Small Cell Wireless Backhaul Business Case

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Executive Summary

The deployment of small cell base stations has been challenged by a number of constraints, of which the cost of backhaul is among the most important. Without cost effective backhaul, it is too expensive to deploy small cells to address the growing demand for mobile data traffic which is being fueled by advances in mobile computing devices. In fact, the entire heterogeneous network architecture concept of multi-technology large and small cells working in unison to meet the throughput and performance metrics demanded by mobile subscribers will not be realized if the backhaul puzzle is not solved.

There are a number of backhaul solutions being proposed today for small cells. Most of these solutions are extensions to what is used on macro-cells: fiber and other wireline technologies, point-to-point line-of-sight microwave and millimeter wave technologies and point-to-multipoint microwave solutions. Such solutions have been used widely and successfully in macro-cell backhaul. They deliver the necessary performance and have proven to be reliable. However, when it comes to small cells, the question is that of scalability: do such solutions allow the operator to deploy the number of small cell base stations forecasted? What would be the total cost of small cell backhaul? And, if the cost is too high, what other solutions could provide lower cost?

We answer such questions in this white paper. We have included non-line-of-sight wireless backhaul in the comparative analysis and demonstrate that this solution provides the lowest total cost of ownership in comparison to traditional wireless backhaul techniques. We have identified key cost drivers for each solution such as spectrum, leasing expenses on poles and other such factors and analyzed their impact on the small cell backhaul business case. While non-line-of-sight wins on total cost, it is not a solution that is used today by wireless operators (with very few exceptions). Its design and deployment is fundamentally different from wireless backhaul solutions which are line-of-sight: their performance is highly predictable as opposed to the wider statistical performance variations of non-line-of-sight systems.

There has been little consensus in the wireless industry on the performance metrics of small cell backhaul. This white paper demonstrates that to achieve the low cost fundamental to small cell deployments, new technologies must be considered to enable a viable business case. Small cells have a unique function in the wireless network which by definition serves a small area. Whether it is for traffic offload of a macro-cell, augmentation of capacity, or extension of coverage, the function of a small cell can be viewed from a different perspective than a macro-cell. One of the purposes of this white paper is to stimulate the discussion on setting the priorities and objectives for small cell backhaul performance and help operators draft their strategy for deploying small cell base stations.

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Introduction

Backhaul is one of today's major impediments to the wide scale adoption and deployment of small cell base stations (SCBS). Small cell backhaul is a multifaceted problem but essentially one that boils down to the issue of cost. Without low cost backhaul, mobile network operators are severely restricted in deploying small cell base stations.

This white paper investigates different wireless backhaul techniques that include non-line-of-sight (NLOS) wireless backhaul, line-of-sight (LOS) point-to-point (PTP) microwave and millimeter wave backhaul and LOS point-to-multipoint (PMP) backhaul. The ten-year total cost of ownership is estimated for different deployment architectures. The numbers are analyzed to identify cost drivers and some key conclusions and insights are derived from the ensuing analysis.

Small Cells Defined

In this white paper, small cell base stations are defined as outdoor base stations mounted below the surrounding roofline. The base stations are typically of compact form factor, with zero-footprint enclosures that house baseband processing and the radio modules. The base stations are typically convection cooled and radiate over an omni-directional antenna, although at times for particular scenarios sectored or directional antennas are used. The power output typically varies between a low of 0.25 W and a high of 4-5 W per antenna port (two antenna ports for 4G/LTE systems and typically 1 transmit port for 3G/HSPA+ systems). The base stations are mounted relatively low above ground at a height of approximately 3-5 meters in urban areas (sometimes higher). Poles of different types (light poles, utility poles, etc.), building sidewalls and other light infrastructure assets are used for mounting. What is essential is that the base station antennas are well below the surrounding roofline.

The wireless industry has used different nomenclature used for small outdoor cells including micro, pico and public-access femto base stations, among others. Our definition encompasses all of these types of base stations and specifically excludes any base station deployed indoors (typically referred to as femto or residential femto).

Small cell base stations are deployed for different purposes that include but are not limited to the following:

1- Providing additional capacity at a high-traffic location (hot-spot).
2- Offloading traffic from a congested macro-cell.
3- Providing higher capacity and performance at the edge of a macro-cell.
4- Extending coverage at the edge of the network and into isolated areas.

For the purpose of this whitepaper, small cells typically fall within categories 1, 2, and 3 in urban and lightly urban (or suburban) environments. In other words, small cell deployments are required in an area of high subscriber density. This results in a relatively high density of small cells which can vary between a few to up to approximately 25 cells per square kilometer.

Capacity of Small Cells

The capacity of small cell base stations will vary depending on a number of factors that include technology (e.g. HSPA+, LTE), coverage footprint, subscriber density, the offered traffic and its type. Furthermore, other features play a part such as coordination between the macro cell layer and the small cell layer which increases average capacity by managing interference between the two layers, the number of antennas on the base station and subscriber station and the channel bandwidth. Additionally, there could be small cells that comprise multiple technologies. To illustrate, the peak capacity for different LTE profiles is shown in Figure 1 and Figure 2.

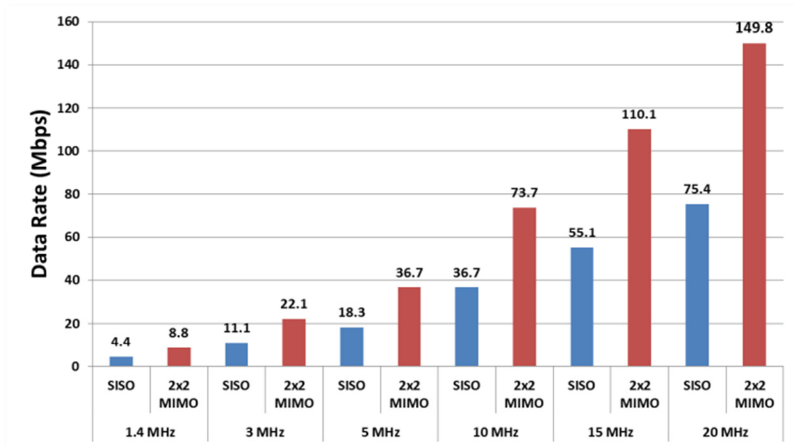

Figure 1 Peak throughput for Downlink LTE (2 Tx antennas, based on 3GPP TS 36.213).

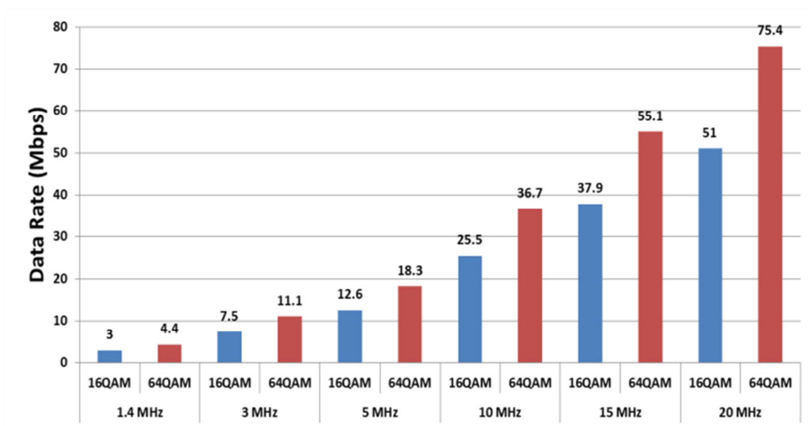

Figure 2 Peak throughput for Uplink LTE (1 Tx antenna, based on 3GPP TS 36.213). Only category 5 terminals will support 64QAM in the uplink.

