G traffic. Among wireless solutions, PMP is the most cost-effective because it requires fewer radios to meet the backhaul requirements than either microwave or E-band PTP does, and this translates into lower equipment and installation costs (fewer radios to install), as well as lower opex (fewer links to operate). Furthermore, the smaller equipment footprint and the ability to use spectrum licences that cover areas instead of individual links make PMP easier and faster to deploy in challenging urban environments.

The cost savings afforded by PMP are further driven by the ability to leverage aggregation gains which arise from the lack of correlation of data traffic patterns from different radio access network (RAN) site sectors. Unlike voice, data traffic is extremely bursty, but traffic peaks across base stations are not correlated. By combining traffic from multiple RAN sites, wireless backhaul throughput requirements are kept in check, even as RAN traffic levels grow, especially when using the PMP architecture, and spectrum resources can be more effectively used.

Our TCO analysis shows that microwave PMP is particularly cost-effective compared to microwave PTP in high-density environments for two main reasons: (1) it efficiently leverages gains from traffic aggregation; and (2) it allows operators to buy, install, and operate less equipment as the hub equipment is shared across multiple RAN locations. PMP gives operators a 49% cost saving over microwave PTP in a LTE macro-cell deployment over five years. The cost savings over E-band are a comparable 47%. A leased fibre solution may cost seven times as much as a PMP solution, due to the high recurring costs for leased circuits.



1. Introduction

Cellular backhaul has become a very hot topic – and a major focus of attention for mobile operators. The stunning growth in data traffic, coupled with the availability of high-throughput third-generation (3G) and fourth-generation (4G) radio access network (RAN) technologies, has brought backhaul to the fore as the crucial link that ensures that subscriber traffic reliably reaches the core network – and as a potentially very damaging bottleneck if it lacks the required capacity.

No longer can backhaul requirements be cost-effectively met by leasing one or more time-division multiplexing (TDM) circuits. TDM circuits are an attractive solution for low traffic loads because they do not require high capex and because the opex scales in line with the number of RAN sites. But as the traffic grows, the number of E1s that have to be leased grows very quickly to a point at which E1 is no longer cost-effective or sufficient to meet the requirements. And backhaul costs represent a large slice of operators' capex and opex. At Vodafone, capex for microwave may account for 37% of a new cell site and leased lines for 21% of opex.[1]

Higher-capacity IP-based solutions provide the capacity mobile operators need, but those solutions have fundamentally different cost drivers – and this makes each solution suitable for a different set of environments. In virtually all cases, mobile operators deploy a portfolio of backhaul technologies in different parts of their network, depending on capacity and cost requirements.

In this paper, we use a total cost of ownership (TCO) financial model to explore the impact that these factors have on the selection of a backhaul solution. The model compares the capex and opex of widely used backhaul solutions – microwave and E-band point-to-point (PTP), point-to-multipoint (PMP) microwave, and leased fibre – in high-density environments where the backhaul capacity requirements are the highest. The first part of the paper gives an overview of different backhaul technologies and topologies, and introduces the TCO model structure and assumptions. The second part presents a comparison of the key cost drivers across backhaul solutions for both capex and opex.

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1. Vodafone Group Technology Update 2008, http://www.vodafone.com/content/index/investors/reports/company_presentations.html

2. Solutions for cellular backhaul

Multiple solutions exist to address the requirements of cellular backhaul, each of which meet different requirements in terms of capacity, reliability, deployment time, cell-site availability and cost. No single solution works across an entire cellular network that covers rural and urban areas, and operators have to select the best-suited solutions to deploy in different parts of their networks.

Fibre is often touted as the perfect solution – easy to connect to the base station and cost-effective if the operator owns a fibre network. However, even in urban or high-traffic areas, fibre may not be available at the base station location, even if available nearby. Operators that do not own a backhaul fibre network often find fibre leasing costs to be too high, and the time to set up a connection too long. Mobile operators may also consider building their own fibre backhaul network, but it is very difficult to justify extensive fibre deployments that carry only cellular backhaul traffic at costs that range between $50,000 and $100,000 per km, and may even exceed this figure in heavily built-up urban areas. Furthermore, fibre is slow to deploy, because of permitting and right-of-way issues, in addition to the installation itself.

Wireless backhaul frees mobile operators from fibre leasing arrangements, but requires them to install and operate their own backhaul infrastructure, find suitable locations for equipment, and pay for cell-site leases, unless they outsource the backhaul to a neutral-host operator. Microwave wireless backhaul requires line of sight (LOS) between the two antennas in a link, and this can be difficult to achieve in heavily built-up environments like central urban areas.

Small cells are emerging as the latest backhaul challenge, because they will be deployed in dense topologies (i.e., a high number of cells per square km), and because they will often be located on non-telecom assets such as light poles and building exterior walls. These locations make it difficult to secure a fibre connection or to establish a one-hop LOS link. The high number of small cells makes cost considerations even more important, because a larger number of backhaul links is typically required to transport the same amount of traffic that would be carried by larger-capacity macro cells using the same air interface.

In addition to fibre, three wireless backhaul technologies are most commonly used in cellular networks (Table 1):

- **Microwave PTP** requires a symmetric link to connect each RAN site to a hub that is in turn connected to the backbone. If the RAN site is too far from the hub or there is no LOS, the backhaul may have to include two hops. Traditionally, PTP links are deployed using a star topology in which all RAN sites are connected directly to the hub. Increasingly, PTP links are organised in tree-and-branch and ring networks, which can increase the efficiency, reach, and reliability of the backhaul (Figure 1). To operate a PTP link, operators typically lease spectrum on a per-link basis.
- **E-band PTP** requires the same symmetric LOS links that microwave PTP uses, and can be deployed using the same topologies (i.e., star, tree-and-branch, and ring), but it uses the 70 to 80 GHz spectrum. Because of the higher frequency, E-band has a shorter reach and its performance is more severely affected by environmental factors like rain. As for microwave PTP, spectrum is leased on a per-link basis.
- **Microwave PMP** allows one access point (AP) in the hub to connect to multiple RAN sites and, as a result, it does not require a dedicated symmetrical link for each backhauled cell site. This results in fewer radios and a potential for higher utilisation of backhaul resources. PMP spectrum is most commonly allocated as a long-term licence within a country or an area within a country.

	Microwave PMP	Microwave PTP	E-band PTP	Leased fibre
Capacity	20–300 mbps	20–500 mbps	240–2,400 mbps	Any capacity required
Link distance	Up to 19.5 km (10.5 GHz), up to 7 km at 26 GHz, and up to 6.4 km at 28 GHz*	Up to 50 km*	Up to 2 km*	Any distance required
Spectrum bands	10.5 GHz, 26 GHz, 28 GHz	5–80 GHz	71–76 GHz, 81–86 GHz	N/A
Spectrum channels	7–56 MHz	3.5–80 MHz	Up to 5 GHz	N/A
Spectrum rights	One spectrum channel supports multiple sites	Limited spectrum availability. Each link requires a separate spectrum lease	Cheaper spectrum than microwave PTP. Each link requires a separate spectrum lease	N/A
Capex/opex trade-offs	More capex-intensive solution than leased fibre	Higher opex than PMP and E-band due to higher spectrum costs	More capex-intensive solution than leased fibre	High opex, low capex
Equipment and installation costs	Lower cost than for microwave and E-band PTP because less equipment is needed	Lower cost per link, but higher installation costs than PMP as more terminals are required	Higher equipment costs than microwave PTP, comparable installation costs	Very low cost, relies on leased infrastructure
Where it works best	High cell-density areas	High cell-density areas, but also suburban and rural areas where wireline connectivity is not available	High cell-density areas	Where fibre is available, accessible, and cost-effective

* Links in most cases are much shorter than the maximum link distance, because they are used in areas with a high concentration of base stations and the distances among them are well below the maximum link distance.

