Fixed Wireless Access in Cable Operator Context

A performance and spend analysis

A Technical Paper prepared for SCTE•ISBE by

Frank Rayal

Partner

XONA Partners

2969 Sable Ridge Dr. Ottawa, ON K1T 3S3

+1-613-600-4400

frank@xonpartners.com

Dr. Sudheer Dharanikota

Managing Director

Duke Tech Solutions Inc.

111 Fieldbrook Ct. Cary, NC 27519

+1-919-961-6175

sudheer@duketechsolutions.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Introduction

5G extends operating frequencies into the millimeter wave (mmWave) bands to enable high-bandwidth services. Mobile network operators (MNOs) with existing infrastructure would have a quick low-cost path to leverage 5G for fixed wireless access (FWA). In contrast, fiber-based access services require higher capex and longer planning that could make FWA more suitable for certain deployments.

In this paper, we set out to compare the performance and cost of deploying fixed wireless access in millimeter waves at 28 GHz to Fiber To The Home (FTTH) deployments. Our objective is to uncover the subtleties of both technologies and identify how they compare. We do this for a specific suburban environment as most of the interest in millimeter wave FWA today focuses on this market. Since in today's market structure, a service provider could operate both wireless and fiber networks, we believe that they would benefit from the key findings of this paper.

2. Different wireline and wireless access technology evolution

Access network capability is essential for the operator to offer different services to the consumers and compete effectively. As shown in Figure 1, Telcos, Cable Operators and Wireless providers have been

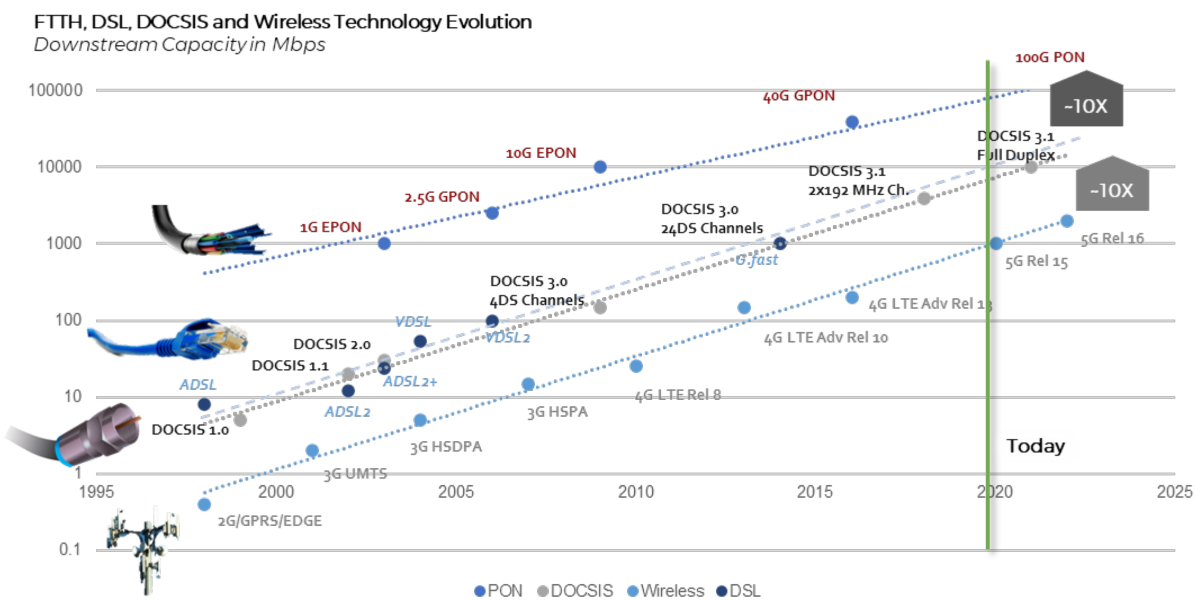


Figure 1 Evolution of Fiber, DOCSIS, DSL and Wireless based access technologies

working diligently to improve their access technology capabilities [1]. From raw technology capacity point of view PON technologies typically offer 10x more than DSL or DOCSIS technologies and 100x more than the wireless technologies. Not considering the costs and deployment considerations yet, Table 1 presents typical average sellable bandwidth per subscriber and maximum distance to the customer from the node (or the antenna). We can observe XGSPON (10 Gbps Passive Optical Network) based FTTH solution offers the highest per sub bandwidth and the longest distance to the end of line from the node. For additional analysis on different access technologies and the transformational strategies refer to [2].

With this high-level understanding of the capabilities, in the rest of the paper we will get into a detailed analysis of FWA solutions and compare them to FTTH-based solutions.

