Rural 5G Fixed Wireless Access. Economics Analysis and Methodology.

A Technical Paper prepared for SCTE by

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1. Introduction

Fixed Wireless Access (FWA) is an alternative to wired broadband services using radio links between two fixed points. With the introduction of 5G, advancements in spectral efficiency and antenna technologies using massive MIMO (Multiple-Input Multiple-Output) and beamforming have become key enablers. The technology and costs have evolved and FWA services are now available from many service providers ranging from niche wireless Internet service providers (WISPs) to the largest mobile carriers. Today's FWA services compete directly with other wired broadband options from telcos (DSL and FTTH) and cable operators (HFC).

While our companion paper, "5G FWA Technical Performance Analysis for Mid-Band Rural Networks", investigates the technical performance characteristics of Rural FWA, this paper seeks to provide a framework to assess the economic considerations for FWA. The methodology involves:

- Defining Rural FWA service assumptions
- Determining spectrum and infrastructure
- Characterizing propagation and available capacity
- Projecting household level broadband demand
- Solving for supportable subscribers
- Pro Forma Economic considerations

FWA can be a strategic opportunity to deliver broadband in unserved and underserved rural areas. The analysis focuses on FWA using mid-band spectrum delivered from macro towers in rural geographies as defined by household density. Broadband usage is expected to continue to grow for the foreseeable future and a FWA service must account for projected demand. Therefore, we forecast average fixed broadband usage at the household level in 2027 and determine how many households can be supported in a typical macro cell at that point in time.

We explore the revenue drivers, variable and fixed cost components and discuss how a provider may consider cost allocations for spectrum and internally across business units. Finally, we develop an Excel model to help analyze projected cash flows and returns on investment based on variable assumptions.

For questions about this paper and/or to obtain a copy of the Excel model with a sample pro-forma, please contact the author at s.patel@cablelabs.com.

2. Service Assumptions

This paper will primarily focus on a target 100 Mbps download/ 10 Mbps upload (headline rate) 5G NR FWA service. The FWA service is assumed to have a 95% availability at the headline speed. Subscribers would still experience a connection at other times, but at lower than headline rate. The analysis assumes indoor customer premise equipment (CPE) requiring a simple self-installation, outdoor-to-indoor (O2I) downstream and indoor-to-outdoor (I2O) upstream signal propagation. Subscribers are assumed to be households with average broadband consumption on a GB/month basis. We model growth in household level broadband consumption at 25% per year and determine how many subscribers can be supported 5-years-out in 2027.

3. Spectrum and Infrastructure Considerations

FWA can be delivered using licensed or unlicensed spectrum ranging from sub-GHz to mmWave. Lower bands such as 600/700 MHz offer much better propagation but lower capacity. Higher bands offer better capacity but with lower propagation. While carriers can leverage their active spectrum and carrier aggregation for FWA, for simplicity, this analysis assumes dedicated spectrum.

We model the use of 100 MHz of 2.6 GHz spectrum on existing macro towers in suburban (30m towers) and rural (60m towers) areas. The main advantage is the ability to use the same infrastructure that is used for mobile service with an added layer of radios for the FWA service. These sites have existing power and backhaul infrastructure and would require incremental capacity to serve FWA needs. The typical clutter in these environments is 1-4 story residential and commercial buildings and representative foliage ranging from shrubbery to mature tree canopies. The 3GPP model values we use incorporate large-scale assumptions for clutter using probability projections for line of site (LOS) and non-line-of-site (NLOS) between transmitting and receive antennas. The end result is a composite propagation value incorporating LOS and NLOS probabilities for the target region.

Figure 1 - Suburban Macro Tower

Figure 2 - 5G In-Home CPE

We model the use of indoor Customer Premise Equipment (CPE). The CPE is assumed to be placed within 1 meter of the closest outside wall to the transmitting tower and at a height of 2 meters in the subscriber home. An alternative scenario, not considered in this analysis, involves the use of an outdoor mounted antenna at or above the subscriber home roofline. The use of outdoor receive antenna can add up to ~40% incremental propagation for a 100 Mbps service in suburban areas and up to 50% in rural. This typically requires a professional install, adds significant cost to the service and can extend the payback period depending on whether the subscriber bears the cost of installation.