For the purpose of this white paper, we base the capacity required according to Table 1 where the average capacity that is frequently encountered in practice for macro-cells is stated. In addition to the stated throughput, up to 20% of additional overhead can be added for base station control and management plane signaling to arrive at the total requirement for a backhaul link. Note that the peak throughput is the same on macro and small cells as this is a technology dependent figure while the average throughput results from the network architecture and deployment scenario among other factors (e.g. subscriber behavior & traffic type). We believe using such numbers for small cells is justified particularly as small cells would tend to have a lower average capacity than macro-cells, particularly in uncoordinated network architectures. This was verified by simulations as shown in Figure 3 where the average throughput of small cells can decrease as the density of small cells increases in a defined area due to interference (Note: this would particularly be the case for uncoordinated small cells as in HSPA and Release 8 LTE technologies). Additionally, the throughput of the small cell in comparison to that of the macro-cell depends to a large degree on the RF output power of the macro and small cell base station. The results presented in Figure 3 are for a macro cell RF output power of 40 W, while 1 and 5 W were used for the small cell base stations[1]. The inter-site (macro-cell) distance is 500 m, which is typical in urban areas (in very dense urban areas, the ISD can be lower).

Table 1 Peak and average data rate for HSPA and LTE technologies.

Air Interface	Peak Rate (Mbps)		Average Rate (Mbps)	
	Downlink	Uplink	Downlink	Uplink
HSPA+ (64QAM)	16	6	4.5	2
HSPA+ (MIMO)	21.6	6	4.4	2
HSPA+ (DC, 64QAM)	32	6	7	2
2x5 MHz LTE	36.7	12.6	8.9	3.6
2x10 MHz LTE	73.4	25.5	18	8
2x20 MHz LTE	149.8	51	37	16

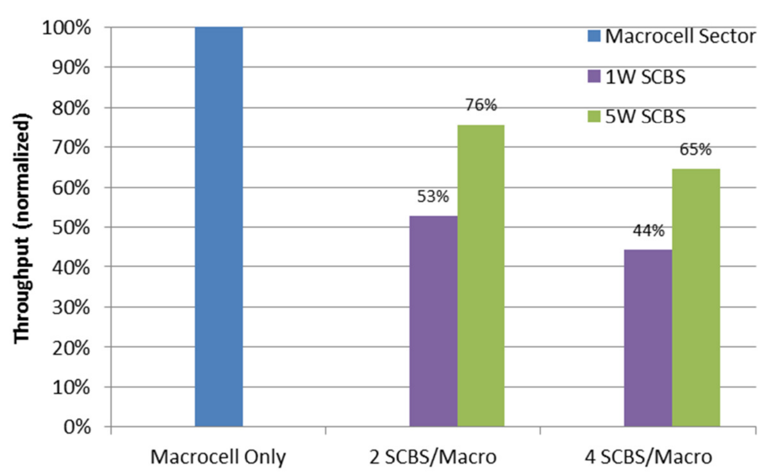

Figure 3 Average downlink throughput per base station in a network with two or four 1W and 5W small cell base stations per macrocell sector.

[1] The results are part of a more comprehensive study of small cell performance by Yuhan Zhou and Professor Wei Yu at the Department of Electrical Engineering, University of Toronto and sponsored in part by BLiNQ Networks.

Small cell base station capacity factors into the backhaul business case in multiple ways. First, for NLOS PMP backhaul, SCBS capacity will impact the number of multi-points (i.e. remote backhaul modules which are collocated with the small cell base stations and connected to a central hub location). For LOS PTP microwave, the capacity would impact the price of the link as vendors often offer higher capacity at additional cost. In all cases, the capacity would impact the amount of spectrum required for backhaul which also impacts cost.

Most PTP and PMP LOS systems would have sufficient capacity to carry single small cell traffic without additional option for enhanced capacity. For the case of NLOS backhaul, we consider the case of 2 and 4 multi-points per hub module as higher number or remotes may results in an oversubscription factor unacceptable to the average mobile network operator.

Description of Wireless Backhaul Options

Non-Line-of-Sight Wireless Backhaul

NLOS wireless backhaul systems are typically based on an OFDM (orthogonal frequency division multiplex) physical layer which is more tolerant to multipath fading than the single carrier physical layer used typically in line-of-sight systems. Many of the systems available on the market are based on TDD access mode with 10 or 20 MHz of channel bandwidth. They operate in the sub 6 GHz frequency spectrum to take advantage of favorable propagation characteristics.

NLOS backhaul systems typically operate in a point-to-multipoint configuration as shown in Figure 4 with a point-to-point configuration being a subset that can easily be supported. They are typically deployed with a hub module located at a relatively high elevation above ground, e.g. 30-40 meters. The hub module connects to the core network and hence it needs to be present where backhaul facilities to the core network are available. In this case, fiber or high capacity LOS microwave or millimeter wave solution is used. This can generally be an operator’s existing macro-cell site, but can be any other location where backhaul to the core network is readily available. Note that it is also possible to locate the hub module below the roofline, in which case the range of the NLOS hub module is reduced.

The hub module communicates with a number of remote backhaul modules (RBMs) wirelessly using a sectored wide-beam antenna similar to those used on macro-cells, although other type of antennas such as narrow-beamformers can be used as well (and in principle provide better frequency reuse performance). Multiple hubs can be deployed on a single site in a 3 or 4-sectored cellular configuration to provide backhaul to as many as 12 or 16 small cells, respectively, in case of a 1:4 PMP configuration. The remote backhaul module is deployed together with the small cell at a relatively low elevation above ground: typically 3-5 meters in an urban environment.

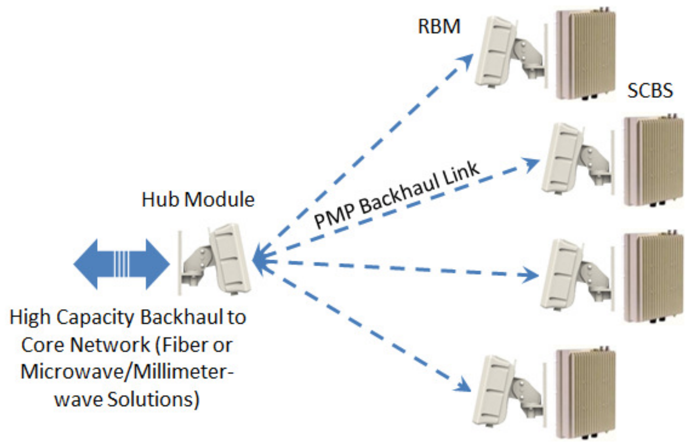

Figure 4 Point-to-multipoint NLOS Wireless Backhaul Deployment Configuration.