Table 1 Average sellable bandwidth per sub and maximum distance to the customer calculation per access technology

Category	Fixed Wireless	DOCSIS	Fiber To The Home
Technology	MmWave	DOCSIS 3.1 with High split	XGSPON
Spectrum block (Downlink/Uplink)	400 MHz	3 x 192 MHz/ 200 MHz	NA
QAM (Downlink/Uplink)	64/16	256/64	NA
Peak capacity (Downlink/Uplink)	2.8 Gbps/0.34 Gbps	4.5 Gbps/1.3 Gbps	10 Gbps/10 Gbps
Non-Overhead	100%*	88%	90%
Oversubscription	20	20	20
Maximum subs (assuming 100% take rate)	200**	600	32
Avg. sellable bandwidth per sub* (Downlink/Uplink)**	**142 Mbps/23 Mbps**	**132 Mbps/38 Mbps**	**5.6 Gbps/5.6 Gbps**
Maximum distance to the customer	**400 Meters**	**~5 Km**	**20 Km**

(*) Overhead is already considered in the capacity calculation for 2 MIMO layers
(**) A maximum of 200 homes covered per sector is considered in this analysis
(***) Average sellable bandwidth per sub = Capacity * Non-Overhead * Over subscription /Maximum subs

3. Fixed Wireless Access deloyment considerations

Wireless signals are prone to different type of losses which we review first before addressing the range and capacity performance. Propagation losses and impairments are a function of the deployment scenario. They affect the design of the equipment and its performance. Consequently, propagation losses and impairments directly impact the outcome of the business case.

3.1. Millimeter Wave propagation impairments

We focus the review of mmWave signal impairments on the 28 GHz band which is the focus of our study. Here, and in the rest of the paper, we use mmWave to imply this frequency.

Material penetration: Millimeter waves suffer from high material penetration losses that make it impractical to provide outdoor-to-indoor service. Penetration losses vary according to the type of material and thickness. Concrete and infrared reflective (IRR) glass stand out in particular as major obstacles to mmWave propagation with about 117 dB and 31 dB at 28 GHz, respectively [3].

Table 2 Penetration loss in different types of materials

Material	Equation (f is in GHz)	Penetration Loss at 28 GHz (dB)
Standard multi-pane glass	$2+0.2*f$	7.6
IRR glass	$23+0.3*f$	31.4
Concrete	$5+4*f$	117
Wood	$4.85+0.12*f$	8.21

Foliage attenuation: Millimeter waves are susceptible to attenuation through foliage. The depth of vegetation is particularly important to range calculations in suburban and rural areas. The ITU-R model estimates foliage attenuation for distances under 400 m, which are typical of FWA, at around 17 dB for 10 m of foliage depth at 28 GHz [4]. For comparison, this is 8 dB higher than the loss at 3.5 GHz as shown in Figure 2.

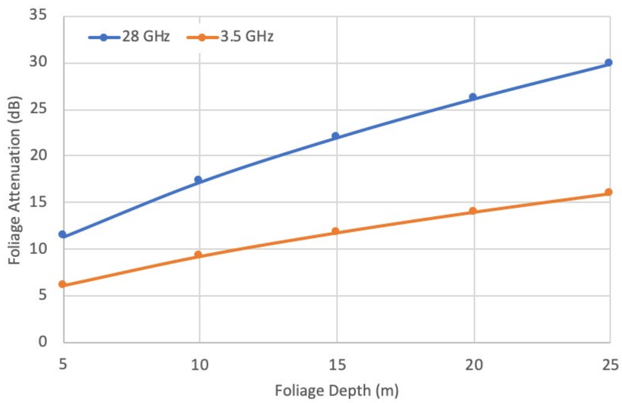


Figure 2 Comparison of foliage loss at 3.5 and 28 GHz

Atmospheric attenuation and rain fades: Atmospheric attenuation from oxygen absorption and water vapor at 28 GHz accounts for a fraction of a dB in FWA applications due to the short range of service. Rain subjects 28 GHz mmWave signals to fading, which is relatively small unless in heavy rain conditions. In this case, attenuation in heavy rain (50 mm / hour) would be about 2 dB for a range of 400 m [5].

Propagation impairments: Wireless signals undergo specular reflection, diffraction and diffusion scattering - behavior that depend on the type and size of surface. Millimeter wave signals have rich diffusion scattering behavior that scatters power in different directions. They are also more prone to diffraction loss than reflection due to their short wavelength.

These behaviors are important to note since they impact the design and performance of equipment. For instance, to overcome path loss impairments, beamforming is used to concentrate power in horizontal and vertical planes. This would leverage any line-of-sight (LOS) component, but limited number of multipath components as may fall within the beam range. Beamforming is effective in environments where the angular spread is low, especially where the desired and interference signals are not incident from the same angle.