4. Propagation and Capacity

CableLabs has been investigating FWA performance since 2018 and has developed a proprietary MATLAB[1] based simulations engine to characterize the performance of different spectrum bands using multiple assumptions. The simulations engine is backed by two technical modeling tools working in tandem; 1) a system level simulator (SLS) based on a 19-cell site topology, which statistically calculates aggregated system interference and 2) a link level simulator (LLS) modeling 5G New Radio (NR) waveforms and multiple-input multiple-output (MIMO) antenna patterns. The LLS uses the results from the (SLS) to evaluate the signal-to-noise ratio (SINR) and throughput versus link distance. The output from these models provides aggregate performance and propagation data to inform this techno-economic analysis. Technical details of the CableLabs SLS and LLS models can be found in the companion SCTE paper.

Table 1 - Calculated 2.6 GHz O2I Propagation (distance from base station) for Target Service Speed and Tower Height

	50 Mbps	100 Mbps	300 Mbps
30m Tower	1,718	1,418	730
60m Tower	4,625	3,600	1,765

Table 1 shows the calculated propagation at 3 different headline speeds for 2.6 GHz spectrum deployed on a 30 meter macro tower in a suburban environment and a 60 meter macro tower in a rural area. The distances can be considered a service edge where connections can still be made beyond the representative values, but at lower than headline speeds. Capacity and throughput diminish the further the FWA subscriber is located from the base station as depicted in Figure 3 – 30m Macro Tower and Figure 4 – 60m Macro Tower, which show available capacity per user in O2I and outdoor receive antenna scenarios respectively. The CableLabs model assumes 3 sectors per cell

[1] MATLAB is a proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks (www.mathworks.com).

and 8 simultaneously active users per sector. It also assumes that subscriber households are distributed evenly across the cell area.

In addition to propagation, the model calculates available capacity for each sector of the macro cell. Radio frequencies lose signal strength and data carrying capacity in correlation to their distance from the gNB. Figure 3 and Figure 4 show available capacity per user at varying distances from 30m and 60m tall macro towers in the case of O2I CPE and with the use of outdoor receive antenna respectively. In the 30m tower case (Figure 3), we see that a 300 Mbps service can be delivered at a distance of 730m and a 100 Mbps service can reach 1418m. Of note, if 300 Mbps is the desired target FWA service, not all households within the area would be considered serviceable.

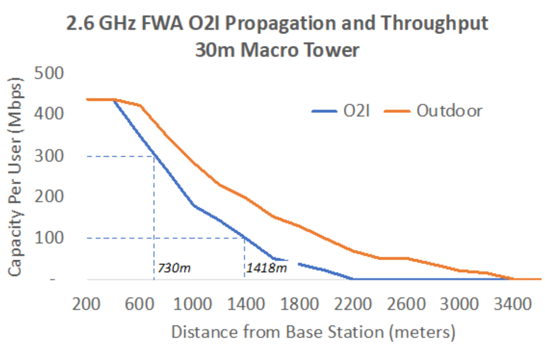

Figure 3 – 30m Macro Tower

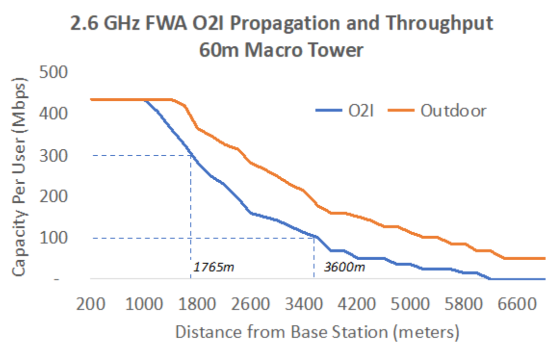

Figure 4 – 60m Macro Tower

We assume that households are evenly distributed across the respective cell coverage areas based on the average density (households/Km^2) in the area of interest. The calculation for mid-cell incorporates the cell edge for a 100 Mbps O2I service, 1419 meters, in the case of 2.6 GHz deployed on a 30m tall macro tower. At roughly 70% of the distance between the gNB and the cell edge (1419m * .7 = 1003m), half of households would be between the base station and mid-cell and half would be between mid-cell and the cell edge. Calculated available capacity at mid-cell is a total of 1,429 Mbps.