Table 1. Comparison among mobile backhaul solutions. Source: Senza Fili Consulting, Cambridge Broadband Networks, microwave PTP and E-band PTP wireless backhaul vendors

Another option available to mobile operators is PMP non-line-of-sight (NLOS) backhaul using the sub–6 GHz spectrum, either in licenced or licence-exempt bands. Mobile operators have never embraced licence-exempt backhaul, with only a few exceptions limited to small deployments, typically in low-traffic, rural areas, because of the potential interference in these bands. NLOS backhaul in licenced bands is becoming more appealing, especially for small-cell deployments, but it is still used very sparingly and mostly for Wi-Fi hotspot backhaul rather than for cellular backhaul. High cost of sub–6 GHz spectrum, limited spectrum availability and narrow channels have limited the appeal of PMP NLOS backhaul for macro cells. Backhaul solutions using time-division duplexing (TDD) sub–6 GHz bands, such as the 3.5 GHz band for small-cell deployments, will increase the demand for PMP NLOS backhaul, because TDD spectrum is cheaper than the frequency-division duplexing (FDD) used in the cellular RAN, and limitations in channel bandwidth are more manageable in a small-cell environment with single-sector base stations. Because of the low adoption rate to date, we have not included sub–6 GHz PMP NLOS solutions in our TCO analysis.

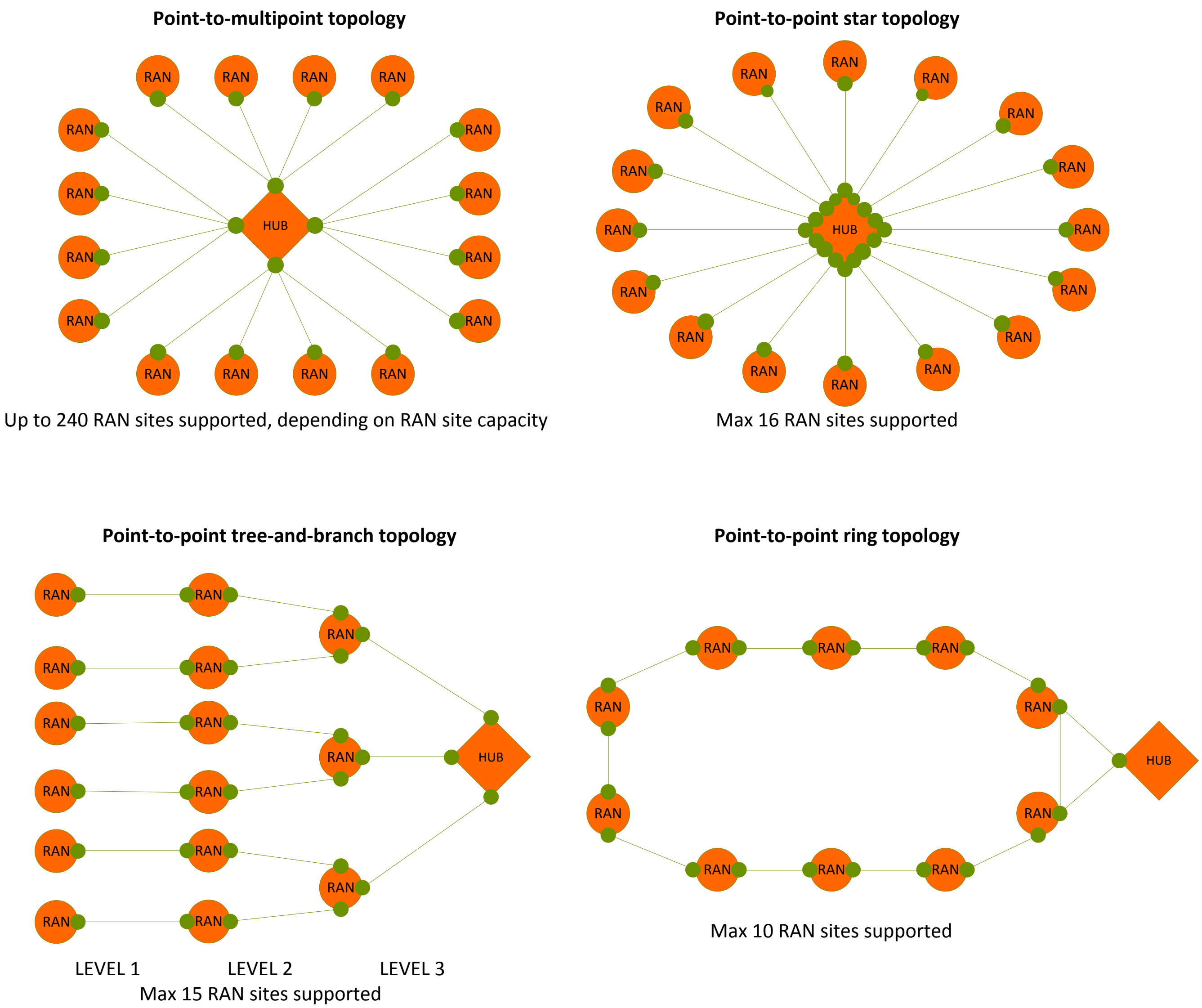

Figure 1. PMP, PTP star, PTP tree-and-branch, and PTP ring topologies. Source: Senza Fili Consulting

3. Total cost of ownership (TCO) model: Methodology and cost assumptions

To get an in-depth understanding of the cost trade-offs that mobile operators face when choosing among backhaul options, we built a TCO model that compares the capex and opex over five years for microwave PTP, E-band PTP, microwave PMP, and leased fibre for three scenarios in an urban/suburban environment, with LTE macro cells, 3G macro cells, and LTE small cells, respectively (Table 2).

	LTE macro cells (base case)	3G macro cells	LTE small cells
Max throughput per base station (sector)	80 mbps	20 mbps	80 mbps
Sectors per RAN site	3	3	1
Number of RAN sites	24	48	96
Topology for PTP and E-band	Tree and branch		

Table 2. Scenarios analysed in the TCO model. Source: Senza Fili Consulting

A financial comparison among backhaul options that generalises across markets is not feasible, because of wide changes in spectrum fees and availability, site rental, and labour costs in different regions, and for different operators. To address market variability, the model allows the user to manipulate all key variables in the backhaul business model to look at the cost trade-offs for specific operators using market- and operator-specific inputs.

In the paper, the cost assumptions are based on median values (Table 3) that, although not modelled on a specific market or operator, are based on information we obtained from operators, regulators, vendors, and other public information sources, and averaged across different markets. In the model, all capex is incurred in the first year, and opex is calculated on a yearly basis from Year 1 to Year 5. However, to validate the findings presented here we extensively looked at variations across multiple capex and opex parameters, and found that the model results are robust, and that main trends and drivers are preserved even as assumptions change within realistic ranges.

To reduce the complexity of the comparison across technologies, no provision for redundancy is included in the results presented in the paper, because operators are bound to choose customised redundancy solutions that reflect their specific requirements, and cannot be generalised as best practice across the industry. We have explored the impact of different redundancy configurations and found that the model generates results that are consistent with those presented here when comparable levels of redundancy are selected across technologies (i.e., microwave PMP, microwave PTP and E-band PTP).

