FWA, The Promise of Broadband Everywhere Lessons Learned & Best Practices

A Technical Paper prepared for SCTE by

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1. Introduction

In today's digital age, access to high-speed internet has become critical for individuals, businesses, and communities to thrive and participate fully in the modern economy. However, despite significant technological progress and infrastructure development, the digital divide persists, leaving a considerable number of households underserved or unserved by broadband connectivity. This paper explores the potential of Fixed Wireless Access (FWA) as a solution on 4G/5G networks to bridge this divide, focusing on the Canadian context while acknowledging the global nature of the issue.

Canada, a developed country with an estimated population of 16.2 million households, faces challenges in providing universal broadband access. According to the Canadian Radio-television and Telecommunications Commission (CRTC), approximately 91.4% of households have access to broadband speeds of at least 50 Mbps download and 10 Mbps upload. However, this leaves around 1.4 million homes as underserved or unserved, with rural communities being particularly affected, where only 62% have access to these reasonable broadband speeds. This persistent digital divide highlights the multifaceted challenges associated with socioeconomic, political, and geographic factors that shape broadband accessibility.

Fixed Wireless Access is not a novel concept, having existed in various technological forms where the last mile connection provided to users is wireless. However, as the demand for data consumption on broadband connections continues to increase, delivering a satisfactory customer experience over wireless networks has become increasingly challenging. The convergence of mobile and fixed wireless broadband services over 4G networks began with the expansion of 4G cellular networks. But bridging the digital divide requires ensuring FWA can deliver an experience comparable to fixed broadband. While 4G based FWA has proven to be promising, it has fallen short particularly in terms of being able to provide comparable throughput speeds and adequate capacity.

However, 5G networks have emerged as a more robust and appropriate solution for applications like FWA while catering to the growing needs of mobile traffic. This is mainly due to the advanced features and capabilities 5G brings such as access to higher bandwidths and frequency spectrum, more efficient radio interface, enhanced radio resource management, higher order Multi-User Multiple Input Multiple Output (MU-MIMO), Beamforming, Dual Connectivity and Carrier Aggregation (CA) for peak performance and coverage extension, higher order modulation, and more capable customer premises equipment (CPE).

It is essential to recognize that FWA users typically consume significantly more data compared to mobile users, often by a factor of 40 to 50 times. Additionally, seasonal traffic variations introduce complexities that necessitates careful capacity planning and resource management. This requires operators offering FWA services over their 4G/5G network to not only rely on the enhanced features now available with 5G, but also to adopt processes and best practices that will protect their network, improve customer experience, provide sustainability, and ensure success.

This technical paper aims to cover the features, processes and best practices utilized by Rogers to accommodate FWA as an application over its 4G/5G Mobile Broadband (MBB) network.

2. State of FWA in Canada

Wireless coverage for 4G extends to 99.4% of the population. Technically FWA can be made available to them; however, not all areas with 4G coverage are able to provide or support speeds of 50 Mbps on the downlink and 10 Mbps on the uplink. It is important to note, while many communities within Canada are served, the high cost of these services makes broadband connectivity inaccessible to many households. Due to these socio-economic factors, it is necessary for service providers to build efficient and cost-effective networks to make high speed internet connections readily available and accessible.

Figure 1 map highlights areas across Canada that have approximately 1.4 million underserved households. As it can be deduced, to capture this FWA opportunity, a very large area needs to be addressed, which makes building efficient networks ever more challenging.