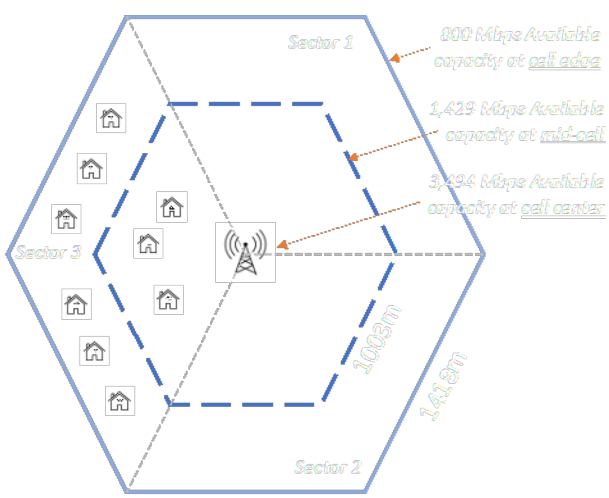

Figure 5 - 2.6 GHz Propagation & Capacity (100 Mbps Service, 30m Macro Tower)

5. Subscriber Household Demand

We assume that a mobile FWA household will have similar usage on a GB/month as a fixed broadband household. OpenVault[2] is a 3rd party firm that collects, tracks and reports average fixed broadband consumption per household. OpenVault's Q4 '21 report shows the average household consumed 504 GB/month downstream and 32 GB/month upstream for a total of 536 GB/month. As we are interested in what consumption will be 5 years in the future, we assume an annual growth rate of 25%[3] and calculate that by 2027, the average fixed broadband household will consume 2,045 GB/month of data. This calculates as an average of 6.2 Mbps in 2027 (2,045 GB/ 30.4 days/ 24 hours/ 3600 seconds * 8000 bytes to bits). While the average usage in Mbps Is useful, operators design their networks to support peak usage. At CableLabs, we have observed that peak usage has maintained a consistent ratio of 2:1 against average usage for a number of years. This implies peak usage per household of 12.5 Mbps in 2027.

Table 2 - Average Projected Broadband Usage per Household

		2021	2022	2023	2024	2025	2026	2027
Total Usage (GB/month)		536						
Annual Growth	25%		670	838	1,047	1,309	1,636	2,045
Mbps Equivalent		1.6	2.0	2.6	3.2	4.0	5.0	6.2
Peak to Average Ratio	2.0X							
Peak Usage (Mbps)		3.3	4.1	5.1	6.4	8.0	10.0	12.5

6. Serviceable Households

We have shown propagation and available capacity for a given suburban macro cell sector and calculated the projected average household demand five-years out in 2027. A straight-forward exercise of dividing available capacity by household demand would yield the maximum number of subscribers that could be supported in the given sector. The resulting value would exhaust all available capacity. Service providers typically operate with a maximum target fill-rate to allow for some spikes in peak consumption but also to allow a margin of time to either manage existing subscribers and policies or to add incremental capacity. For a FWA network, this could involve activating additional spectrum, improving the efficiency of the existing network with more advanced radios and CPE or densifying the network with additional macro towers or small cells.

[2] www.openvault.com. OVBI_4Q21_Report.
[3] 25% represents a reasonable growth assumption based on recent non-Covid period data and can be adjusted as consumption data is reported over time. The same growth rate for upstream and downstream is used for simplicity.

In our example of a 30m suburban macro tower, we use mid-cell capacity and apply a max fill-rate of 50% as the average available across all households in the footprint (1429 Mbps * 50% = 715 Mbps). We recognize that households nearer the gNB could experience significantly higher throughput, depending on the providers' policies and practices of limiting available speeds to any given subscriber. Households at the service edge would typically experience the headline speed subject to the number of active users in the sector.

715 Mbps would support approximately 57 households per sector or 171 household per cell (715 Mbps ÷ 12.5 Peak Average usage/Household in 2027 = 57 X 3 sectors = 171). Our calculations are based on average household consumption. Service providers may have the ability to segment and target users i.e. lower usage households and to manage how many subscribers are offered the service and supported in a given cell sector.

An alternative view of serviceability for FWA is to understand how many households can be supported in a given area. The 100 Mbps service edge in our 30m suburban tower example above is at a radius of 1,418 meters equating to a coverage area of 6.3 Km^2. With 171 maximum serviceable households per cell we arrive at a maximum of 27 on a per Km^2 basis. Table 3 below shows the maximum number of households can be supported (in green) for a 100 Mbps FWA service across a range of household densities and market penetrations. Note that where the number of macro towers in an area of interest does not provide ubiquitous coverage for the given service, an adjustment would need to be made to account for non-addressable households.