In summary, foliage and material penetration losses are the most serious impediments to mmWave propagation. Next, we characterize the coverage distance provided by commercial equipment.

3.2. Range performance

We devised a representative link budget for mmWave system combining best of breed features in the equipment to arrive at representative, yet somewhat optimistic evaluation of performance. For instance, we opted to maximize both the transmit RF power of the base station and user customer premise equipment (CPE). In a real deployment scenario, other considerations may not result in such a choice, leading to shorter coverage.

Table 3 Link budget for a mmWave FWA deployment

General parameters	Downlink	Uplink	Unit
Bandwidth per carrier	100	100	MHz
Occupied channel bandwidth	95.04	95.04	MHz
Carriers	4	4	
Total bandwidth	400	400	MHz
PRB per carrier	66	66	
Transmitter parameters			
Tx Power (all carriers)	32	20	dBm
Tx antenna gain	28	19	dB

EiRP	60	39	dBm
EiRP per carrier	54	33	dBm
Receiver parameters			
Thermal noise density	-174	-174	dBm/Hz
Receiver noise figure	7	6	dB
Effective noise power	-87.2	-88.2	dBm
Modulation & coding scheme	QPSK	QPSK	
SNR	-0.9	-0.9	dB
Receiver sensitivity	-88.1	-89.1	dBm
Rx antenna gain	19	28	dB
Rx power	-107	-117	dBm
Path loss	167.1	156.1	dB
Margins			
Implementation margin	2	2	dB
Interference margin	6	2.5	dB
Lognormal fading	10	10	dB
MAPL - Outdoor	149.1	141.6	dB

The link budget reflects the configuration parameters used in typical solutions deployed in the United States, primarily, up to 60 dBm effective isotropic radiated power (EiRP) for the base station, a 400 MHz channel bandwidth consisting of 4x100 MHz carrier aggregation; and beamforming and multiple-input multiple-output (MIMO) antenna capability. The resulting maximum allowable path loss (MAPL) is 141 dB limited by the uplink path. Note this value is for outdoor CPE as it excludes any penetration losses.

To estimate the coverage range, we used the non-line-of-sight (NLOS) Macrocell Urban Area model (Uma) as defined by 3GPP TR 38.901 [1]. This model fixes the base station height at h_{BS} = 25 m. We chose to place the CPE at h_{UT} = 5 m, which is typically used in FWA applications. The resulting range is 389 m for an outdoor CPE as shown in Figure 3. The range is shorter for an indoor installation subject to glass attenuation loss, since practically anything other than clear glass will eliminate service.

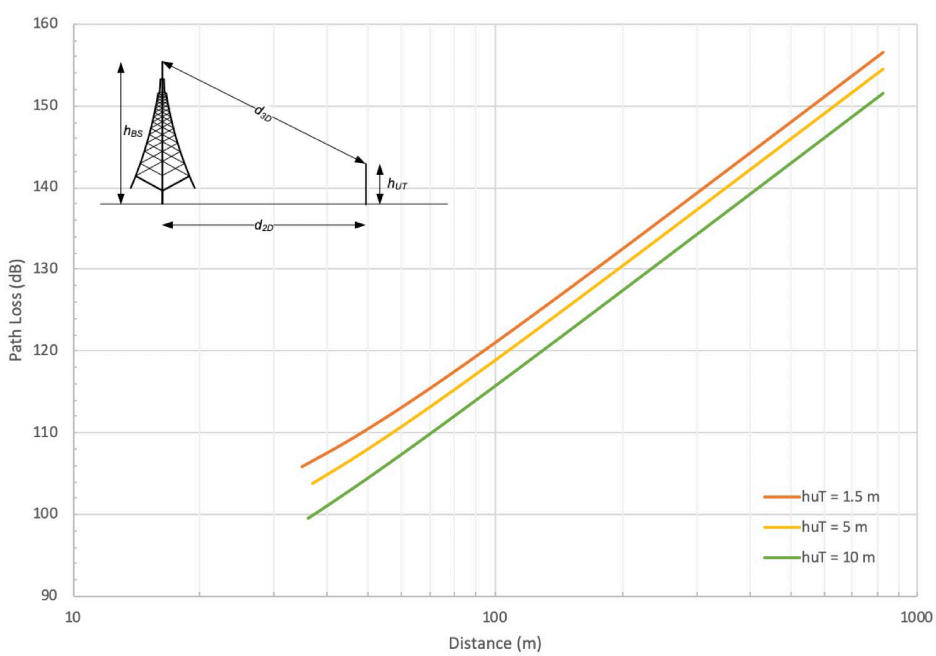


Figure 3 Path loss for millimeter wave signals at 28 GHz using macrocell Urban Area Model (UAM)

3.3. Capacity performance

We calculate the peak throughput of the channel as defined in [6]. The peak throughput will depend on the peak modulation scheme which is 64QAM in the downlink (DL) and 16QAM in the uplink (UL) typically supported in commercially available terminals. This results in 2,771 Mbps and 338 Mbps for the downlink and uplink, respectively, for two MIMO layers, as shown in Table 4. In this calculation, we used Frame Structure 31 which has 11 downlink slots, 2 uplink slots and 1 flexible slot that could be allocated to either the downlink or the uplink. This frame structure results in 6:1 *DL:UL* traffic ratio typically used in FWA applications. We also calculated the average throughput based on uniform user distribution to be a total of 1650 Mbps for two MIMO layers.