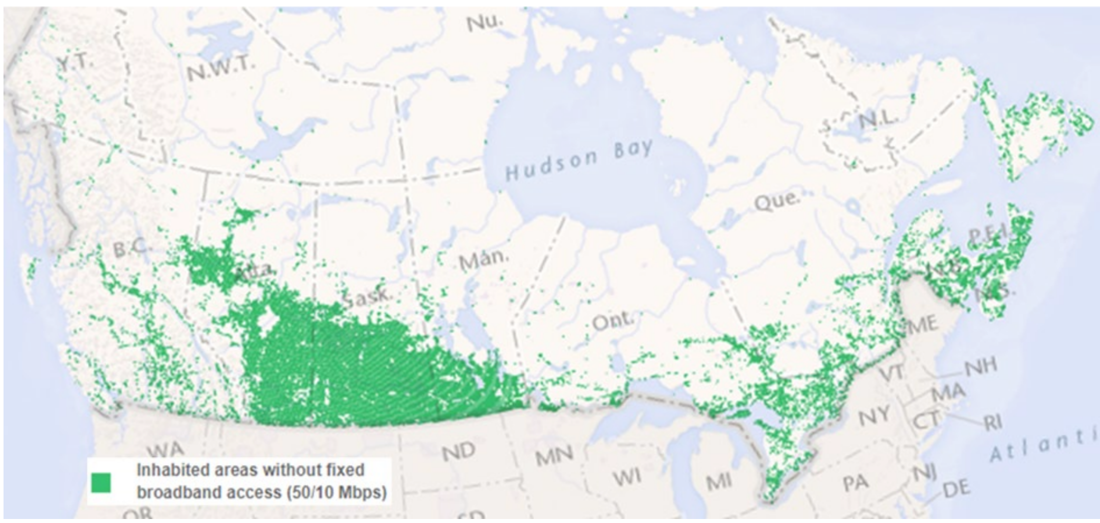

Figure 1 – Underserved Households across Canada

Low population density appears to be a big challenge for Canada. To put this into perspective, Canada only has four 4 people per square km, while USA has 34 people per square km.

Therefore, to bridge this digital divide, the government has initiated broadband fund programs to subsidize the build of broadband connectivity to these underserved communities. This primarily includes fiber build but also considers FWA as a viable alternative option.

The success of FWA relies on the support of clear and transparent regulatory policies governing spectrum licensing and usage. The Canadian Radio-television and Telecommunications Commission (CRTC) plays a crucial role in promoting fair competition and universal access, encouraging operators to invest in FWA deployments. Therefore, FWA deployment has gained momentum across Canada with various operators utilizing their existing 4G/5G mobile networks.

3. Best Practices & Processes for FWA

This section will cover best practices and recommended processes based on Rogers' learnings and experience from onboarding FWA customers to its 4G/5G MBB network.

3.1. Serviceability and Coverage Qualification

Typical network strategy is to offload heavy traffic on to higher capacity or larger bandwidth channels. 3.5GHz (n78) being the primary Frequency Range 1 (FR1) 5G high bandwidth band available in Canada, FWA traffic is preferred to be steered towards this band, if available. Therefore, when it comes to a serviceability check for customers, it is desirable to base it on the coverage of this 5G band or other 4G high bands.

The CRTC defines households as underserved if they do not have access to broadband service offerings of at least 50 Mbps on the downlink (DL) and 10 Mbps on the uplink (UL). To provide the mandated service levels, appropriate coverage thresholds should be considered depending on the operator's network configuration. A detailed Link Budget analysis is required that takes into consideration the spectrum available to the operator, Radio hardware capabilities, and end user equipment specifications. The table below shows an example of a Link Budget analysis for a given scenario with the given assumptions.

Table 1 - FWA Link Budget Assumptions & Considerations

Table Heading	Scenario 1	Scenario 2
Technology	NR TDD	
Frequency	3.5 GHz	
Band	N78	
DL/UL Ratio (for TDD)	70/30	
Implementation (Mobile/FWA)	FWA	
Radio	32T32R (Massive MIMO)	
Power	200 W	
Antenna Gain	N/A	
EIRP	70 dBm	
UE Antenna Gain	16 dBi	
UE TX Power	26 dBm	
DL MIMO (SU)	4x4	
UL MIMO	1x4	
Modulation Supported (DL/UL)	256 QAM/64 QAM	
Bandwidth	60 MHz	
Morphology	Rural	
Site Height	40 m	
UE Height	4 m	
Environment (Indoor/Outdoor)	Outdoor	
LOS/NLOS	NLOS	
Coverage Probability	85%	
Cell Loading	80%	
Cell Edge DL Throughput Target	50 Mbps	25 Mbps
Cell Edge UL Throughput Target	10 Mbps	5 Mbps
Limiting Channel	PUSCH	PUSCH
MAPL	155.4 dB	159.6 dB