Table 3 - Maximum Supportable Households for a 100 Mbps FWA Service

Market	Household Density/Square Km						
Penetration	100	200	300	400	500	750	1,000
2.5%	3	5	8	10	13	19	25
5.0%	5	10	15	20	25	38	50
7.5%	8	15	23	30	38	57	75
10.0%	10	20	30	40	50	75	100
12.5%	13	25	38	50	63	94	125
15.0%	15	30	45	60	75	113	150
17.5%	18	35	53	70	88	132	175
20.0%	20	40	60	80	100	150	200
22.5%	23	45	68	90	113	169	225
25.0%	25	50	75	100	125	188	250

The U.S. Census defines an area with less than ~325 households/Km^2 as rural[4]. We can see from the results in Table 3 that, in general in suburban areas, available capacity would be exhausted in areas up to 500 households/Km^2 once 5% of households have signed up for the service. At this point, the provider would either need to manage the demand i.e. halt additional subscriber adds or increase capacity by adding more spectrum, increasing the efficiency of the network or adding more towers in the service area.

[4] https://www.ers.usda.gov/topics/rural-economy-population/rural-classifications/what-is-rural.aspx. We use 2.5 persons/household to arrive at approximately ~325 households/Km^2.

Demand could be tempered by targeting areas with smaller households size (predominance of single-person households) or segments that have lower overall usage. Over-the-top video is a significant driver of data consumption and providers could target areas or segments with higher traditional linear video subscribership or lower rates of work and/or study from home.

7. Economic Considerations

To understand the business case for FWA, a proforma of discounted cash flows with the following assumptions and factors should be considered. To obtain a sample Excel based pro-forma incorporating the factors below, please contact the author at s.patel@cablelabs.com:

Revenue and Top Line:	
Area of Interest	• 3GPP considers different performance models for Urban Macro and Rural Macro scenarios. • Can be defined as a market, defined target service area or macro cell.
Service Offering	• ARPUs and incentives may vary depending on whether a subscriber bundles mobile and FWA. • Target speed offerings affect the service edge or how far signals propagate. A 300 Mbps service would offer a smaller serviceable footprint than a 100 Mbps service. • Target availability of headline speeds. There is a direct correlation between propagation and target service availability. • Spectrum to be used for the FWA service including depth.
Household Density	• Households/Km^2 can be translated into addressable subscribers once the service and calculated propagation are defined.
Subscriber Penetration	• Drives the calculation for demand. • Consider mobile market share and the type and number of available competing broadband options in the area of interest i.e. FTTH, DSL, HFC, FWA, LEOS. • Some MDUs offer broadband as part of their rent or Home Owners Association (HOA) benefits. • Consider that a certain (small) percentage of households will not subscribe to any broadband service.
Subscriber Ramp	• Time it will take in years to reach target penetration rates.
Max Supportable Subscribers	• Note in Section 4, we describe how to calculate available capacity in a cell and in Section 6 the maximum number of subscribers that can be supported based on average household demand. This serves as a subscriber ceiling until additional capacity can be created.
CPE Revenue	• If the subscriber bears either a partial or full upfront cost or monthly lease cost for CPE.

Variable Costs:	
CPE	• Cost per unit for new indoor 5G CPE. • Useful life and/or replacement cycles. • Distribution costs i.e. warehousing, shipping, delivery, returns. • Cost to refurbish and package for churned units. • We model CPE cost as being borne by the operator. Subscribers may bear part or all of the cost and those revenues should be accounted for accordingly.
Customer Acquisition	• Retail, channel partners, online acquisition paths and associated costs. • Promotions i.e. X months free service and other tie-ins i.e. bundled OTT video services or other discounts i.e fixed and mobile.
Churn	• Rate of monthly disconnects. Given the nature of the service, FWA churn may be higher than typical fixed broadband or mobile subscriber churn rates. • For a model that considers a terminal number of subscribers following a ramp up, a service provider would need to replace disconnecting subscribers on a regular basis to maintain counts and account for CPE and subscriber acquisition costs.
Customer Cost to Serve	• Customer support including retail, online channels, call centers, back-office systems, field techs, trucks, consumable tools. • Can be expressed as a percent of revenue for simplicity.
Tower leases	• Incremental cost to lease space on existing towers for FWA specific radios, and land for power and backhaul.
Power	• Incremental cost for radios, networking equipment.
Backhaul	• Incremental cost to add capacity or new links.
Maintenance	• For new equipment and incremental infrastructure
Licensing and Support Agreements	• As applicable from vendors for hardware and software.