Because the TCO model compares different solutions and does not directly estimate the traffic load operators should expect based on their subscribership, it computes the backhaul requirements on the basis of the RAN sites' maximum throughput; this provides a useful basis for a comparison over a five-year period, allowing for increase in traffic load and subscribership during this period.

Because mobile operators typically use multiple backhaul solutions across their networks, the model computes the costs for small backhaul network configurations and then extrapolates the cost on a per-RAN site or per mbps basis; this enables operators to easily scale the model's results to the desired deployment size. While the model is RAN-technology neutral, our scenarios make assumptions about RAN throughput that are typical of LTE macro and small cells and 3G macro cells (Table 2). For each scenario and backhaul topology selected, the model identifies the most cost-effective network architecture, and estimates the equipment needs and the corresponding costs to deploy and operate the network over the subsequent five years.

	Microwave PMP	Microwave PTP	E-band PTP	Leased fibre
Capex				
Equipment costs, outdoor[2]	\$9,100–\$11,900 (AP); \$3,800–\$4,170 (terminal)	\$4,400–\$11,500 (link)	\$11,300–\$19,500 (link)	\$2,000 (connection setup)
Equipment costs, indoor	\$9,000			N/A
Network planning, site acquisition, installation	\$5,950 (hub site); \$3,650 (RAN site)	\$8,700 (link)		\$2,000 (RAN site)
Opex				
Site rental fees, leased line fees (per year)	Outdoor equipment: \$4,000 (AP); \$3,000 (terminal). Indoor equipment: \$1,000 (AP); \$500 (terminal)	Outdoor equipment: \$7,000 (link) Indoor equipment: \$1,500 (link)		\$50,000–\$140,000[3]
Spectrum licensing fees (UK pricing)[4]	\$3–\$6 per MHz per AP[5]	\$37–\$387 per MHz per link	\$81 per link per year	N/A
Other recurring operating costs (power, maintenance, etc.)	\$4,000 per RAN site and per hub	\$8,000 per link		\$1,000 per RAN site

Table 3. TCO model assumptions, based on median values across markets. Source: Senza Fili Consulting

2. Prices depend on frequency and maximum throughput supported.

3. Lease price depends on capacity.

4. Licensing fees are available from Ofcom, the UK telecom regulator, at www.ofcom.org.uk. Fees are listed as a range, as they depend on frequency, in addition to bandwidth. For microwave PMP, fees have been extrapolated from multiyear regional or national licences, making the conservative assumption that the licensing fees were used across only 50 hubs within the region covered by the licence. Unlike microwave and E-band PTP spectrum, which is typically licenced on a per-link basis, PMP spectrum can be used for any number of hubs by the licensee. We used the UK spectrum licensing fees in the model because they are publicly available and they are in the middle of the price range across different countries. However, spectrum licensing fees and regimes, as well as spectrum availability, vary significantly across markets. We ran sensitivity analyses with spectrum costs from other countries and found that they did not alter the overall result trends.

5. We assumed that in a PMP network, each AP has a separate spectrum channel, with up to four channels per hub. If more than four APs are used in a network, the initial four frequency channels can be reused in non-contiguous sectors.

Backhaul capacity requirements are often computed as the sum of the maximum throughput requirements of each RAN site that feeds to the backhaul link. However, this approach leads to overestimating backhaul capacity needs, because throughput across multiple sectors fluctuates through time and traffic peaks are uncorrelated across sectors. The fluctuation and lack of correlation are particularly prominent for data traffic, which tends to be burstier than voice traffic and should be taken into account when selecting the backhaul link needed. As a result, when a backhaul link aggregates traffic across multiple sectors, the link capacity can be less than the sum of the peak capacity across sectors, resulting in what we call an "aggregation gain".

To take aggregation gains into account, the backhaul capacity requirements are calculated on the basis of the network architecture, the topology (e.g., star or tree-and-branch for PTP), the number of RAN sites, the sector throughput, and the number of sectors per RAN site, using the following formula recommended by the Next Generation Mobile Networks (NGMN) Alliance[6]:

Backhaul provisioning requirements (mbps) = max (peak sector throughput, busy-time mean traffic *x* number of sectors)

The number of sectors includes all the sectors in RAN sites that feed to the link. In a tree-and-branch configuration at level 3 (Figure 1), the number of sectors is 15 (3 multiplied by 5) for three-sector RAN sites. In line with the NGMN Alliance guidelines, we estimate the mean sector traffic throughput to be 19 % of the peak sector throughput—for example, a sector with a peak capacity of 80 mbps has a mean capacity of 15 mbps.

The traffic requirement is computed for each node, depending on the number of RAN sites and sectors served by each node (Figure 2, Table 4). Figure 3 illustrates how the model calculates the backhaul link requirements with (labelled "W/agg") and without ("Max") taking traffic aggregation into account, for both the microwave PTP and the E-band PTP tree-and-branch topology, and for microwave PMP. The network in Figure 3 uses the same assumptions as our base case, with three sectors per RAN site and a maximum throughput of 80 mbps per sector.

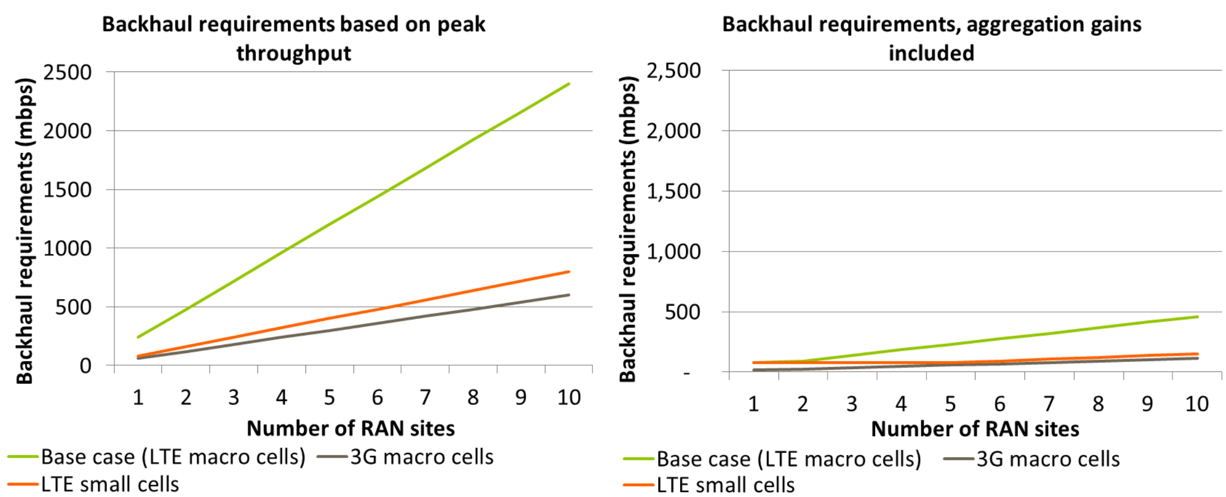

Figure 2. Comparison of backhaul requirements computed using peak throughput or taking aggregation gains into account, as a function of the number of RAN sites served. In the base case and 3G scenarios, each RAN site has three sectors. In the LTE small-cell scenario, there is one sector per RAN site. Source: Senza Fili Consulting.