Table Heading	Scenario 1	Scenario 2
Min RSRP Threshold (Cell Edge)	-101.3 dBm	-105.5 dBm
- 0 dB log normal fading (LNF) margin was applied since receiver is static - Considering high cell ranges and directional antennas on the CPE, UL interference margin considered was <0.5 dB - Propagation loss for a RMa (Rural Macro) environment considered - CPE considered to be Power Class 2 (PC 2) for N78		

For the given cell edge throughput targets, it can be observed that the UL data channel (PUSCH) is the limiting channel while there is still substantial headroom available on DL data channels. It is critical for operators to calculate their link budgets based on the site configuration and the equipment deployed as well as align with vendor link curves for radio hardware used. The minimum cell edge RSRP threshold is then calculated for desired service levels, which operators can then use as a reference or as an input to their preferred RF propagation modeling tools. It is recommended to use industry standard tools that are capable to model exact network and site configurations and use up to date terrain, clutter, building and foliage data. This will allow operators to precisely identify serviceable areas and accurately plan for their FWA deployment.

Rogers has worked extensively with its vendor partners to have tuned propagation models and then calibrated those models for FWA deployments, accommodating higher CPE heights and antenna gains. Field measurement validation has shown a correlation of > 0.7 between measured and predicted values when within 3 km range of the site. Beyond that accurate alignment of CPE towards the best server becomes more challenging considering the environmental and clutter unknowns contributing to the variations. As per industry standards, propagation models when tuned are converged to have a mean error of < 2 dB and a standard deviation of < 7 dB. Therefore, adjusting propagation models and tool settings should be a continuous improvement process undertaken by operators along with continuous investment in highly accurate and up to date geo data sets. Figure 4.12 shows an example of a propagation analysis done for a cluster of sites planned in a rural area for FWA.

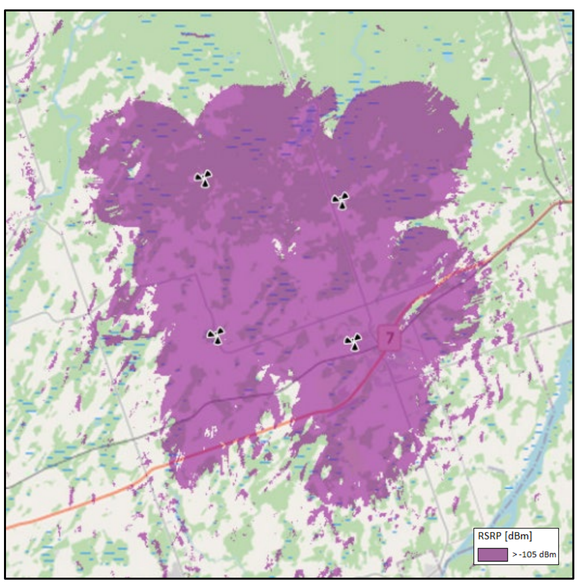

Figure 2 - Rural FWA Coverage

3.2. Capacity Management

As service providers embark on offering FWA services over their cellular network, capacity planning becomes an even more critical component of their cellular network strategy. Careful capacity planning ensures that the network is designed and optimized to manage the growing demands of FWA subscribers, provides subscribers with a high-quality experience, and allows operators to make informed decisions regarding network expansion and upgrades.

By analyzing historical data, traffic patterns, seasonal variations, and user behavior, operators can identify peak usage times, areas with high demand, and any potential bottlenecks that could lead to congestion and poor experience. Similarly, it is critical to forecast factors like subscriber growth, market penetration, year over year increase in data usage, and emerging applications so that operators can make provisions for expanding network capacity accordingly. Effective planning also helps with cost optimization which allows operators to avoid over provisioning that may cause unnecessary capital investment or under-provisioning that would lead to performance issues and dissatisfied customers.