Table 4 Throughput characteristics of mmWave FWA

	Downlink	Uplink	Unit
Data rate (2 MIMO layers)	2771	338	Mbps
Total peak data rate	3108		Mbps
Average data rate	1650		Mbps
Spectral Efficiency	6.93	0.84	b/s/Hz
Traffic percentage	86%	14%	
Traffic ratio	6	1	

Backhaul requirements: We dimensioned the backhaul capacity $T_{backhaul}$ for each cell according to:

$$T_{backhaul} = Max(T_{peak}, N \times T_{average})$$

where T_{peak} and $T_{average}$ are the peak and average sector throughput, respectively, and N is the number of sectors in a cell site. We used 3 sectored-sites in our deployment scenario, leading to 5 Gbps backhaul connectivity requirement.

Subscriber capacity: Residential service typically has an oversubscription rate of 20 or better. At this oversubscription rate, a 400 MHz FWA channel can support 125 users with a 220 Mbps / 36 Mbps (DL/UL) service.

Figure 4 Example North American suburban topology considered for this analysis

4. Deployment scenario and market parameters

The following analysis is performed for a greenfield deployment. This is an important point our readers need to remember as the costs can be significantly higher in both FWA and FTTH cases for brownfield deployments.

Millimeter wave FWA services are most prevalent in suburban areas, which we chose for our cost comparison analysis with fiber networks. We estimated that a 389 m cell radius would cover on average 600 houses in a typical North American suburban area, similar to the one in Figure 4. ***Table 5*** summarizes the key parameters.

Table 5 FWA deployment scenario parameters

Base station height	25 m
CPE height	5 m
Sectors per base station	3
Coverage radius	389 m
Cell area	0.136 sq. km
Number of houses covered	600

There are different approaches to build the wireless infrastructure: an option to lease or build one's own infrastructure. We opted for the former, leasing, model where already several infrastructure companies provide towers, backhaul and power for fast access to market. However, in practice, service providers are not constrained by one model or the other. External factors, such as zoning and permitting, impact the timeline and cost of the service roll out, such that in practice it is possible to have a hybrid approach depending on the market.

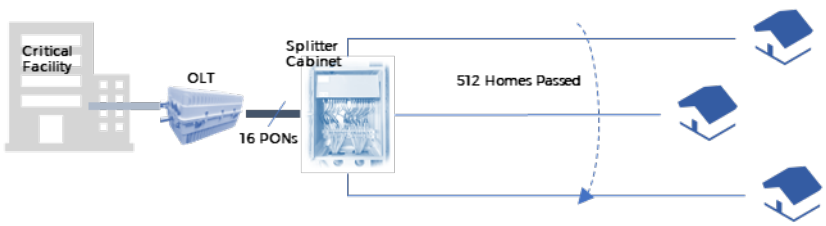


Figure 5 Typical hardened outside plant based FTTH deployment

As shown in Figure 5, we consider a typical outside plant deployed FTTH solution to compare a typical FWA architecture. Note that in this configuration we have used 512 homes passed Optiacl Line Termination (OLT) configuration with a centralized passive splitter cabinet. The PON network is based on XGSPON technology (10 Gbps upstream and 10 Gbps downstream capability) which is prevalently been deployed by operators around the globe. This provides significantly higher capacity per subscriber than earlier technologies leading to a longer lifetime from a product offering perspective. We assumed a 1:32 split per PON with 16 PONs per OLT. This allows for a total of 512 homes passed. The construction is mixed with one mile of aerial and three miles of underground fiber construction to address the above suburban topology. Finally, we assumed a drop length of 100 ft. per home. We don't consider any conduit sharing in this greenfield deployment. RF over Glass (RFOG) is not considered in this deployment, as this architecture is based on an all IP based solution (i.e., both voice and video are based on end to end IP based solutions).

We made certain market assumptions related to pricing, penetration rate, churn, and the business model related to CPEs as summarized in Table 6.

Table 6 Assumption for key market parameters.