6. "Guidelines for LTE backhaul Traffic Estimation", NGMN Alliance, 2011 (www.ngmn.org).

	RAN sites served	Sectors served	Maximum total throughput (no aggregation gain)	Backhaul requirement taking aggregation gains into account
PMP, access point	5	15	1,200 mbps	230 mbps
Microwave/E-band PTP, tree-and-branch, level 1	1	3	240 mbps	80 mbps
Microwave/E-band PTP, tree-and-branch, level 2	2	6	480 mbps	92 mbps
Microwave/E-band PTP, tree-and-branch, level 3	5	15	1,200 mbps	230 mbps
Microwave/E-band PTP, star, single link	1	3	240 mbps	80 mbps

Table 4. Estimation of backhaul requirements taking aggregation gains into account. Source: Senza Fili Consulting, using the backhaul estimation model from the NGMN Alliance.

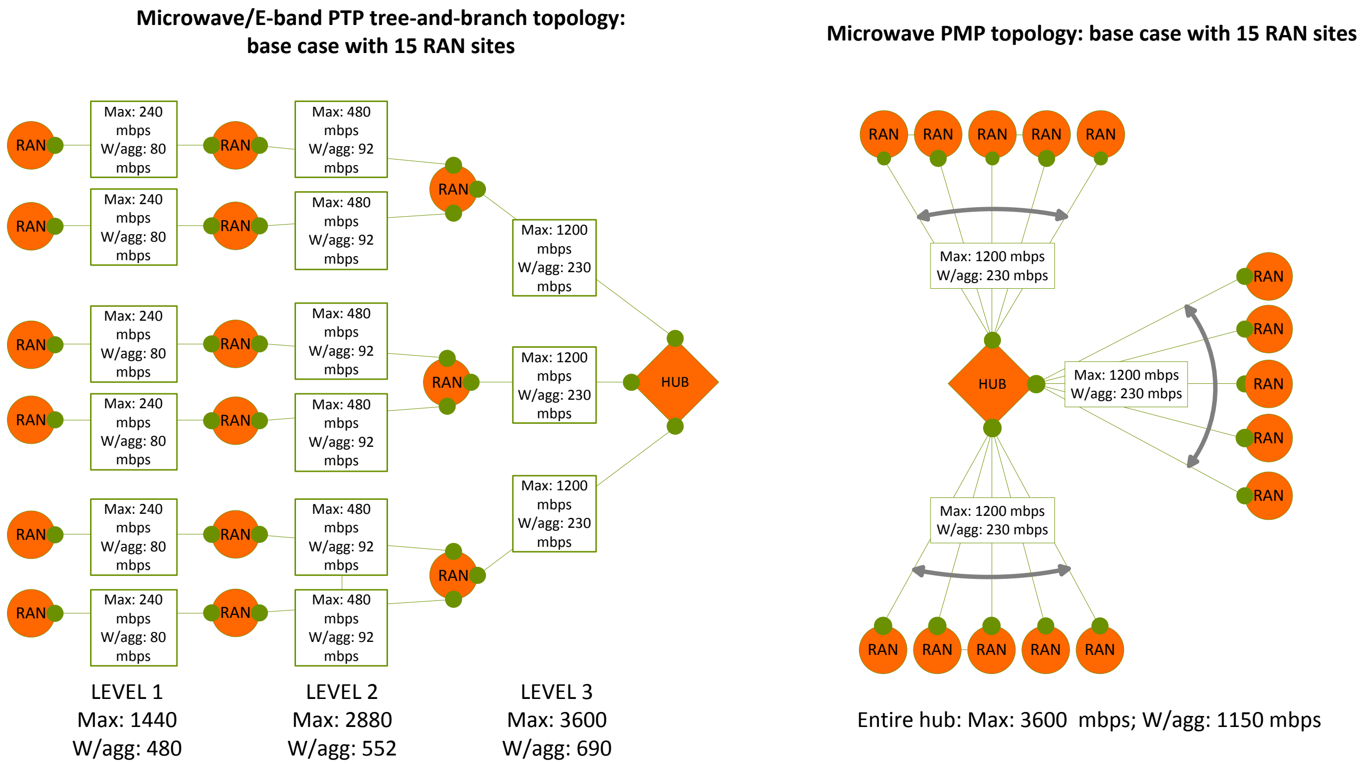

Figure 3. Backhaul requirements for a microwave or E-band PTP tree-and-branch network, and for a microwave PMP network, with ("W/agg") and without ("Max") taking into account aggregation gains. Source: Senza Fili Consulting.

If multiple sectors are used, backhaul solutions that use fibre or a star topology benefit from traffic aggregation only within the RAN site. PMP, as well as microwave and E-band PTP when using a tree-and-branch or ring topology benefit from traffic aggregation beyond the RAN site, because the backhaul network introduces further aggregation gains by combining traffic from a larger number of sites over the same link, as demonstrated in Figure 3.

4. Capex

The capex to provide backhaul to a RAN site with three 80 mbps sectors (base case) ranges from $4,800 (leased fibre) to $22,300 (E-band) (

Figure 4), equivalent to $20 (leased fibre) to $93 (E-band PTP) per mbps. For the three wireless solutions considered, equipment contributes 56% (microwave PTP) to 66% (E-band PTP) and 67% (microwave PMP) of capex (Figure 4).

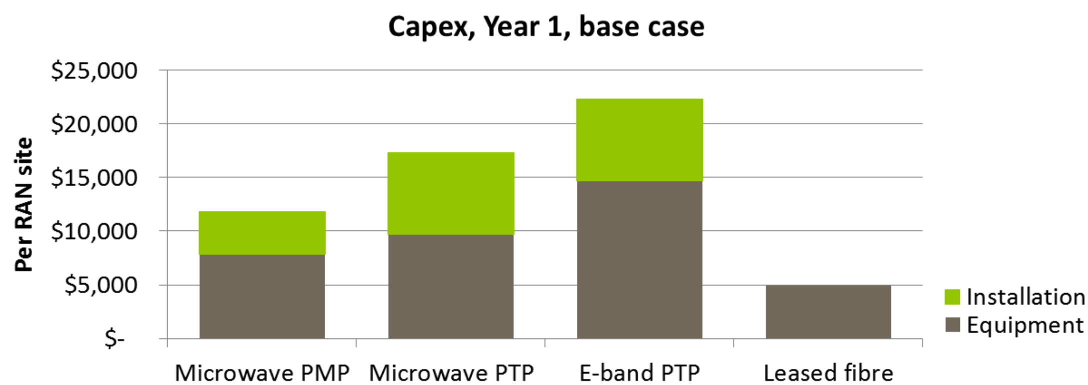

Figure 4. Year 1 capex for the base case. Source: Senza Fili Consulting

Fibre has the lowest capex, because the operator has to pay only for terminal equipment fees to set up the service – even though in some cases operators have to commit to multi-year contracts, or have to pay high installation costs (however, we did not include either in the TCO model). Most of the backhaul costs are recurring costs from leasing the fibre circuits. Where available, fibre is better suited to operators who prefer to allocate backhaul costs to opex, or that have access to low line-rental fees.