The strategy for each operator may differ depending on the type or grade of services offered, dedicated, or shared spectrum available, network sharing with other services such as mobile, expected market penetration and product offerings. This section will focus on how to estimate capacity requirements and available capacity on a network that serves both mobile and FWA users.

3.2.1. Estimating User Capacity Requirements

There are several frameworks available to estimate user requirements. Utilizing usage statistics has proven to be effective and widely adopted, which will be discussed in this section. The following details are required:

- Average monthly data usage $\mathbf{D_{Avg}}$. This can be further categorized into the type of plans offered to customers. E.g., typical monthly usage observed in a market on a 25DL/5UL plan is ~500 GB/Month
- Average duration of daily peak usage times $\mathbf{T_{Peak}}$. E.g., high traffic or peak data consumption is observed on the network between 6 PM to 10 PM [4 hours]
- Percentage of traffic during peak hours $\mathbf{P_{\%}}$. An 80-20 rule can be applied here which can be interpreted as 80% of the traffic is observed during 20% of the time

With the above variables known, average user consumption during peak hours $\mathbf{U_{Avg}}$ can be determined as follows:

$$\boldsymbol{U_{Avg.}} = \left[\frac{(\boldsymbol{D_{Avg.}} \times \boldsymbol{P_{\%}})}{(\boldsymbol{T_{Peak}} \times \boldsymbol{30_{Days}} \times \boldsymbol{60_{min}} \times \boldsymbol{60_{sec}})}\right] \times \boldsymbol{1000_{MB}} \times \boldsymbol{8_{bits}}$$

e.g.

$$U_{Avg.} = \left[\frac{(500GB \times 80\%)}{(4.8 \times 30_{Days} \times 60_{min} \times 60_{sec})}\right] \times 1000_{MB} \times 8_{bits} = 6.2Mbps$$

Therefore, the capacity on the network is not necessarily determined by the plans or bandwidth offered, but by the expected consumption of network resources. This makes it important to introduce policies that would limit or influence the usage pattern of customers.

3.2.2. Available Capacity

Available capacity can be calculated on cell level that can then be aggregated to sector level, site level or market level capacity. There are several different approaches that can be adopted. However, utilizing channel spectral efficiency simplifies many aspects of capacity calculation and will be the one discussed here. One of the main assumptions associated with it is that any new customers added within the cell coverage range will conform to the same statistical distribution as existing users or traffic. They will experience radio conditions that are reflective of the spectral efficiency used, which can either be a network average, cell average, cell average during busy hours or spectral efficiency with any other criteria. This approach blends in all the radio parameters, such as Signal to Interference Noise Ratio (SINR), Rank Indicator (RI), Channel Quality Indicator (CQI), Modulation Coding Scheme (MCS), Block Error Rate (BLER), that have a direct impact on achievable throughput. Therefore, there are limitations of using spectral efficiency which will be examined later in this section as well as possible ways to address them.

Realistically, however, with each added user, there is increased interference within the cell and on adjacent cells, which should be factored in separately. The link budget analysis done initially accounts for the impact of a given cell load (80% in the above example) and reflects that in the required RSRP for the target throughput desired. For further accuracy, actual cell loading can be taken into consideration and align it with vendors' product capabilities of mitigating interference, which could either be through interference cancellation soft features or hardware capabilities such as beamforming. Figure 3 shows the impact of cell loading on SINR across the cell for two different 3.5 GHz radios. As the loading increases, the delta of achievable good SINR (>20 dB) increases between the non-beamforming 8x8 radio and the massive MIMO beamforming 32x32 radio. The impact of massive MIMO on spectral efficiency is further discussed in detail in case study 2 in section 5.2