Assumption	Value	Applicability	Comments
Service price	$75	FWA and FTTH	$50 - $90 typical
Penetration rate	50%	FWA and FTTH	300 subscribers / cell
CPE installation	50% professional install	FWA and FTTH	Requires truck roll
CPE business model	Free with subscription	FWA and FTTH	Typically, 2-year contract
Customer churn	8%	FWA only	

Our FWA financial analysis excludes two aspects. The first is the cost of the wireless core network and operation and business support systems (OSS/BSS). The second is the cost of spectrum. While elements such as OSS/BSS would be equally required in fiber networks, the cost of spectrum is important to consider for any service provider seeking to engage in FWA. We have included a note on this topic in Appendix 1 for additional context.

5. Financial analysis

We present the outcome for a comparative financial analysis for mmWave FWA and FTTH deployments for the suburban scenario mentioned above. The critical parameter is the cost per household covered in FWA or passed for FTTH. We follow that with a discussion on the sensitivity of the model to key parameters that are critical to the success of the business case.

5.1. FWA financial analysis

The financial performance of FWA depends on the cell radius and number of covered houses. The larger the number of houses covered, the lower the unit cost. In our analysis scenario, the cost per house covered is $607 based on a 7-year project lifetime. This leads to a 22-month period to breakeven as shown in Figure 7.

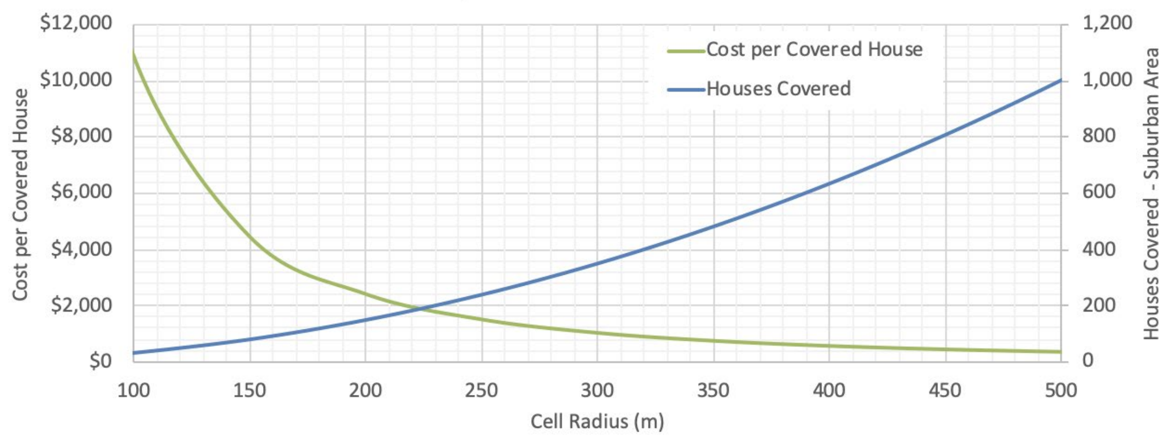


Figure 6 Number of covered houses and cost per house covered for mmWave cell site

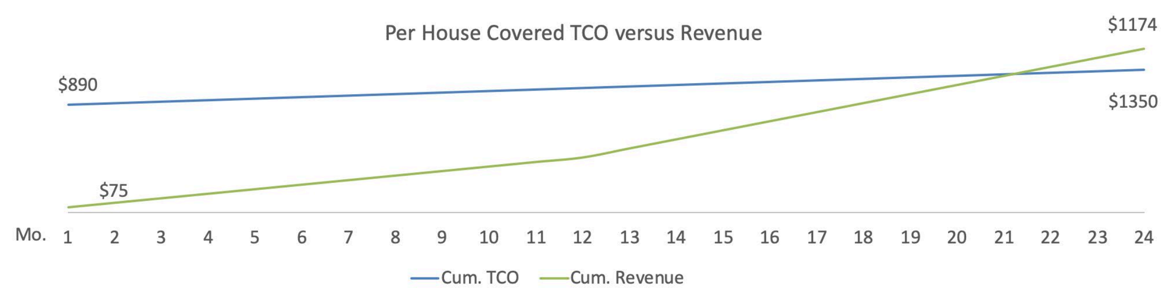
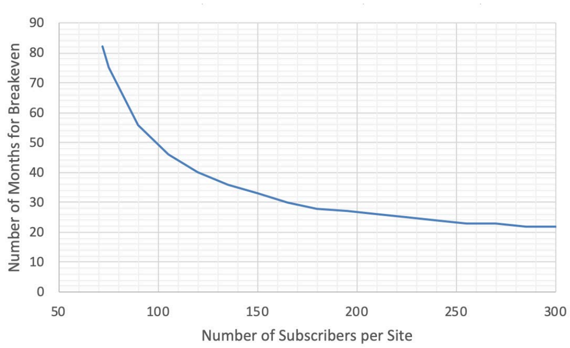