For wireless solutions, capex is lowest for PMP because it requires less equipment, which translates to savings from both equipment and installation (Table 5). For instance, in a PTP tree-and-branch or star network with 15 RAN sites, 15 links are needed, each with two radios, for a total of 30 radios. In a PMP network, 15 RAN sites can be served by three APs, which translates into three AP radios and 15 terminal radios, for a total of 18 radios, 40% fewer than microwave PTP. Although the cost of the individual radios is higher for microwave PMP (i.e., an AP and one terminal are more expensive than a microwave PTP link), the need for fewer radios results in a 19% saving for PMP compared with microwave PTP. Because the installation costs are comparable for microwave PMP and PTP, the total cost of installation is 49% lower for PMP, with its smaller number of radios, than for PTP. E-band PTP capex is 29% higher than microwave PTP despite the fact that its installation costs are the same (i.e., the same number of radios to be installed), because the

Microwave PMP	LTE (base case)	3G	LTE small cells
Number of APs	4	2	6
Terminals supported by one AP	6	24	16
Total number of RAN sites	24	48	96
Average number of radios per RAN site	1.17	1.04	1.06
Fewer radios than for PTP	20	46	90

Table 5. Number of radios required in different scenarios for PMP backhaul. Source: Senza Fili Consulting

Capex, Year 5 – PMP cost savings over:	Microwave PTP	E-band PTP	Leased fibre
LTE macro cells (base case)	31%	47%	-127%
3G macro cells	37%	56%	-89%
LTE small cells	40%	56%	-91%

Table 6. PMP capex cost savings over other solutions. Negative values indicate higher costs for PMP over compared solution. Source: Senza Fili Consulting

equipment is 51% more expensive.[7] Overall in the base case, microwave PMP capex cost savings for Year 1 are 31% of microwave PTP capex and 47% of E-band PTP capex (Table 6).

The capex per RAN site is affected by the scenario (Figure 5), but the overall effect is smaller than the difference across technologies. Installation costs are the same across scenarios, because a comparable number of radios are involved. The number of terminals supported by an AP in the PMP case may change with changes in throughput for RAN sites, but the impact on the average RAN site is contained, because the change in the average number of radios per RAN site is small (Table 5). As a result, for microwave PMP the 3G capex is 17% less than the base case, and LTE small-cell capex is 16% less. For microwave PTP, the 3G capex is 9% less than for the base case, and the small-cell capex is 3% less. In the case of E-band PTP, the capex per RAN site is the same across scenarios because the E-band link with the lowest throughput (240 mbps) can support the backhaul requirements for all links in all scenarios. As a result, the equipment and installation requirements are the same across scenarios. For the same reason, the capex remains the same across scenarios for the leased fibre solution. Overall, in the 3G scenario, the capex in Year 1 for PMP is 39% lower than the capex for microwave PTP, and 56% lower than the capex for E-band PTP (Table 6). For small cells, the PMP capex is 40% lower than for microwave PTP, and 56% lower than E-band PTP.

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7. The higher equipment cost for E-band is only in part due to the higher individual radio costs for equipment for the same supported throughput. A substantial cost difference comes from the fact that E-band links support higher throughput than microwave PTP links, so operators using E-band PTP have to buy higher-capacity links than backhaul demands. Furthermore, we assume that all E-band links are single links, but double links (one link feeding to another to extend link distance) may be required in some instances, and this would of course effectively double the cost of the affected links.

While the capex per RAN site (Figure 5) remains largely unchanged across scenarios, the capex per mbps varies significantly (Figure 6). For all technologies considered, the per-mbps capex is the lowest for the base case, because this scenario has the highest throughput by far (240 mbps, compared to 60 mbps for the 3G scenario and 80 mbps for the small-cell scenario), and therefore it uses backhaul resources the most effectively (i.e., the backhaul throughput is higher for each link). As a result, backhaul in the 3G scenario is 233% more expensive using microwave PMP and 263% using microwave PTP. In the small-cell scenario, backhaul costs are 153% more expensive using microwave PMP and 192% when using microwave PTP. While the overall costs are higher in the 3G and small-cell scenarios across wireless solutions, the relative cost increase for PMP is lower, thus strengthening PMP position as the lowest capex wireless solution.

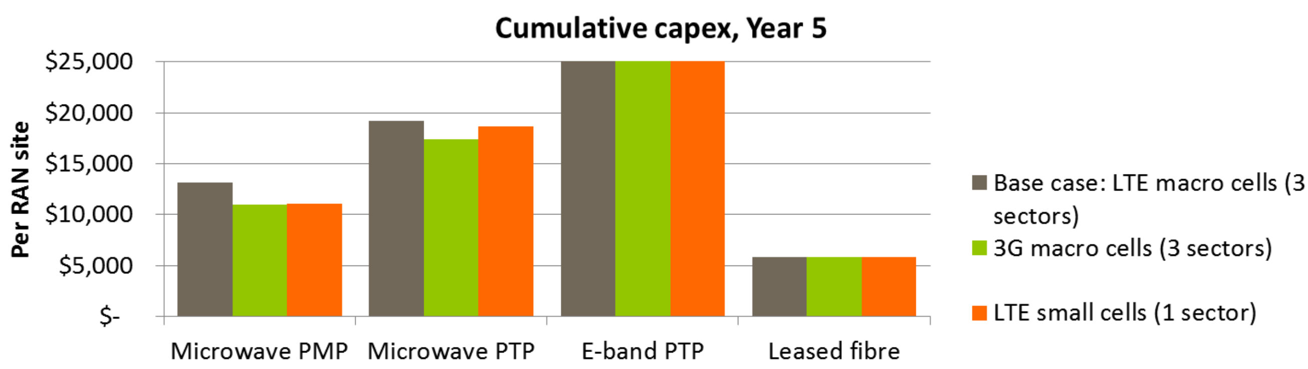

Figure 5. Year 5 cumulative capex per RAN site, comparison across scenarios. All capex, with the exception of maintenance replacements, is incurred in Year 1. Source: Senza Fili Consulting

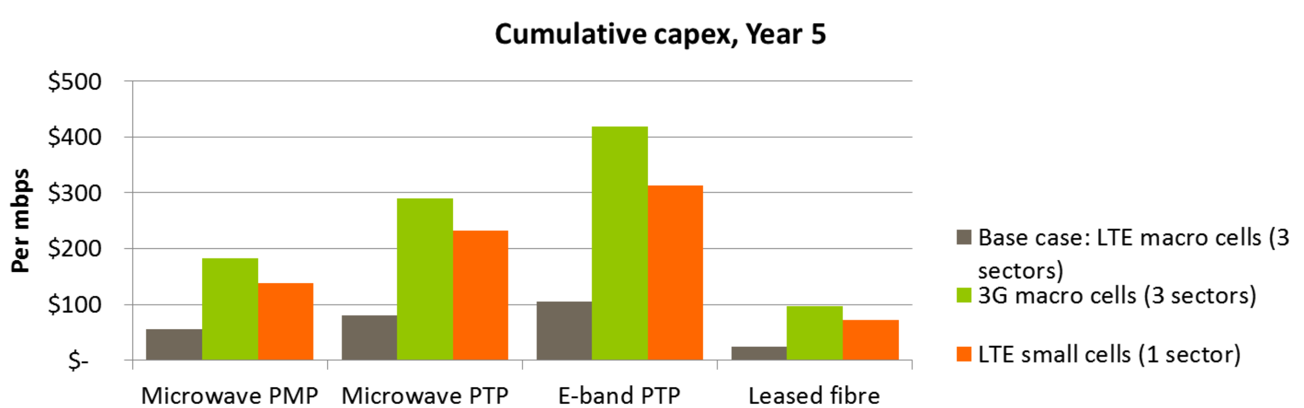

Figure 6. Year 5 cumulative capex per mbps, comparison across scenarios. Lower per-mbps cost for the base case scenario is due to the higher throughput per link or network hub. Source: Senza Fili Consulting

5. Opex

> **"With PMP, our savings range from 40% to 80% over PTP on spectrum alone"**
> ***African mobile operator***

The opex per RAN site presents a markedly different trade-off than the capex (Figure 7). The leased fibre option, assuming the operator is leasing from a third party and cannot secure below-market prices, is by far the most expensive. This counteracts the much lower initial capex expenditure.