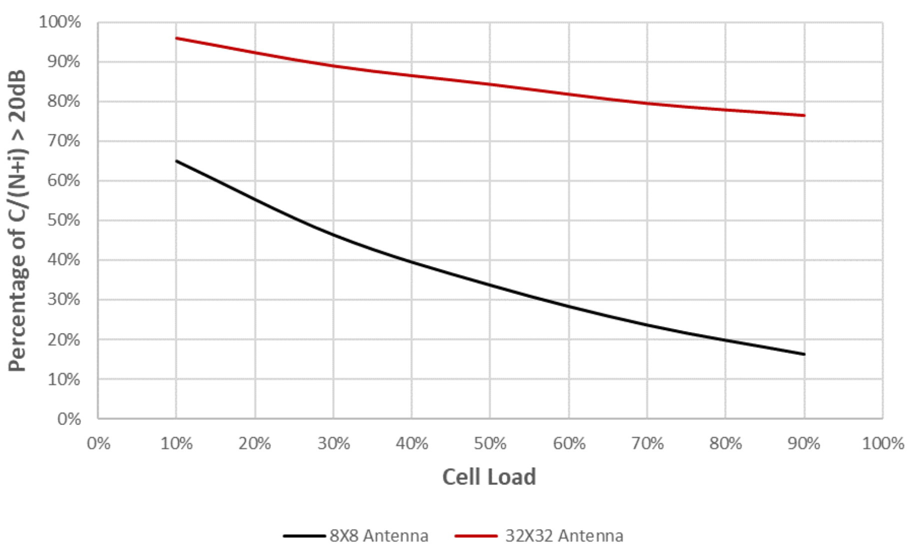

Figure 3 - Impact of Cell Loading on SINR for 8x8 and 32x32 radios

Existing usage, which may either be mobile usage or FWA usage, is accounted for by taking current average Physical Resource Block (PRB) utilization during peak hours. Only the remaining resources are then considered as available capacity. Maximum allowed PRB utilization threshold sets the upper limit before a sector is considered as congested. Operators can decide to relax or tighten this limit depending on the market type and the amount of headroom they prefer to keep.

To efficiently serve a large customer base, it is common and economically feasible for operators to oversubscribe. Oversubscription ratio is a term used to describe the practice of selling more network resources such as bandwidth or data capacity to customers than what is available on the network. Not all users use their capacity simultaneously, therefore a concurrency factor or appropriate oversubscription ratios can be determined by analyzing historical data and customer usage patterns. Oversubscription should be carefully managed to avoid potential issues of network congestion and poor user experience during peak hours. The objective is to ensure maximum number of users to experience satisfactory performance without any noticeable degradation.

In the equation below, we aggregate the capacity to sector level.

∴ for x number of channels on sector S:

C_S = Sector Capacity (Mbps)

P_t = Max PRB threshold considered before congestion (%)

P_k = Average PRB utilization for channel k during peak hours (%)

B_k = Channel Bandwidth of channel k (MHz)

S_k = Average Spectral Efficiency of channel k (bits/sec/Hz)

R_{TDD} = Downlink Ratio for TDD channels only

I = Interference factor due to added traffic $\{I < 1\}$

U_{Avg} = Average usage during busy period (Mbps)

OSR = Oversubscription ratio $\{OSR \geq 1\}$

N = Number of users that can be supported on sector S with U_{Avg} usage

$$C_S = \sum_{k=1}^{x} \left(\left(\frac{P_t - P_k}{100} \right) B_k S_k R_{TDD} I \right) OSR$$

$$N = C_S \div U_{Avg.}$$

Figure 4 shows the impact spectral efficiency has on the number of users that can be supported on a 20 MHz channel as the usage pattern changes. An OSR of 2.5:1 is considered, and the cell is assumed to be 50% loaded with 30% resources still available before congestion occurs.