Point-to-Point Wireless Backhaul

Point-to-point wireless backhaul is extensively used for macro base stations especially where fiber is not available. These systems typically operate in the spectrum between 6 GHz and 80 GHz. They require line-of-sight connection between the two transceiver nodes which in practice is taken to be clearance from obstacles within 60% of the first Fresnel zone. This zone is smaller for higher frequency bands (consequently one may presume that it is more likely to achieve clearance in the higher spectrum bands).

The focus of this white paper will be on PTP microwave systems that operate typically between 18 – 42 GHz. Preference is given to higher bands for small cell applications as the size of the antenna would be smaller in addition to lower license costs in many countries which bodes well for the small cell backhaul business case. We will also consider 60 GHz millimeter wave solutions that operate in unlicensed bands as they have been promoted heavily as an option for small cell backhaul. An example of a PTP LOS link is shown in Figure 5. The main difference between microwave and millimeter wave solutions from a business case perspective is the cost of spectrum, cost of equipment and the difference in time on site for pointing and alignment. There are some practical aspects that could add significant cost which have not been included (e.g. sturdiness of poles in case of narrow-beamwidth millimeter wave backhaul).

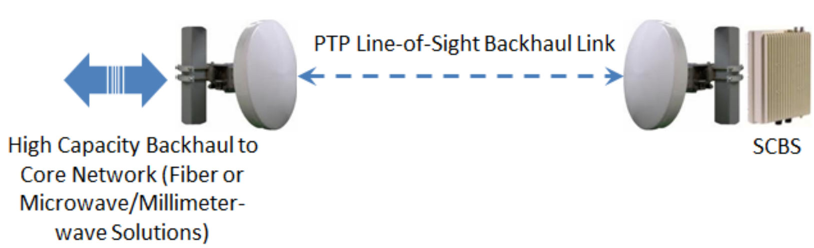

Figure 5 Point-to-point line-of-sight wireless backhaul link.

Because PTP microwave and millimeter wave systems require line-of-sight connectivity, it can be challenging to establish a connection between the small cell base station location and the transmission module located at an aggregation point connected to the core network. This is a very important issue that impacts the business case in a very pronounced way. For this reason, we will consider different scenarios where LOS connection is a variable.

When a LOS connection is not available in a single direct line (or 'shot'), we consider two options:

1- Hop scenario: this scenario, as shown in Figure 6, includes reaching the small cell base station through an intermediate location. Therefore, two links will be required in this case: one from the aggregation point to the 'hop' location and a second link from the 'hop' location to the small cell base station location. Consequently the cost will increase as site selection and acquisition will be required for the 'hop' nodes. Engineering and path planning will effectively double (at a minimum) along with other costs. The two links in this case can have the same capacity and can have the same equipment cost (if the same type of equipment is used).
2- Relay scenario: this scenario, as shown in Figure 7, includes reaching the small cell base station through a secondary location where a base station is also located. In this case, the link between the aggregation node and the first small cell would need to be of higher capacity than the second link.

Figure 6 Small cell base station connected to aggregation node through an intermediate node (Hop).

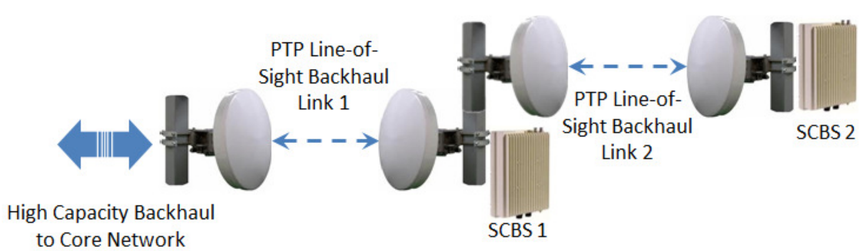

Figure 7 Small cell base station connected to aggregation node through an intermediate node that includes another small cell base station (Relay).

The availability of a clear line-of-sight between the aggregation node and the small cell base station will largely depend on the small cell location and deployment strategy of the mobile network operator.

Point-to-Multipoint Wireless Backhaul

Point-to-multipoint line-of-sight wireless backhaul is another technology that has been publicized as a solution for small cell wireless backhaul. This technology results in lower costs than PTP LOS microwave systems in many situations because of spectrum rules (regional block license versus per link license) as well as the lower number of modules at the aggregation point (imagine having 4, 5, or more different PTP LOS links aggregated on one site!). Therefore, in case most small cell locations are available through a first direct link, it would make sense to choose PMP LOS solutions over PTP LOS solutions. However, if a small cell cannot be reached with a first direct link, then a relay scenario would apply. In this case, PTP LOS microwave or millimeter wave system may be used.

For the purpose of this business case, we will look at a deployment using PMP LOS wireless backhaul coupled with a 60 GHz solution as shown in Figure 8. This scenario will involve the least amount of spectrum coordination and could be the most readily implementable.

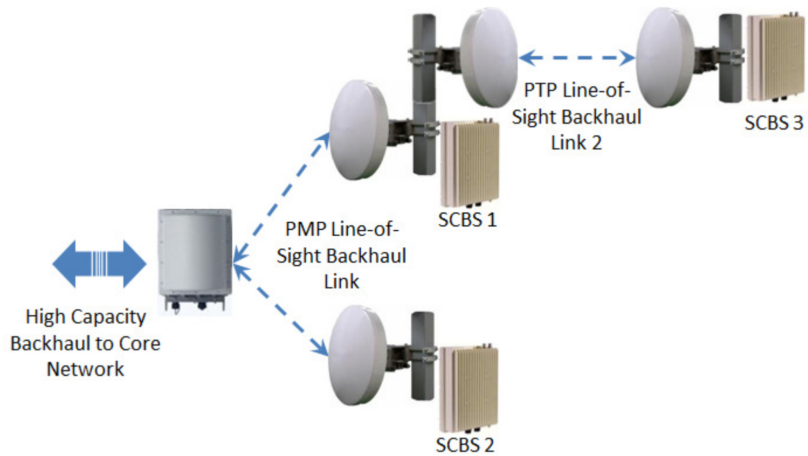

Figure 8 Point-to-multipoint line-of-sight wireless backhaul coupled with PTP LOS links for secondary small cell base stations.

The deployment scenarios presented above are typical of what has been proposed by the industry. There are some other variations which are based on this structure that we will touch upon in brief. For example, unlicensed band NLOS which typically operates at 5.8 GHz shares some commonality with NLOS backhaul in licensed bands; however, there are limitations due to unpredictable interference that will force a certain deployment scenario. For example, interference would tend to push the deployment of the unlicensed band hub module below the roofline which further limits range. In this case, it may be more plausible to assume a point to point deployment for unlicensed band products than a point to multipoint deployment which helps in reducing the effects of interference further by limiting the hub antenna azimuthal beamwidth. Another scenario involves E band solutions in the 70 and 80 GHz bands. Such solutions would have similar business cases to that of 60 GHz solutions with the addition of a nominal spectrum license fee. A comparison between the different types of backhaul solutions is presented in Table 2.

Table 2 Comparative summary of small cell wireless backhaul solutions.