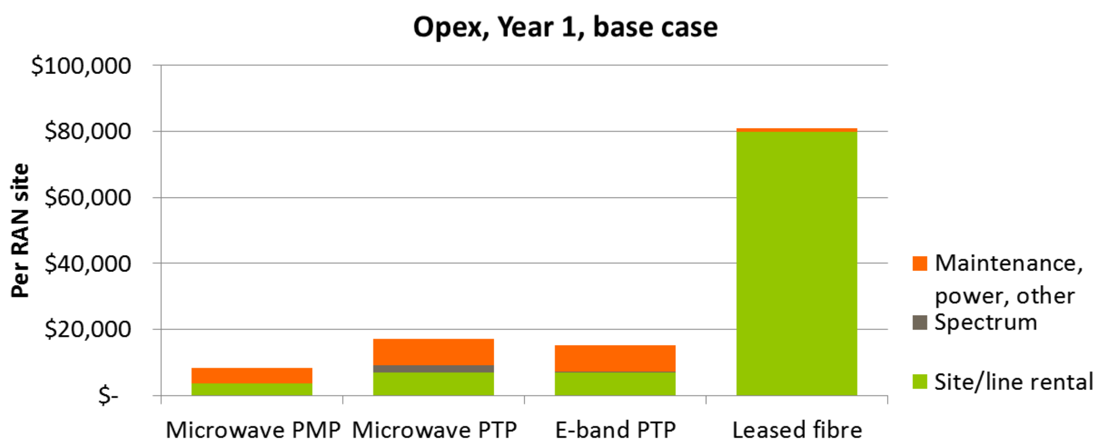

Figure 7. Year 1 opex for the base case. Source: Senza Fili Consulting

Among wireless technologies, microwave PMP is again the cheapest option, and E-band is second-cheapest. Two factors account for this: the smaller number of radios required for PMP and its lower spectrum costs. PMP's lighter demand for radios saves it 48% on site rental, compared to microwave and E-band PTP, and 42% on maintenance, power, and miscellaneous. The second factor making microwave PMP cheaper than microwave PTP is spectrum costs, which account for only 1% of its opex, compared with 12% of microwave PTP's opex. Spectrum costs vary widely across markets, but because spectrum costs account for such a small portion of the difference in opex across technologies, the wide variance across markets does not change the relative cost-effectiveness of different technology solutions. Overall, in the base case, microwave PMP opex is 53% lower than for microwave PTP's, and 47% lower than for E-band PTP (Table 7).

Opex across the wireless scenarios does not vary dramatically, (Figure 8), because most cost items (other than those just discussed) are the same for the different wireless technologies considered (e.g., power costs are the same for microwave PTP, microwave PMP, and E-band PTP). For microwave PMP, 3G opex is 14% less than the base case, and the opex of the LTE small-cell scenario is 11% less than in the base case. In microwave PTP, the 3G macro-cell scenario requires 4% less on opex and the LTE small-cell scenario 2% less than the base case does. In the E-band PTP case, opex is the same across all three

> **"Fibre is available everywhere in urban areas, but it takes a long time to set up the connections and the yearly rental is high. PMP allows us to reduce steeply our running costs"**
> ***Western Europe mobile operator***

scenarios, as was the capex. The big variation comes from leased fibre: the opex for the 3G macro-cell scenario is much lower than for LTE small cells and even the base case, because 3G's lower throughput requirements allow the operator to lease a cheaper circuit. Overall, in the 3G macro-cell scenario, PMP opex is 58% lower than for microwave PTP and 54% lower than for E-band PTP. For the small-cell scenario, PMP opex is 57% lower than for microwave PTP and 53% lower than for E-band PTP (Table 7).

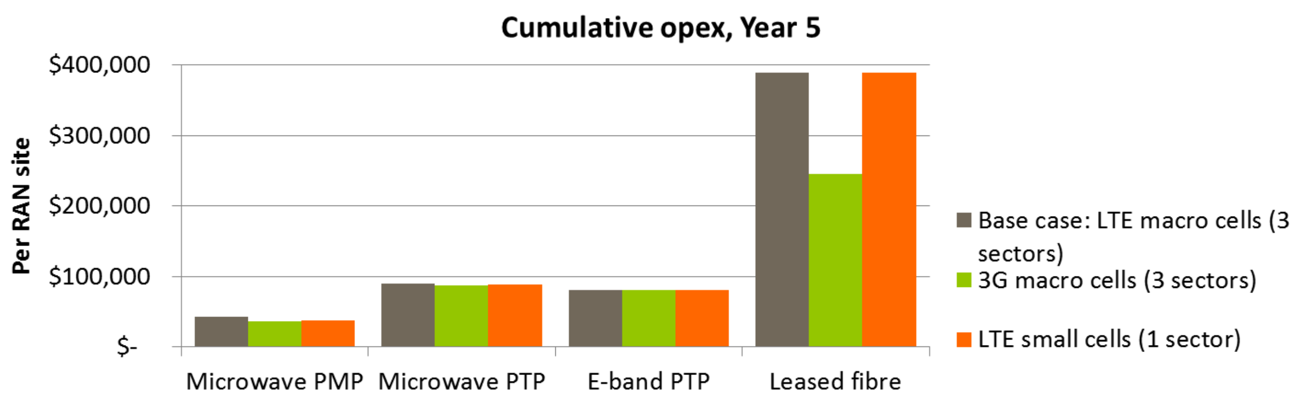

Figure 8. Year 5 cumulative opex per RAN site, comparison across scenarios. Source: Senza Fili Consulting

Opex, Year 5 – PMP cost savings over:	Microwave PTP	E-band PTP	Leased fibre
LTE macro cells (base case)	53%	47%	89%
3G macro cells	58%	54%	85%
LTE small cells	57%	53%	90%

Table 7. Microwave PMP opex cost savings over other solutions. Source: Senza Fili Consulting

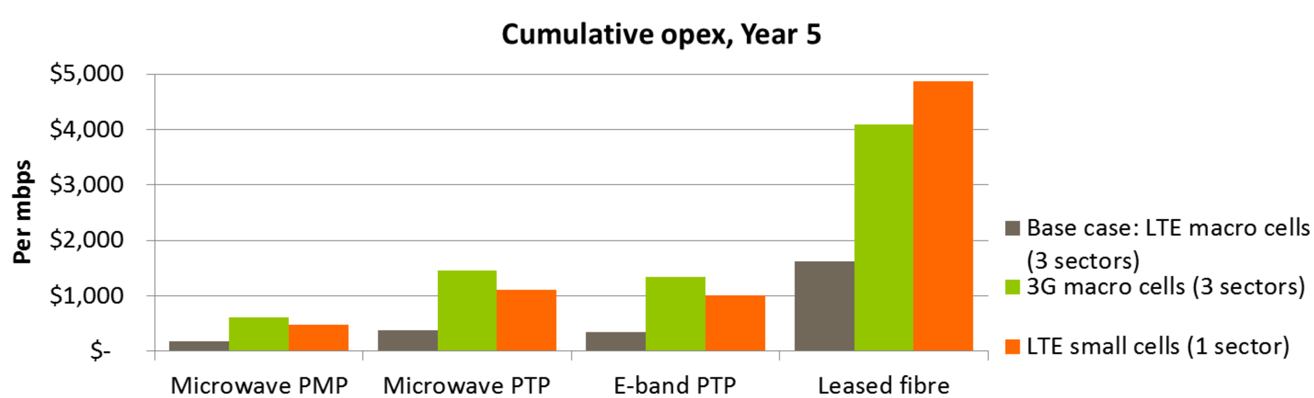

Figure 9. Year 5 cumulative opex per mbps, comparison across scenarios. Source: Senza Fili Consulting