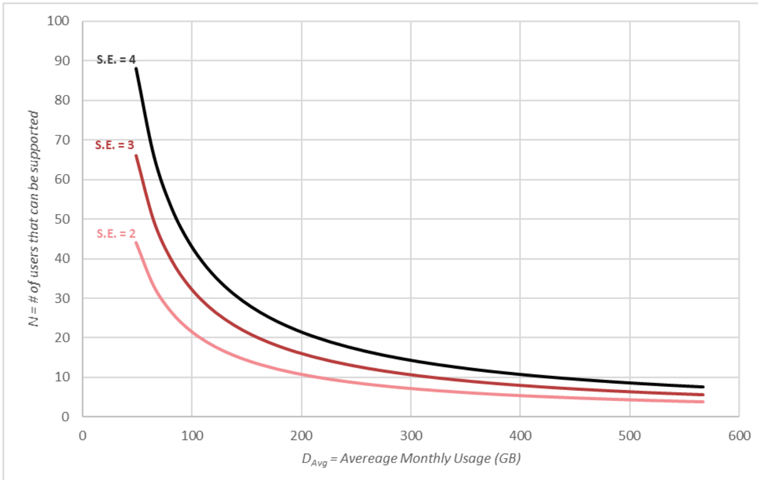

Figure 4 - Impact of Spectral Efficiency on Capacity

3.2.2.1. Limitations of Spectral Efficiency

While spectral efficiency is a good indicator of how well network resources are utilized, it can sometimes be misleading if there is no demand on the network. Evaluation was performed for congested cases and cases with low traffic demand.

The graph in Figure 5 shows a typical case where high data consumption during busy hours drives congestion and interference, resulting in reduced spectral efficiency. As utilization decreases, the interference reduces, and the spectral efficiency improves.

The site shown here in Figure 5 has 10MHz of high band LTE deployed on three sectors and is serving ~60 FWA users that account for almost 70% of the total traffic, the remaining being mobile traffic. Average distance of FWA users from the site is approximately 3.5 km with 20% users at cell edge beyond 6 km from the site. Weekly FWA download volume incurred is around 4.5 TB

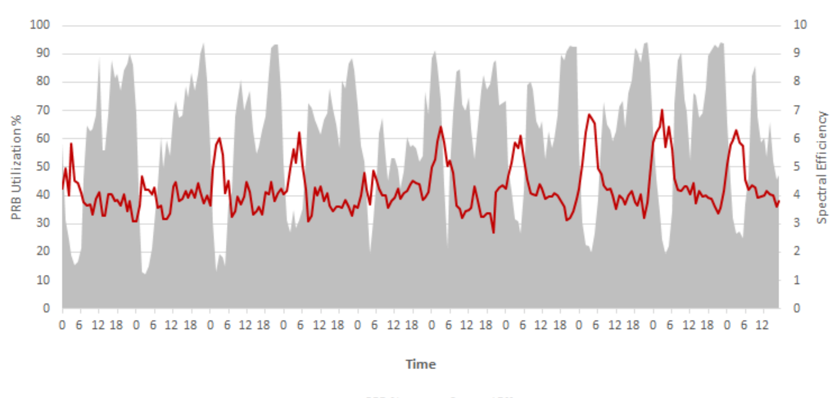

Figure 5 - High Traffic High Efficiency Site

The graph in Figure 6 ,however, shows a case which is less loaded but also with lower than expected, spectral efficiency. This is because most of the FWA traffic is generated from cell edge. As the traffic reduces, there is not much impact on spectral efficiency because there is not enough demand to efficiently utilize all resources. In these cases, spectral efficiency achievable during non-busy hours could potentially be much higher.

The site shown here in Figure 6 has 10 MHz of high band LTE deployed on three sectors and is serving ~25 FWA users that account for almost 36% of the total traffic, the remaining being mobile traffic. Average distance of FWA users from the site is approximately 5 km with 30% users at cell edge beyond 10 km from the site. Weekly FWA download volume incurred is around 2 TB