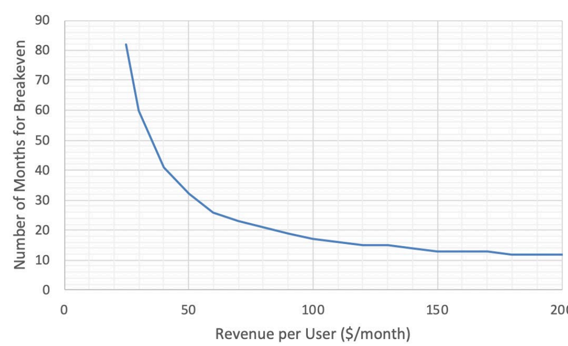
Figure 7 Cost and revenue per subscriber for FWA

What's more important is to determine the sensitivity of the model to different variables. Two variables - the number of subscribers and the revenue per subscriber - impact the model significantly. Both variables belong to the revenue side of the profit equation. Service providers looking at deploying mmWave FWA have to think carefully about the competitive landscape, pricing and their ability to sign up and retain a sufficient number of subscribers to monetize the network.

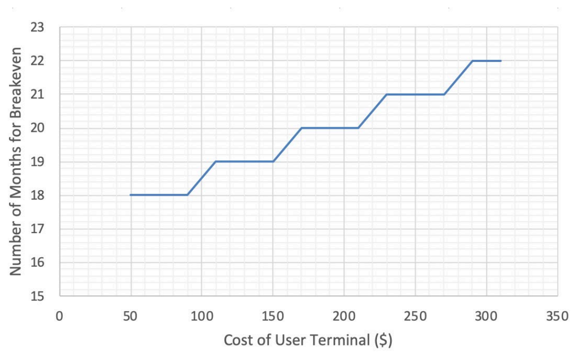
The model is somewhat sensitive to the cost of the user terminal and its installation. However, it takes high variance - e.g. double the costs of these parameters - to impact the breakeven period by 1 or 2 months. Traditionally, the cost of CPE and its installation are key factors to the success of FWA business case. This is not the case in mmWave networks, primarily because the small cell coverage area shifts the efficacy of the business case to the revenue side.



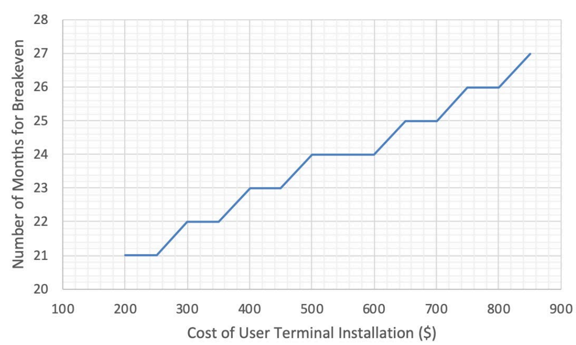
(a)



(b)



(c)



(d)

Figure 8 Sensitivity of FWA financial model to (a) number of subscribers per cell; (b) revenue per subscriber; (c) cost of user terminal; and (d) cost of user terminal installation. The financial mode is over 7 years, or 84 months

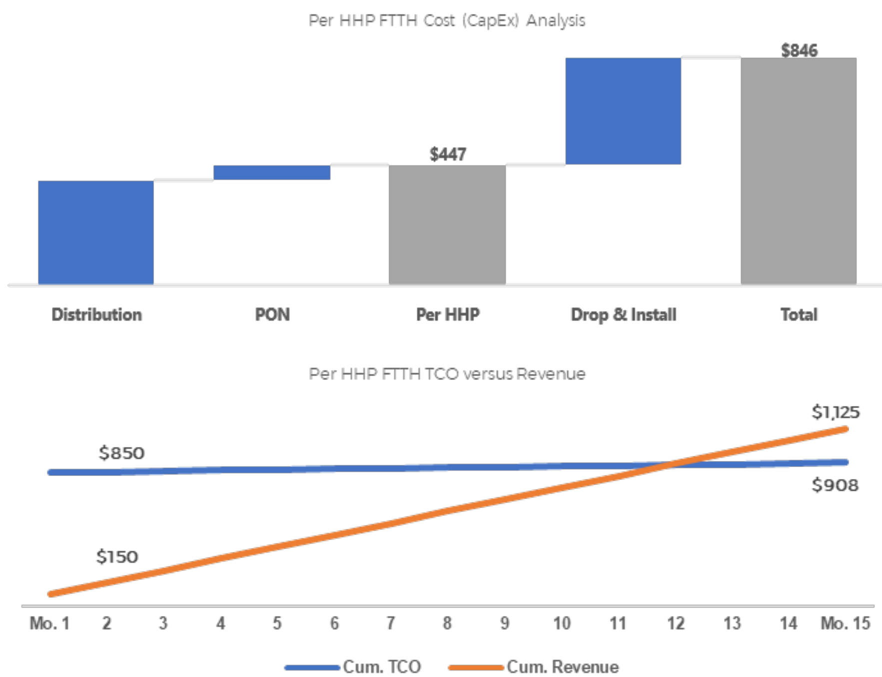
The cost of backhaul and site lease are other variables impacting the business case. The model is more sensitive to the cost of backhaul and pole lease when the cell is lightly loaded as smaller revenue coupled with high cost quickly pushes the breakeven period out into the future.