As in the capex analysis, the per-mbps opex shows substantially lower costs for the base case scenario because of the higher throughput (Figure 9), with a steeper cost difference for microwave PTP than for microwave PMP. For microwave PTP, the per-mbps opex in the 3G macro-cell scenario is 285% higher than the base case, and in the LTE small-cell scenario, 194% higher. For microwave PMP, the differences from the base case are 245% in the 3G macro-cell scenario and 166% in the LTE small-cell scenario.

6. Implications

"PTP is on average three times as expensive as PMP on a per-mbps basis, if you take into account a five-year depreciation period, depending on the country. For instance, spectrum costs for PMP are 80% to 85% cheaper than for PTP. We expect the PMP deployment to be 35% to 45% cheaper than PTP."
African operator

The capex and opex analyses allowed us to identify the individual cost items across different solutions and scenarios (Table 8) that lead to a substantially lower combined capex and opex for microwave PMP compared to microwave PTP, E-band PTP, and leased fibre.

By combining the capex and opex contributions, we can now compare the overall value proposition of the solutions for the LTE macro-cell (base case), 3G macro-cell, and LTE small-cell scenarios. Capex accounts for a relatively small part of the TCO for cellular backhaul, ranging from 1% for leased fibre to 17% for microwave PTP and 24% for both microwave PMP and E-band PTP (Figure 10). By Year 5, the cumulative capex and opex are substantially lower for microwave PMP because of the lower number of radios required. Despite the fact that E-band PTP cumulative capex is 31% higher than microwave PTP, the E-band PTP opex is 11% lower due to the lower spectrum licensing fees, and, as a result, overall E-band PTP is 3% less expensive than microwave PTP.

Microwave PTP compared to:	Microwave PMP	E-band PTP	Leased fibre
Capex			
Equipment costs, outdoor	▼	▲	▼
Equipment costs, indoor	◀▶	◀▶	▼
Network planning, site acquisition, installation	▼	◀▶	▼
Opex			
Site rental fees, leased line fees	▼	◀▶	▲
Spectrum licensing fees	▼	▼	N/A
Other recurring operating costs	◀▶	◀▶	▼

▲ = higher cost than microwave PTP; ▼= lower cost than microwave PTP; ◀▶ = cost comparable to microwave PTP

Table 8. Capex and opex comparison across solutions. Source: Senza Fili Consulting

Overall, the cost savings for microwave PMP cumulative capex and opex in Year 5 are 49% over microwave PTP, 47% over E-band PTP, and 86% of leased fibre cumulative capex and opex (Table 9).

As noted above, the differences across scenarios are not as strong as those across solutions when looking at the costs per RAN site. Using microwave PMP in the 3G macro-cell scenario saves 14% on cumulative opex and capex compared with the LTE base case; using LTE small cells saves 12% (Figure 11). In the microwave PTP case, savings are 5% and 2% for the 3G macro cell and the LTE small cell scenarios, respectively. For E-band PTP, all three scenarios are the same because deployment is unchanged across scenarios. For leased fibre, the 3G scenario costs 36% less than the base case, reflecting the lower throughput requirement. For the 3G scenario, microwave PMP cumulative capex and opex costs savings are 54% over microwave PTP's, 55% over E-band's PTP, and 81% over leased fibre. In the small-cell scenario, the corresponding figures are 54% over microwave and E-band PTP and 84% over leased fibre (Table 9).

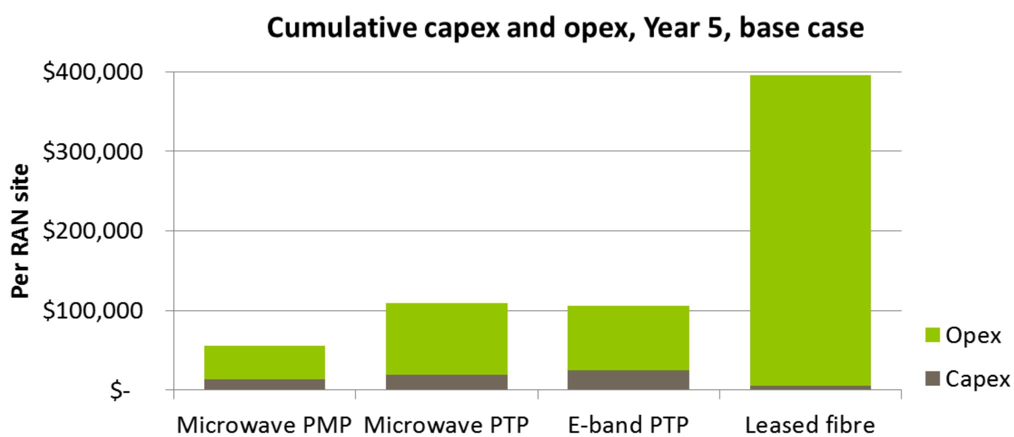

Figure 10. Year 5 cumulative capex and opex for base case. Source: Senza Fili Consulting

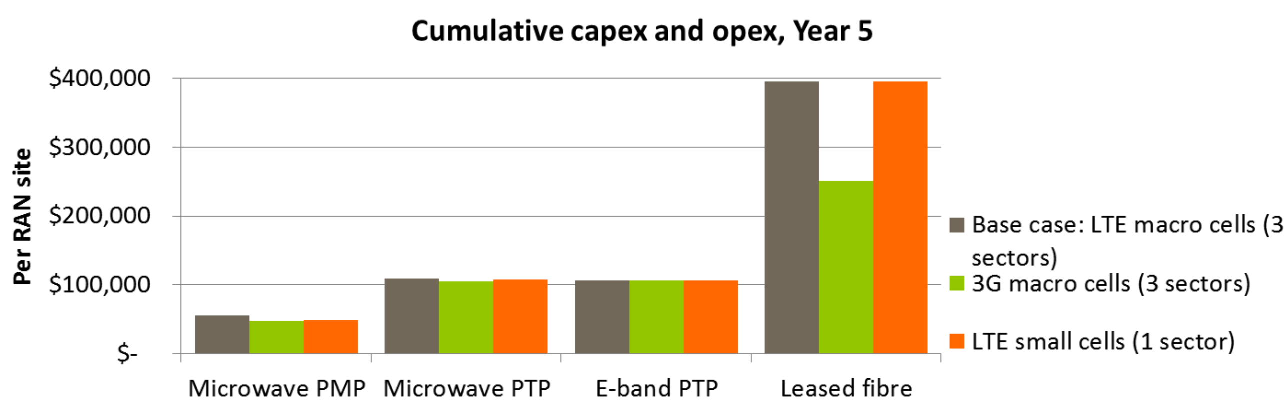

Figure 11. Year 5 cumulative capex and opex, comparison across scenarios. Source: Senza Fili Consulting

PMP's cumulative capex and opex, Year 5 – cost savings over:	Microwave PTP	E-band PTP	Leased fibre
LTE macro cells (base case)	49%	47%	86%
3G macro cells	54%	55%	81%
LTE small cells	54%	54%	88%

Table 9. Cost savings for PMP cumulative capex and opex as a percentage of cumulative capex and opex. Source: Senza Fili Consulting

The combined capex and opex computed on a per-mbps basis is greater for the 3G macro-cell and the LTE small-cell scenarios than for the base case (Figure 12) scenario across technologies, in line with what we observed for opex and capex separately. For microwave PMP, the combined cumulative capex and opex in the 3G macro-cell scenario is 242% higher than in the base case, and in the LTE small-cell scenario, 163% higher. For microwave PTP, the 3G macro-cell and the LTE small-cell scenarios require 281% and 194% additional spending, respectively, than the base case.