Backhaul Type	Advantages	Disadvantages
NLOS Licensed Band (< 6 GHz)	• Simple to plan • Easy to deploy • Short installation time • Scalable business case (diminishing marginal cost per link)	• Statistical performance: lower reliability & capacity than LOS systems • Smaller channel bandwidth than LOS (e.g. 10/20/40 MHz) • Co-channel interference
'NLOS' Unlicensed Band (<6 GHz)	• Very low equipment cost • 'Free' spectrum	• Unpredictable level of interference results in unknown and widely varying backhaul link availability • Most systems are not true 'NLOS': support near-line-of-sight • Limited range • Unquantifiable performance (latency, jitter, throughput, etc.)
PTP Microwave	• High capacity (up to 2x56 MHz channels) • Low latency • High link availability (99.995%)	• Limited reach (LOS) • High frequency coordination • Longer planning & deployment cycle than NLOS • Low business case scalability (linear)
60 GHz	• Very capacity (Gbps speed) • Unlicensed spectrum: shorter total deployment cycle than microwave • Immunity to interference	• Limited reach (LOS) • Longer planning & deployment cycle than NLOS • Low business case scalability (linear)
PMP Line-of-sight	• Very low cost spectrum; block licensed • PMP configuration reduces cost	• Limited reach (LOS)
70/80 GHz	• Very capacity (Gbps speed) • Lightly licensed spectrum: shorter total deployment cycle than microwave	• Limited reach (LOS) • Longer planning & deployment cycle than NLOS • Low business case scalability (linear)

Spectrum for Wireless Backhaul

NLOS Backhaul Spectrum

NLOS wireless backhaul systems typically operate in licensed bands that were made available in abundance during the last 10 years for broadband wireless services. However, some consider the use of NLOS backhaul in unlicensed (e.g. 5.8 GHz) or lightly licensed bands (e.g. 3.65 GHz in the USA). For the purpose of the analysis in this white paper, we focus on licensed band backhaul which provides higher reliability and performance (better latency, jitter, spectral efficiency, etc.) than unlicensed band backhaul. The business case for unlicensed band solutions would be offset mainly by the cost of spectrum and some delta in the cost of equipment in favor of unlicensed band products, but would show some increase in the cost of planning and deployment due to unpredictability of performance at the deployment site due to interference which requires a site visit to quantify.

Figure 9 shows the main spectrum bands available for licensed bands wireless backhaul. It must be noted that there are some variations within these regions. For example, 3.5 GHz band has been licensed in Canada and is available for use in NLOS wireless backhaul applications.

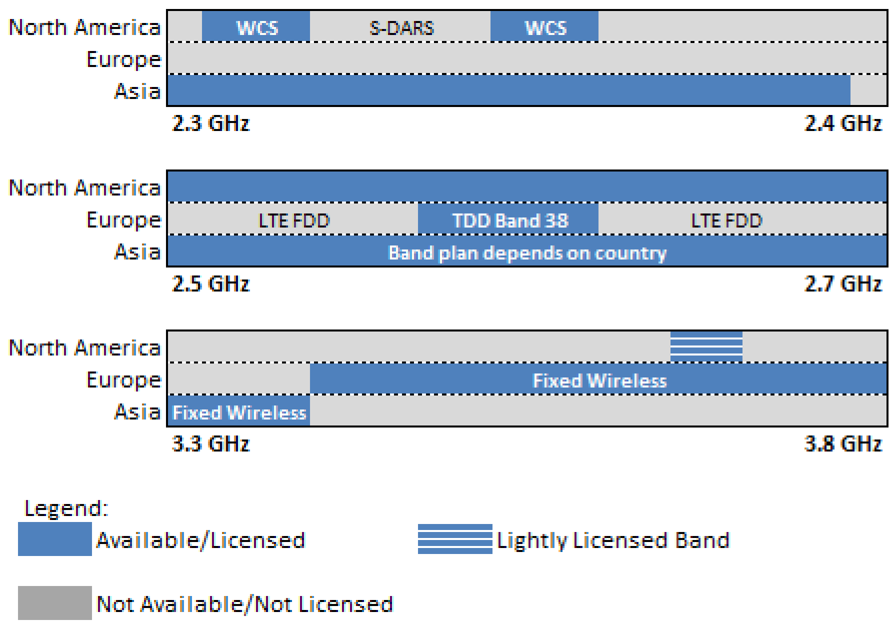

Figure 9 NLOS wireless backhaul spectrum bands.

Spectrum in the 2.3, 2.5 and 3.5 GHz bands is priced at a large discount compared to that of prime access spectrum (sub 1 GHz). This is shown in Table 3 for 3.x GHz license where the price is a fraction of a cent per MHz-PoP. In the 2.x GHz band, spectrum costs a few cents per MHz-PoP particularly in the TDD bands as shown in Table 4. (The FDD band pricing is included for comparison. It is commonly understood that most operators choose to deploy LTE systems in the FDD 2.5 GHz band). For comparison, recent auctions of the 800 MHz digital dividend band in Europe resulted in a range from €0.39 (Sweden) to €0.81 (Italy) per MHz-PoP while in the USA, Verizon spent $0.7 per MHz-PoP on 700 MHz band license, and AT&T paid $0.85 for the 700 MHz unpaired D and E bands.

Table 3 Sample pricing of 3.x GHz band spectrum.

Country	Band	Price of 10 MHz	Per MHz-PoP
Italy	3.5 GHz	€ 10,793,651	€ 0.0189
Germany	3.5 GHz	€ 4,325,397	€ 0.0053
UK	3.5 GHz	£1,750,000	£ 0.0030
UK	3.8 GHz	£744,048	£ 0.0012
Netherlands	3.5 GHz	€ 500,000	€ 0.0030
Switzerland	3.5 GHz	CHF 1,416,667	CHF 0.0178
Canada	3.5 GHz	$2,877,402	$ 0.0049

Table 4 Sample pricing of 2.x GHz band spectrum.

Country	Band	Price of 10 MHz	Per MHz-PoP
Sweden	2.5 GHz FDD	€ 14,867,475	€ 0.159
France	2.5 GHz FDD	€ 66,866,394	€ 0.106
Italy	2.5 GHz FDD	€ 35,996,667	€ 0.059
Belgium	2.5 GHz FDD	€ 5,025,455	€ 0.046
Belgium	2.5 GHz TDD	€ 5,002,222	€ 0.045
Italy	2.5 GHz TDD	€ 24,678,367	€ 0.041
Sweden	2.5 GHz TDD	€ 3,416,868	€ 0.037
Spain	2.5 GHz FDD	€ 12,334,753	€ 0.027
Germany	2.5 GHz FDD	€ 18,412,643	€ 0.023
Germany	2.5 GHz TDD	€ 17,303,600	€ 0.021
Netherlands	2.5 GHz FDD	€ 2,627,000	€ 0.0012
Canada WCS	2.3 GHz WCS	$ 6,136,598	$ 0.018

Line-of-Sight Spectrum

We break the review of LOS spectrum analysis into three subsections based on the systems included in the analysis:

Point-to-point Microwave Spectrum

PTP microwave systems typically operate in the range between 7 and 42 GHz over a channel bandwidth ranging between 7 and 56 MHz in FDD mode (frequency division duplex). There are different licensing schemes in different countries which factor in any of a number of variables that include in addition to the band of operation, the channel bandwidth, path length, availability and data rate (for example, Ofcom in the UK factors all of the above variables in determining the cost of license). Furthermore, the license fee can be annually recurrent (e.g. UK, Poland), or based on a one time set up fee that may include a modest recurring fee (e.g. US; in Germany, a modest fee is charged in addition to the one-time setup fee). Hence, the cost of microwave spectrum license will vary significantly depending on location and link characteristics.