5.2. Fiber To The Home financial analysis

FTTH deployments is different than FWA in multiple aspects. We highlighted few of them here that are relevant for this financial analysis. In case of FTTH

- All homes are connected due to franchise agreements
- Leasing equipment or fiber is not considered as they are not typical
- Conduit sharing (join trenching) is not considered in this analysis although it is prevalent in the greenfield deployment cases

Figure 9 shows a typical per home passed capital expense (CapEx) of a greenfield FTTH deployment. More details on different access networks related capital and operational spend analysis can be found at [7]. As can be observed the construction costs that are part of the distribution contribute to most of the CapEx. For the given 600 homes passed suburban topology, as considered in this paper, we estimate the cost to be around $850 per homes passed.



We estimate the operating costs for FTTH to be around $53/HHP per year. A detailed analysis on the access network operating costs can be found at [8]. As shown in the Figure 9, with a $75 monthly plan, it only takes approximately 12 months to breakeven. Note that this analysis performed on a greenfield deployment. Brownfield deployment costs and hence the breakeven timeline will be different than what we are presenting here.

Figure 9 Greenfield FTTH CapEx and TCO versus revenue analysis

6. Comparing FWA and FTTH

The primary advantage of FWA over fiber is quick time-to-market and the ability to selectively target areas for service. This compares favorably with the long planning and permitting cycle for fiber infrastructure which in turn is heavy on capex. In contrast, fiber offers lower operational expenditures than FWA depending on the approach to wireless infrastructure buildout. Fiber brings superior performance, as we outlined earlier, which includes higher throughput than FWA, and symmetric and predictable traffic. Table 7 provides a comparative summary between FWA and fiber along critical dimensions.

Table 7 Comparative summary between mmWave FWA and Fiber.

Category	mmWave Fixed Wireless		Fiber-To-The-Home	
	Pros	**Cons**	**Pros**	**Cons**
Deployment	Quick access to market Could be deployed quickly	Propagation characteristics (foliage, material, clutter) impact on range	Can be deployed in any terrain	Requires advanced planning, permitting
Quality of Experience		Variable depending on location	Constant & predictable	
Throughput		Decreases proportionally to distance, varies depending on obstructions in signal path Traffic is non-symmetric in favor of downlink	Constant & predictable; ~100x more capability than FWA Traffic can be symmetrical	
Availability		Depends on distance and location of user terminal; foliage and IRR glass reduce availability	Constant & predictable	
Number of users	Cell densification to increase capacity; Roadmap to support greater throughput/# of users	Variable depending on deployment scenario in addition to other factors	Linearly scalable	
Financial Structure	Lower CapEx (scenario specific), quick access to market	High OpEx (scenario specific)	Low OpEx	Initial CapEx investment heavy
TCO	22 Months to breakeven (case dependent)	1. Small coverage range or low sub penetration lead to poor biz case 2. Actual breakeven is longer when factoring cost of core network and spectrum	~ 12 mo. breakeven; Better product offers	

7. FWA in rural areas

A few characteristics differentiate rural areas from suburban areas - primarily lower subscriber density. Other aspects such as the type of terrain and vegetation will vary and its impact of wireless coverage could be positive in open flat terrain, or negative in high-vegetation hilly terrain. Hence, the primary consideration for rural areas is subscriber density which will stretch the business case for mmWave fixed wireless access. For instance, mmWave systems can provide for up to 10 km range based on the free space path loss model. Therefore, to achieve range, the CPE will need to clear all obstacles for a line-of-sight connection. In other words, one needs to hoist CPEs on poles and towers to achieve range, which raises the cost to the consumer and makes the deployment impractical.

Similarly, the cost of building fiber plants rises in rocky terrain rural areas. Low subscriber density leads to long distribution and fiber drop points. This increases the cost of roll out, even to a level above that of mmWave FWA in our opinion.