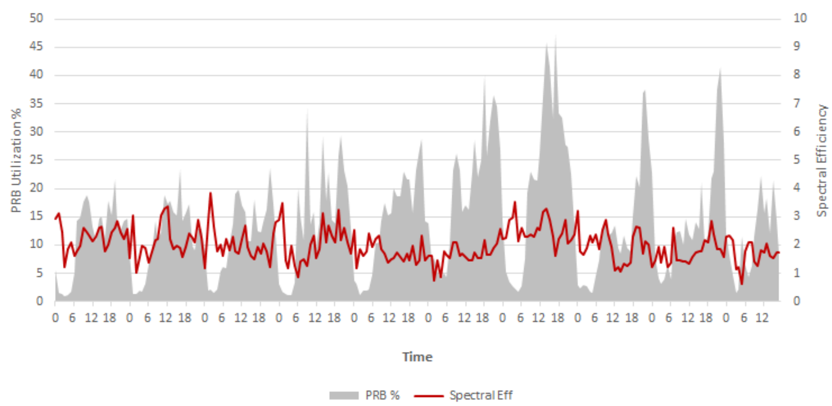

Figure 6 - Low Traffic Low Efficiency Site

Figure 7 shows how variation in demand and average RF conditions impacts spectral efficiency and could therefore impact capacity analysis. It is important for operators to consider these cases and determine whether the spectral efficiency considered is a true representation or not.

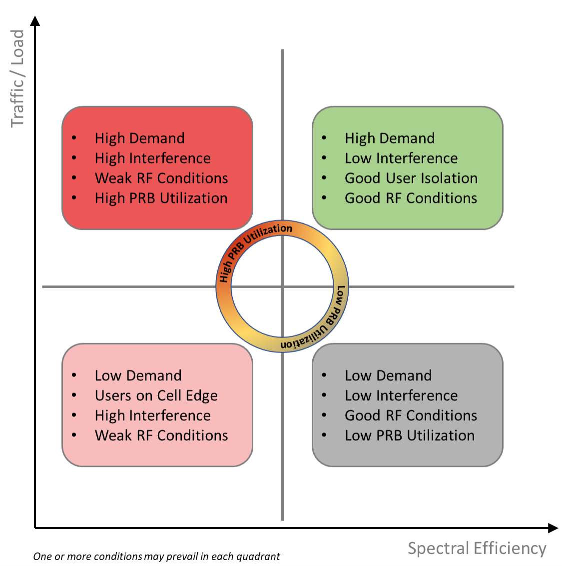

Figure 7 - Spectral Efficience & Traffic

3.3. Serviceability Recommendations

To deem a customer as serviceable, both coverage in the form of RF conditions and capacity play an integral role. RF conditions dictate how efficiently network resources can be utilized and that efficiency dictates how much capacity we obtain.

The following factors have significant influence on serviceability:

- **Technology deployed:** 5G in comparison to LTE can have up to 6% more resources blocks available for the same bandwidth at 15khz sub carrier spacing (SCS). 5G also allows for higher bandwidths and more flexibility on the air interface in terms of higher SCS and shorter timeslots.
- **Radio conditions:** Ability to achieve higher order modulation such as 256 QAM
- **Spectrum:** Available bandwidth and number of channels
- **CPE capability:** User Equipment (UE) category and type, e.g., equipped with high gain directional antenna, modulation and MIMO order supported, indoor in comparison to outdoor
- **Radio/Base Station capability:** MIMO streams or number of DL & UL streams supported. MU-MIMO capability increases spectrum efficiency tremendously, however, to achieve the right conditions to utilize MU-MIMO is very challenging
- **Data consumption / Traffic pattern:** Busy hour usage or data volume observed on the channels being considered
- **User distribution:** How are users spread across the coverage of the cell

All these factors significantly impact cell capacity and coverage reach. While it is possible to get a reasonable view of how many users can be supported on a given cell, the actual numbers will always vary depending on the impact on resource utilization with the addition of each user.

Figure 8 illustrates the concept of how the calculated capacity of X users with a given spectral efficiency can be impacted if users are added in favorable or unfavorable conditions.