Fixed Costs & Other:	
Spectrum	• Acquisition cost or calculated as $/MHz Pop based on the population for the area of interest. • Population for a given area can be referenced or calculated based on household data. A typical household has ~2.3 residents in the U.S. • Depending on licensing terms, where regulators extend spectrum licenses indefinitely, they could be considered an asset for accounting purposes. In that case, a carrying cost calculated as the provider's cost of capital against the acquisition cost could be applied. For example, in the FCC's recent C-Band auction, the average price paid was $1.17/MHz Pop. If the area of interest was a market with a population of 1 Mil, and the operator dedicates 100 MHz of spectrum for the service, the spectrum for that market would $117 Mil. A carrying cost using a cost of capital of 8%/year would equal a monthly spectrum expense of $780,000 ($117 Mil * 8% /12). Note that spectrum cost can vary market by market. • Another consideration is whether the operator has indefinite rights to the spectrum. In cases where the spectrum is considered owned, its value could be incorporated into the pro-forma as a future cash flow if the service is being evaluated on a standalone basis i.e. the spectrum could be re-allocated for mobile use or otherwise monetized. We do not make consideration of a future cash flow in our analysis.
FWA Antennas, cabling, power, networking equipment	• MIMO characteristics for the antennas. • Hardware and installation. • Useful life or technology replacement considerations. • Distributed units, Central units. • Incremental core networking and management.
Tax Savings	• In some countries, spectrum and other capital investments can be amortized and are tax deductible for cash tax purposes. A typical amortization period would be straight line over 15 years. • www.csimarket.com offers data on tax rates for U.S. companies.
Cost of Capital	• Also referred to as the Discount Rate used for Net Present Value (NPV) calculations. • See NYU Stern for average cost of capital rates across U.S. industries[5].

[5] https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/wacc.html

Financial Metrics	• Cash Flow: increase or decrease in cash for a period once revenues, variable and fixed costs are accounted. • Net Present Value: The current dollar value of future cash flows discounted at the cost of capital. • Payback: Number of years for discounted cash flows to become positive. • IRR: Internal Rate of Return.

A pro-forma designed with the above assumptions would calculate contribution margin and cash flows from which a FWA service can be assessed on a net present value basis and payback basis. For an Excel-based example, please contact the author directly.

A final key consideration depending on the operator is cost allocation. Many FWA operators are primarily mobile service providers. Where they build excess capacity, it makes economic sense to use that capacity for other revenue generating activities such as FWA as long as they don't degrade the mobile experience. In that case, a consideration can be made as to how much of the spectrum and infrastructure costs should be allocated to the FWA service. Our Excel tool allows for understanding the impacts to ROI with different sensitivities for revenue, cost and allocation assumptions.

8. Conclusion

This paper lays out the economic considerations for a rural FWA based broadband service. It is a companion to our technical paper which is also submitted for Tec-Expo 2022 titled "5G FWA Technical Performance Analysis for Mid-Band Rural Networks". We show how calculations for propagation and capacity based on a number of service assumptions can be applied to understand how much coverage can be created for a given macro cell and market area. We further describe the concept of service edge and show how capacity diminishes with distance from the service antennas. A methodology to calculate peak average demand for a broadband household and forecast usage 5-years out is used to understand how many subscribers can be supported in a given cell and sector. Finally, we present the revenue, variable, fixed and other considerations that drive a financial analysis of the economics for FWA. Should you have any questions or would like to obtain a reference Excel pro-forma model, please reach out to the author directly at s.patel@cablelabs.com,

Abbreviations

3GPP	Third-generation partnership project
5G	Fifth-generation technology standard for broadband cellular networks
ARPU	Average revenue per unit
CPE	Customer premise equipment
DSL	Digital subscriber line
FTTH	Fiber to the home
FWA	Fixed wireless access

HFC	Hybrid fiber coax
GB	Giga-Byte
gNB	Next generation node-B
I2O	Indoor to outdoor
LLS	Link level simulator
LOS	Line of site
MIMO	Multiple in multiple out
Mbps	Megabit per second
NLOS	Non-line of site
NPV	Net present value
NR	New radio
O2I	Outdoor to indoor
SINR	Signal to noise ratio
SLS	System level simulator
OTT	Over the top
WISP	Wireless Internet service provider