In the case of small cell backhaul, it is expected that when PTP microwave systems are used, they will operate in the higher frequency bands which would have universally lower licensing fees than the lower bands. This is because in the higher bands, the antenna size would be smaller and more amenable to pole deployment (or in general, deployment at low elevation: one would expect greater public resistance to larger antennas mounted at low elevation!).

For the purpose of this white paper, we assume that the channel bandwidth does not need to exceed 2x28 MHz to meet the capacity requirements for a single small cell base station. However, should a number of small cell base stations need to be aggregated (e.g. relay or hop deployment scenarios), then an increase in the channel bandwidth may be required which increases the spectrum licensing fees. We also assume that the link availability required by the operator does not exceed 99.9% for the small cell. It may be desired to have higher link availability for the aggregated link in case a relay or hop is used. Increasing the availability would increase spectrum license fees in some countries.

In the United States, It is common to assume for business case purposes the price of PTP spectrum license per link at $2,500 for 10 years which includes frequency coordination and preliminary and final approval processes with the FCC. We base one scenario on this figure.

For business case calculations, we don't factor the lead time necessary to obtain a PTP license.

Table 5 Example of PTP Microwave Spectrum license fees.

UK: 24-33 GHz; 2x28 MHz; < 1 km; 99.9%	£897, annual
UK: 24-33 GHz; 2x28 MHz; < 1 km; 99.99%	£1281, annual
UK: 24-33 GHz; 2x14 MHz; < 1 km; 99.9%	£448, annual
UK: 24-33 GHz; 2x14 MHz; < 1 km; 99.99%	£641, annual
UK: 24-33 GHz; 2x7 MHz; < 1 km; 99.9%	£224, annual
Netherlands: 12-24 GHz; 7-28 MHz	€140-€220, annual
Netherlands: 24-39 GHz; 7-28 MHz	€90-€180, annual
Netherlands: >39 GHz; 7-28 MHz	€50-€75, annual
Germany: 18.7 GHz, 2x28 MHz	€1,070 one time + €50 annual

Point-to-point 60 GHz spectrum

The 60 GHz band is subject to high attenuation due to atmospheric absorption (Oxygen in particular) on the order of 20 dB per kilometer (in comparison atmospheric absorption at sub 6 GHz bands is negligible at under 0.01 dB per kilometer). For this reason, the 60 GHz band is unlicensed in many countries around the world where typically up to 7 GHz is available for use between 57 and 66 GHz. Therefore, we assign no spectrum cost to 60 GHz band solutions.

Point-to-multipoint spectrum

Point-to-multipoint line-of-sight systems typically operate in the 10.5, 26, 28, and 32 GHz bands. The prime bands will depend on the country, but in general it is acknowledged that 26 and 28 GHz are the prime bands considered in small cell backhaul applications. Spectrum in those bands is sold in blocks on a regional basis for a number of years (e.g. 15 years in the UK) similar to the case of sub-6 GHz licensed spectrum. Spectrum auctions in many countries for these bands resulted in limited interest and at times allocations remained unsold or their sale was delayed by as much as a few years. For example, in a 2008 auction in the UK, £250,000 was paid for two 2x112 MHz licenses in 28 GHz and £200,000 for two 2x112 MHz licenses in 32 GHz; both are nationwide licenses for 15-year terms.

Other Spectrum Considerations

Although we did not consider E-Band solutions (millimeter wave products in 70 and 80 GHz bands), the business case for these systems would match closely with that of 60 GHz spectrum plus the addition of a nominal spectrum license fee. For example, in the USA, the license fee for these bands is $75/link for a period of 10 years.

Assumptions

Key baseline assumptions for non-line-of-sight and line-of-sight wireless backhaul are presented in Table 6 and Table 7, respectively.

For NLOS spectrum, we base our scenario on $0.007 per MHz-PoP for 40 MHz of spectrum license of 15 years which is amortized for the 10-year period considered in the total cost of ownership (TCO) calculations. Since this is a fixed one-time cost, any difference is a net addition to the TCO.

For LOS spectrum we consider a baseline case with a fixed upfront fee of $2,500 (capex) and then make a comparison with the case of $200, $400, and $600 annual fee (opex).

NLOS systems require less planning and design, shorter site visits (if any) and quicker deployment and installation time. On the other hand, LOS systems require a detailed path profile, a longer design and planning cycle, a longer spectrum licensing process (for PTP microwave systems), and additionally longer installation time for precise alignment. Maintenance and support is taken to be slightly lower in NLOS systems than LOS systems as NLOS systems are less sensitive to alignment and to variations in landscape over a long period of time. This increases the likelihood of realignment in LOS systems. (In fact, urban development may result in blocking a LOS link and necessitate a path redesign. Such contingency is not factored into the financial model.)

The cost of leasing space on poles or building sidewalls is assumed to be the same in all cases.

Table 6 Key assumptions for NLOS wireless backhaul deployment scenario.

Capital Expenditure	$US
Hub Module	4,000
Remote Backhaul Module	2,000
Planning Services	225
Hub Module Deployment & Installation	270
Remote Module Deployment & Installation	140
Spectrum Expenses (million)	11.57
Operational Expenditure	**$US**
Power	31
Hub Module Site Lease Expenses	800
RBM Pole Lease Expenses	600
Maintenance & Support (% of ASP)	3%

Table 7 Key assumptions for line-of-sight wireless backhaul deployment scenarios.

Capital Expenditure	$US
PTP LOS Microwave ASP Per Link	6,000
60 GHz ASP Per Link	8,000
PMP LOS Access Point ASP	8,000
PMP LOS Remote Node ASP	3,000
Intermediate Node Site Acquisition Services	4,000
PTP Planning Services	525
PTP Deployment & Installation	1,200
PMP Deployment & Installation	780
Operational Expenditure	**$US**
Power	39
Building/Tower Lease Expenses	800
Pole Lease Expenses	600
Maintenance & Support (% of ASP)	5%
Spectrum Expenses	**$US**
PTP LOS Microwave Spectrum Expenses	2,500 (One-time, Capex) Or, 200/400/600 (Annual, Opex)
LOS PMP Microwave Spectrum License	150,000 (Capex)

Scenario Analysis

Based on the above key assumptions we calculate the 10-year total cost of ownership for a 3,000 small cell base station backhaul using the four main deployment scenarios described earlier: NLOS wireless backhaul, PTP LOS microwave, PTP 60 GHz band, and PMP LOS microwave coupled with 60 GHz band 'relays' as defined in this white paper above. We assume that the base stations were all deployed in the first year and none in following years.

Figure 10 shows the example of NLOS in 1:4 PMP configuration and for PTP LOS microwave with a one-time spectrum license setup fee of $2,500 per link. In this scenario, which we will call 'optimistic,' it is possible to reach 90% of the small cells using LOS solutions in one direct 'shot.' The remaining 10% are divided equally between hops (5%) and relays (5%) in the PTP LOS case, while in the PMP case the remaining 10% are over 60 GHz band relays only (no hops, hence, giving this deployment scenario a financial advantage). It is important to note that the PMP LOS/60 GHz combined solution represents a best case scenario for LOS technologies. This is because of the following:

1- Spectrum is priced as a block for PMP LOS and is available at very low price
2- 60 GHz band spectrum is unlicensed
3- Point-to-multipoint configuration reduces overall cost of ownership
4- The example assumes 60 GHz relays (as opposed to hops) to the PMP remote node

The combination of the factors above result in the lowest cost deployment using LOS technologies.