The higher per-mbps cost for the small-cell scenario calls to the attention a critical realization that is emerging as operators start planning small-cell deployments: the macro-cell backhaul solutions that dominate the market and that are at the core of our TCO model are not well-suited to meet the cost requirements for dense networks of cell sites with a lower throughput than macro cells. The results indicate that small-cell backhaul has to develop as a separate market with customized products to meet the mobile operators' specific requirements for small-cell deployments. They also strengthen the relative advantage of PMP backhaul: the lower equipment needs and throughput requirements of the PMP solution result in an even larger cost saving of PMP over microwave and E-band PTP solutions.

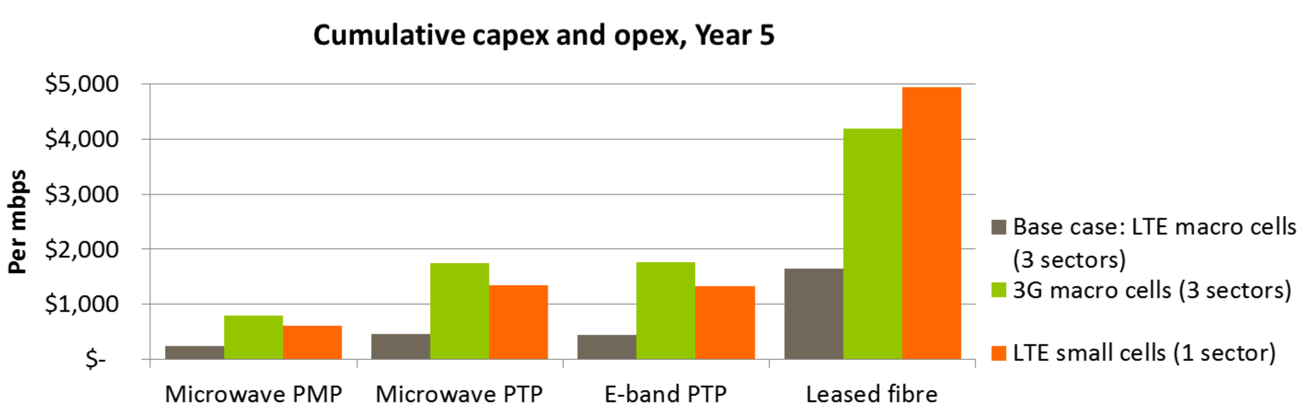

Figure 12. Year 5 cumulative capex and opex per mbps, comparison across scenarios. Source: Senza Fili Consulting

7. Conclusions

For a mobile operator, the choice of backhaul is a challenging one, because many factors have to be taken into account. Fibre and spectrum availability and cost are typically the main determinants. Base station density, building materials, construction density, weather, and labour costs all can have a strong impact on the choice. Our TCO analysis compares four technologies – microwave PTP, microwave PMP, E-band PTP, and leased fibre –, across three RAN scenarios – LTE macro cells, 3G macro cells, and LTE small cells.

Leased fibre requires little initial investment, but it has an onerous opex. As a result, it is by far the most expensive solution. Yet most high-capacity, high-utilisation macro-cell sites will eventually move to fibre because fibre is not subjected to the throughput limitations of wireless technologies. With the traffic levels supported today, mobile operators may benefit from adopting a wireless backhaul solution even in sites where fibre is available to serve their backhaul needs in the short to medium term. Our TCO model shows that within a five-year period, an operator is financially better off choosing a wireless backhaul solution over a leased fibre solution at nonsubsidized market prices.

Among wireless solutions, microwave PMP is by far the most cost effective, both for capex and opex. Two key factors drive the savings across scenarios. The first is the lower number of radios needed, as multiple terminals can feed traffic to one access point. The cost savings grow as the number of terminals that feed to an AP increases. This is demonstrated by the lower costs associated with the 3G macro-cell and LTE small-cell scenarios, in which more terminals per AP can be supported because the total RAN site throughput is lower. The lower number of radios means both lower capex (i.e., lower equipment and installation costs) and lower opex (i.e., fewer radios to operate and maintain). The result is robust in the face of changes in cost items, because most of them are the same across solutions – for example, the site rental fees are comparable for all microwave technologies.

The second cost-saving driver is the ability to leverage traffic aggregation gains to estimate the backhaul provisioning requirements more efficiently, which leads to a more efficient use of spectrum. Because traffic from different sectors is very bursty and uncorrelated, backhaul requirements can be computed on the basis of mean busy-hour traffic, rather than the higher peak traffic. While both PTP and PMP technologies benefit from aggregation gains, the impact on PMP is larger because lower throughput requirements result in fewer radios. In the microwave PTP and E-band PTP cases, the cost savings are driven by the use of lower-capacity, lower-cost links, but the number of links is unchanged.

Microwave PTP and E-band PTP backhaul present similar cost profiles, because the topology – and the number of radios deployed to meet the same backhaul requirements – is the same for both solutions. In an environment with long link distances, E-band stands at a disadvantage: it has a shorter reach, and more expensive multi-hop links may have to be deployed.

Microwave PTP is the most widely adopted solution, because in most markets, spectrum leases on a per-link basis make it a more convenient solution than microwave PMP, especially if it is deployed to provide backhaul only to a small portion of the cellular network. However, with the increase in cell density and the deployment of small-cell underlays, which will mostly rely on wireless backhaul, the simplicity of the PTP per-link licensing disappears because operators need to register for a high number of links. As a result, operators may prefer to obtain a nationwide or regional licence for microwave PMP that they can use everywhere within their assigned area and take advantage of the lower costs of PMP. In particular, in small-cell deployments characterised by a high density of base stations and an environment that is often inhospitable to telecom equipment, the reduction in the number of radios that PMP allows may bring, in addition to financial benefits, faster and more flexible deployments.

About Senza Fili

Senza Fili provides advisory support on wireless data technologies and services. At Senza Fili we have in-depth expertise in financial modelling, market forecasts and research, white paper preparation, business plan support, RFP preparation and management, due diligence, and training. Our client base is international and spans the entire value chain: clients include wireline, fixed wireless and mobile operators, enterprises and other vertical players, vendors, system integrators, investors, regulators, and industry associations.

We provide a bridge between technologies and services, helping our clients assess established and emerging technologies, leverage these technologies to support new or existing services, and build solid, profitable business models. Independent advice, a strong quantitative orientation, and an international perspective are the hallmarks of our work. For additional information, visit www.senzafiliconsulting.com or contact us at info@senzafiliconsulting.com or +1 425 657 4991.

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