We suggest that FWA in mid-band frequencies - such as 3.5 GHz - would fill a gap in rural access services. Mid-band spectrum is available in large allocations of about 100 MHz according to recent auctions from countries around the world. In the United States, the CBRS band provides 150 MHz of which at least 80 MHz is available on unlicensed basis. Technologies such as massive MIMO enable gigabit throughput capability. The range of 3.5 GHz signals is longer than mmWave signals and less susceptible to foliage and material penetration losses as we indicated above. Together, we believe that 3.5 GHz solutions provide a better cost-performance trade-off than mmWave in rural areas.

8. Conclusions

Millimeter wave FWA is a complementary but not a substitute to fiber services. FWA is quick to deploy which provides an interim solution in case fiber roll out is not possible in the short or medium terms. Moreover, since the performance of FWA depends on the location, deployments can only be selective and limited to areas where technical and financial performance benchmarks could be achieved.

Fiber on the other hand provides higher performance in terms of consistent, symmetric throughput that exceeds that of mmWave FWA. This does come at a higher capital expenditure. But over time, fiber has low operating costs in comparison with FWA where recurring costs of tower and backhaul chip away at profitability in a leased infrastructure scenario.

9. References

[1] *Who can provide the fastest internet connection*, Duke Tech Solutions blog, Sudheer Dharanikota, March 2017, available here

[2] *Brownfield broadband access network planning in a rapidly changing environment*, Rajesh Abbi, Luc Absillis, Sudheer Dharanikota, April 2019, available here

[3] *3GPP TR 38.901: Study on channel model for frequencies from 0.5 to 100 GHz*; v16.1.0 (2019-12), available here

[4] *Attenuation in vegetation*, International Telecommunication Union, Geneva, Switzerland, Recommendation P.833-8, Sep. 2016, available here

[5] *Characteristics of precipitation for propagation modelling*, International Telecommunication Union, Geneva, Switzerland, Recommendation P.837-6, Feb. 2012, available here

[6] *3GPP TR 38.306: User Equipment (UE) radio access capabilities*; v16.2.0 (2020-10), available here

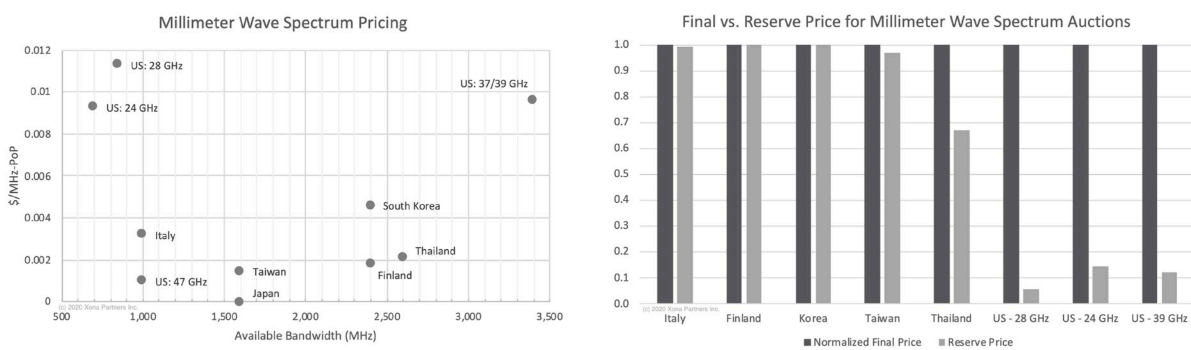
[7] *Capital and Operational spend aspects in Cable Operator 10G evolution*, Sudheer Dharanikota, Luc Absillis, Mark Welsko, September 2020 SCTE Energy Journal, available here

[8] *Operational expense comparison in access networks*, Fiber Broadband Association, June 2020, available here

[9] *CBRS Spectrum Auction Pricing*, Frank Rayal, August 29, 2020, available here

10. Appendix 1: A note on spectrum costs

Over the past two years, regulators in different countries around the world, including the FCC in the United States have released mmWave spectrum for use in fixed and mobile applications. The spectrum is licensed on area-basis in the United States and typically on national basis in other countries. Figure 10 (a) shows the pricing in $/MHz-PoP (per person) from recent auctions. For context, 700 MHz of 24 GHz spectrum in the US fetched just over $2 billion.



(a) (b)

Figure 10 (a) Millimeter wave spectrum prices in international spectrum auctions; and (b) final price vs. reserve price in select mmWave band auctions

Two observations are worth noting in relation to mmWave spectrum cost. First, there is higher demand in the United States than other countries as evident by a large difference between the reserve price and the final price as shown in Figure 10 (b). Second, the price of mmWave spectrum in the United States is significantly higher than other countries. Yet, the cost of mmWave spectrum remain orders of magnitude lower than mid-band spectrum. For instance, the average price for a 10 MHz license in the 3.5 GHz CBRS band in the United States is $0.22/MHz-PoP [9], or about 20x higher than that for mmWave.