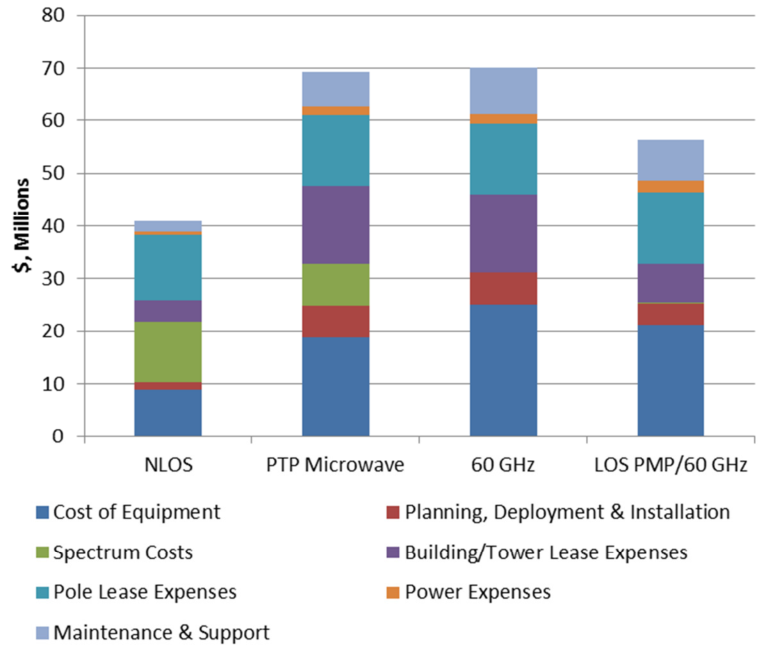

Figure 10 Scenario 1 'optimistic': ten-year total cost of ownership with 1:4 PMP NLOS and where 90% of small cells are reached through first LOS link.

To consider a 'pessimistic' scenario, we set the NLOS PMP ratio to 2 and decrease the percentage of small cells that can be reached through one first link to 20% in both the PTP and PMP LOS cases. The remaining 80% is divided as follows:

a. In PTP LOS: 40% through PTP relays and 40% through hops. (Note that hops require intermediate site acquisition and associated cost which are lumped into planning deployment & installation costs to simplify the presentation).
b. In PMP LOS: 80% through 60 GHz relays. Note that this scenario is very advantageous as relays preclude additional site acquisition costs and additional pole leasing expenses. We opted to present this case as otherwise the business case would approach that for a 60 GHz band solution only (the upper limit for the scenario).

This scenario is shown in Figure 11. It can be seen that the 10-year TCO for PTP LOS solutions quickly increases by over 20% due to the additional relay and hop links.

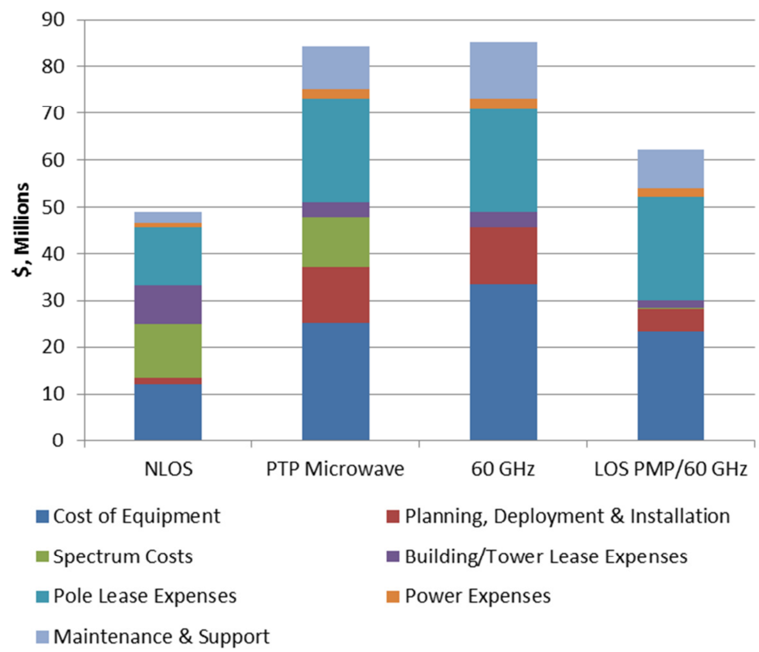

Figure 11 Scenario 2 'pessimistic': ten-year total cost of ownership with 1:2 PMP NLOS and where 20% of small cells reached through first LOS link.

In both scenarios above we assumed 1:2 ratio for PMP LOS microwave. This is because unlike NLOS backhaul where the PMP ratio is related to capacity and deployment architecture, in LOS case, this ratio is mainly driven by the ability to establish a line-of-sight connectivity with the small cell remote backhaul connection. Table 8 shows the average ten-year total cost of backhaul per small cell base station.

Table 8 Average ten-year total cost of backhaul per small cell base station.

Scenario	NLOS	PTP Microwave	60 GHz	LOS PMP/60 GHz
Optimistic	$13,607	$23,129	$23,351	$18,916
Pessimistic	$16,291	$28,090	$28,385	$20,628

The effects of different spectrum license fees and types for PTP microwave is shown in Figure 12 and Figure 13 for the optimistic and pessimistic scenarios, respectively. The average total cost of PTP backhaul per small cell base station over the ten-year period of the financial model is shown in Table 9 for different spectrum licensing fees.

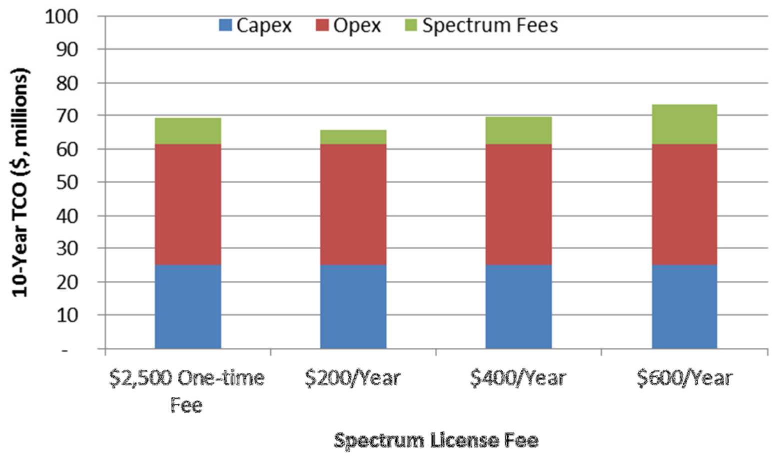

Figure 12 Ten-year TCO for PTP Microwave with different spectrum license fees (optimistic scenario).

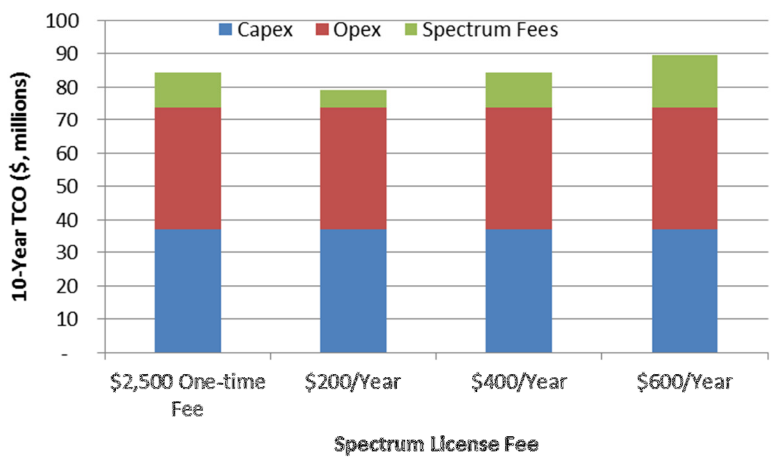

Figure 13 Ten-year TCO for PTP Microwave with different spectrum license fees (pessimistic scenario).

Table 9 Average total 10-year cost of PTP Microwave backhaul per small cell base station for different spectrum licensing fee scenarios.

Scenario	$2,500 One-time Fee	$200/Year	$400/Year	$600/Year
Optimistic	$23,129	$21,833	$23,162	$24,491
Pessimistic	$28,090	$26,362	$28,134	$29,905

Discussion of Results

The small cell financial model reveals a number of aspects that are critically important to minimizing the total cost of ownership of small cell backhaul as well as outlining the advantages and disadvantages of each type of backhaul solution. Some of the main issues are discussed below.

Spectrum Costs

NLOS Spectrum

Spectrum is one of the main cost drivers for NLOS particularly as it is a fixed cost paid at the start of the project. In the scenarios provided here, spectrum cost is about a quarter of the 10-year TCO. However, once the decision to deploy small cells in volume is made, NLOS spectrum would be amortized over an incrementally larger number of small cells resulting in a diminishing marginal cost per link. This is the opposite of PTP LOS microwave where spectrum cost is fixed on a per link basis and therefore would continue to increase linearly with every additional link.

In the 'optimistic' scenario where 90% of small cells are reached through one LOS PTP link, 864 small cells in 1:4 PMP or 1,090 small cells in 1:2 PMP NLOS configuration are required to achieve breakeven with the TCO for LOS PTP.

The deployment of about 1,000 small cells in a market justifies the acquisition of spectrum for NLOS wireless backhaul.

When it comes to NLOS spectrum, it's obviously desirable to use the lowest cost spectrum possible. Figure 14 shows the sensitivity of the cost of a single NLOS link to the cost of spectrum for the scenario of 3,000 small cells in 1:2 and 1:4 PMP configurations.

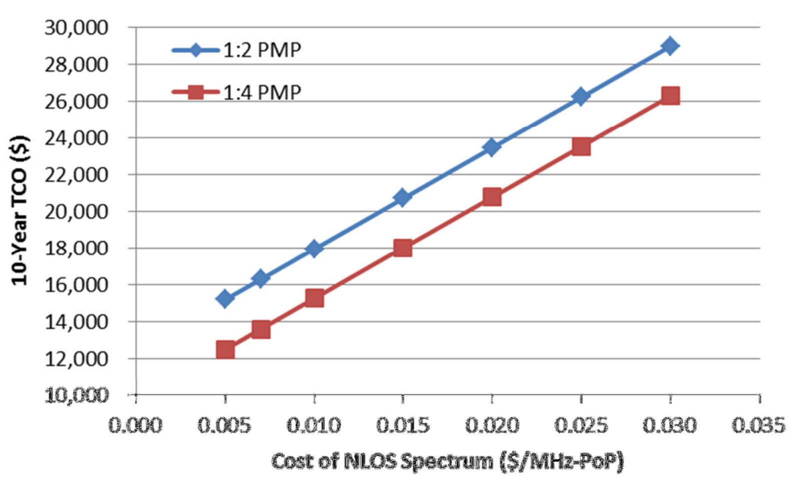

Figure 14 Sensitivity of 10-year TCO for a single NLOS link to price of spectrum.

To minimize spectrum cost in the initial stages of small cell backhaul network buildout, it is advantageous for a spectrum holder other than a mobile network operator to offer small cell backhaul as a service. This business model is highly scalable and would be very successful if one aggregates the need of 3-4 MNOs to deploy small cells in a single market.

NLOS Backhaul as a service is a highly scalable business model especially at the initial stage of small cell deployments given the number of MNOs vying to deploy small cells.

LOS Spectrum

There is large variability in the cost of LOS spectrum (one-time or annual fee subject to different parameters such as bandwidth, data rate, availability, etc.). In the scenarios we presented, we assumed a one-time fee of $2,500 for a 10 year license (about 11% of 10-Yr TCO) and compared results with the case where the license fee is $200, $400, and $600 on an annual basis. Here, we reiterate that the cost of LOS PTP spectrum license can grow easily when the license is annual as shown in Table 10 and Table 11 for the ‘optimistic’ and ‘pessimistic’ models, respectively.

Table 10 PTP LOS microwave spectrum license fees for 3000 small cells in the ‘optimistic’ deployment scenario (90% of small cells reachable with first link).

License Fee	10-Yr Cost ($)	% of 10-Yr TCO
$2,500, one-time	7,875,000	11% (Capex)
$250, annual	4,983,497	7% (Opex)
$1,000 annual	19,933,987	24% (Opex)

Table 11 PTP LOS microwave spectrum license fees for 3000 small cells in the ‘pessimistic’ deployment scenario (20% of small cells reachable with first link).

License Fee	10-Yr Cost ($)	% of 10-Yr TCO
$2,500, one-time	10,500,000	12% (Capex)
$250, annual	6,644,662	8% (Opex)
$1,000 annual	26,578,649	26% (Opex)

In short, spectrum license fees are a major handicap for scaling PTP LOS microwave in small cell applications. This is aside from the logistical complexity of deploying such a number of small cells in a short timeframe as two crews are typically required and the process is fairly time intensive (i.e. only one or two small cells can be deployed in a day – if small cells are to be deployed in quantity, the process must be well defined and short.)

PTP LOS microwave spectrum license fees limits the scalability of small cell deployment especially when the fees are annual and/or the number of small cells reachable with 1 direct link is limited.

Equipment & Configuration

Depending on the scenario and type of backhaul solution, equipment cost accounted between 22% and 38% of the 10-year TCO. For NLOS and LOS point-to-multipoint technologies, it is advantageous from a cost perspective to increase the PMP ratio. While this is a function of spectrum availability and deployment architecture (sectorization and frequency reuse plan) in the case of NLOS backhaul, it is mainly a function of link availability (Fresnel zone clearance) for PMP LOS systems.

PMP architecture also reduces the operational cost associated with leasing expenses on the hub module site. Table 12 shows the NLOS cost of backhaul in 1:1 through 1:4 PMP configurations. However, one additional (and very important) factor that further reduces the TCO for PMP is that of the cost of backhaul to the core network which would be reduced as multiple small cells are tied to the same aggregation point. This effect is not captured in this financial model.

Table 12 10-Year NLOS backhaul TCO of single small cell base station.

PMP Configuration	1:1	1:2	1:3	1:4
10-Year TCO	$21,661	$16,291	$14,502	$13,607

PMP Architecture reduces the TCO through lower equipment costs (capex), hub site lease expenses (opex) and lower cost of backhaul to the core network.

For LOS backhaul solutions, the ability to backhaul small cells over the first link, or in the absence of this, over a relay configuration rather than a hop is important to reducing the TCO. The absence of a direct first link in the pessimistic scenario increased the equipment capex over the optimistic scenario by $6.3m and $8.4m for PTP LOS microwave and 60 GHz band solutions, respectively.

While 60 GHz band solutions are license free, they have resulted in similar overall cost in the scenarios presented here. This is because the difference in link price with PTP microwave ($2,000) is close to the LOS microwave spectrum license fee. For 60 GHz solutions to be competitive on the market, it is necessary that their cost per link be substantially lower than what is commonly encountered on the market today and in particular should be no greater than the combined cost of PTP LOS microwave and its spectrum licensing fees.

60 GHz millimeter wave solutions need to achieve a lower cost per link than the combined cost of a microwave link and its spectrum license fee to be competitive.

Pole Lease Expenses

The financial model assumes that pole mounting expenses on a per module basis are $50/month, or $600 per year. However, there are markets where this number is far exceeded in which case it would have a very negative effect on the overall business case of small cells. Pole mounting expenses are a major cost driver of the TCO and account anywhere between 19-36% of the TCO. This expense is larger in the case of microwave and 60 GHz band solutions especially when no direct first link is possible to the small cell base station. Relays and Hops require 2 PTP units be installed on a pole. This results in a large expenditure over the course of the deployment lifecycle. The pessimistic scenario results in a 64% increase in pole leasing expenses from $13.5m to $22m.

One way to reduce pole mounting expenses is to integrate the backhaul and small cell base station into a single module. This model fits NLOS backhaul well: NLOS backhaul uses a directional antenna that has a relatively large degree of freedom in comparison to LOS backhaul antennas (wider azimuthal and elevation plane patterns) which allow greater flexibility in pointing and deployment – aspects that become more problematic when LOS systems are integrated with the small cell base station. Furthermore, integration saves some of the equipment cost (depending on the extent and type of integration) by as much as 30% over the combined cost of base station and backhaul. This works well to heavily favor NLOS backhaul in any sizeable small cell deployment.

Scalability of Small Cell Deployments

NLOS wireless backhaul is unique in that it scales better for larger volumes of deployed small cells. Figure 15 shows the declining cost of NLOS wireless backhaul as additional small cell base stations are deployed. In this case, we used similar parameters to the 'optimistic' scenario. The base stations were deployed over the first three years of the financial model. While LOS technologies provide a linear increase in cost as the number of deployed base stations rises (as demonstrated by maintaining the same cost per link shown below), NLOS cost per small cell declines by 60% between 750 and 9,000 deployed small cells.

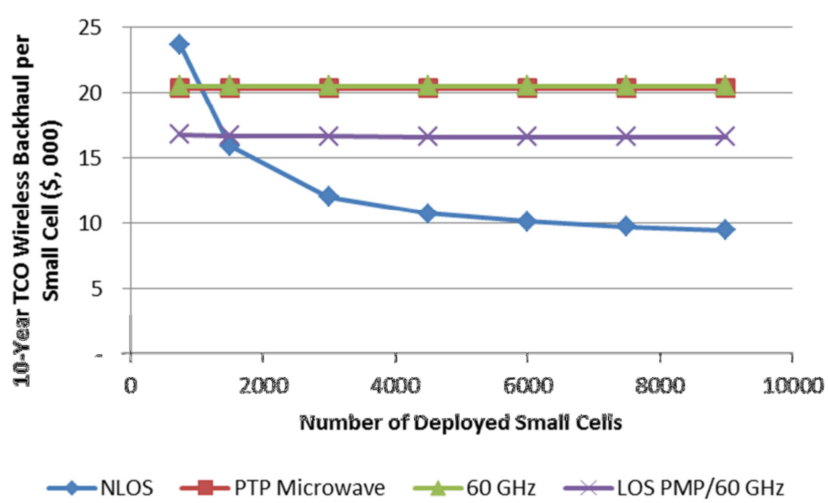

Figure 15 Cost of wireless backhaul per small cell using the parameters of the 'optimistic' scenario.

The NLOS scalability captured in the above example mainly relies on amortizing the cost of spectrum over a greater number of links. However, as we assumed that the PMP ratio is maintained at 1:2, there is potential for even higher reduction in the cost per link if the PMP ratio is increased. This is very practical since one can anticipate that the operator will deploy a hub module first in 1:1 or 1:2 configuration and grow that proportion as more small cells are deployed within the coverage area of the hub module.

Additional Considerations

There are many aspects and subtleties that are difficult to capture in a financial model which can have a large impact on the business case. For example:

1- It may not be practical to deploy several PTP LOS microwave links at a single point of presence of backhaul to the core network for different reasons (aesthetics, municipal permits, etc.).
2- It may not be possible to deploy three modules on a pole as in the case of PTP LOS backhaul relays where two PTP modules in addition to a small cell base station are mounted onto a pole.
3- It may not be practical to deploy a large number of small cells in a certain timeframe especially when the backhaul deployment cycle is lengthy as is the case with LOS solutions.

Such issues are bound to impact the operator’s small cell deployment strategy including the choice of backhaul solution.

Conclusion

Cost effective backhaul is critical for scalable small cell deployments. The financial model for small cell backhaul demonstrates how quickly the cost of backhaul can increase and add up to make small cell base station deployments prohibitively expensive. Therefore, a new technique is required that can allow the scalability of small cell deployments. NLOS wireless backhaul is one such technique because it is inherently scalable due to its main characteristics: block spectrum pricing, point to multipoint configuration, ease of deployment and installation. Additionally, NLOS wireless backhaul is more suited than other wireless backhaul solutions for integration with the small cell base station. The result is diminishing marginal cost per link which allows small cell base station deployments to scale.

Acronyms

FCC	Federal Communications Commission (USA)	PMP	Point to Multipoint
FDD	Frequency Division Duplex	PTP	Point to Point
HSPA	High Speed Packet Access	QAM	Quadrature Amplitude Modulation
LOS	Line-of-Sight	RBM	Remote Backhaul Module
LTE	Long Term Evolution	SCBS	Small Cell Base Station
MIMO	Multiple Input Multiple Output	TCO	Total Cost of Ownership
NLOS	None Line-of-Sight	TDD	Time Division Duplex

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BLiNQ Networks was founded in June 2010 after the acquisition of intellectual property and wireless assets from Nortel Networks. BLiNQ is a pioneer of wireless backhaul solutions that fundamentally change the way mobile operators deliver mobile broadband services in urban areas. BLiNQ uses cost-effective sub-6 GHz spectrum and unique and patent-pending Managed Adaptive Resource Allocation (MARA) technology to provide network-level intelligence, self-organizing network capabilities, and eliminate interference challenges to maximize spectral efficiency. BLiNQ is headquartered in Plano, TX with research and development facilities in Ottawa, Canada. For more information, please visit www.blinqnetworks.com.

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