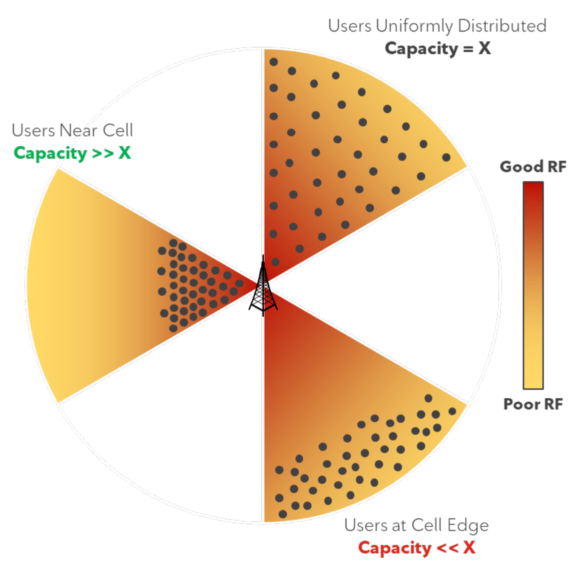

Figure 8 - Impact of user distribution across a cell on capacity

Therefore, when adding FWA users to a network, it is critical to target users that are:

- Located near the site, preferably with LOS (line of sight)
- Within good RF conditions of high band spectrum
- Using an outdoor CPE with a high gain directional antenna installed at a good height
- Served by cells that have high channel bandwidth and use advanced radios capable of MU-MIMO and beamforming
- Offered plans that control user behavior to avoid misuse or abuse of network resources. E.g., limit plans to advertised throughput speeds such as 50DL/10UL or 25DL/5UL. Or impose data volume caps or enforce throttling after a certain amount of monthly consumption.

3.4. Device Considerations

Device or CPE selection is critical as its capabilities determine the efficiency with which network resources can be utilized. With the device landscape maturing for 5G, it is recommended for operators to offer devices that support:

- 4G & 5G, including Dual Connectivity for supporting 5G-NSA (EN-DC)
- Carrier aggregation with 3, 4 or 5 component carriers depending on technology & network mode
- Higher order MIMO, supporting up to 4 downlink MIMO layers. Devices are also beginning to support up to 2 uplink MIMO layers
- 256 QAM on both downlink and uplink
- High channel bandwidth (individual and aggregated)
- 26 dBm maximum output power, power class 2 support on higher bands for better uplink performance
- Device management and performance measurement via TR-069, TR-143, TR-390
- External high gain directional antenna for better reception

However, service providers are often challenged with the kind of CPE that can be offered to their target markets. Primarily it is a choice between an indoor and outdoor device, and there are various factors and CPE attributes that operators need to evaluate to make that decision. These factors also lead to compromises on the features listed above. Table 2 - Indoor vs Outdoor CPE Comparison covers some of them.

Table 2 - Indoor vs Outdoor CPE Comparison

Attribute	Indoor CPE	Outdoor CPE
Form Factor	Typically, the size of a regular indoor wireless router	Bulky, like an outdoor access point, depends on antenna size
Installation	Simple, quicker, and easier to install. Do it yourself (DIY) job for customer	Complex, needs to be mounted securely and aligned towards the best server, usually requires a professional install
Coverage & Range	Limited coverage and signal reception due to in-building penetration losses, higher interference from other close by devices and lower antenna gains	Extended coverage. Outdoor placement allows for direct line of sight with the base station, which leads to better signal reception. Directional high gain antenna also leads to better isolation from other devices for lower interference and improved signal quality

Attribute	Indoor CPE	Outdoor CPE
Performance	Peak throughput performance is impacted because it is usually equipped with smaller lower gain antennas which causes weaker signal reception. Its small factor also often results in reduced capabilities such as number of downlink MIMO layers supported.	With the use of large higher gain antennas and better signal reception, peak throughputs are easily achievable.

Outdoor CPEs, professionally installed, are generally preferred for their better signal reception, extended coverage, and higher performance particularly in rural or challenging deployment scenarios. They help with improving spectral efficiency and put less stress on network capacity. However, indoor devices are still offered for better market penetration and customer acceptance because of their quick and simple DIY installation, aesthetic designs, and flexibility to place them anywhere where there is coverage. Figure 9 gives a general FWA setup for indoor and outdoor CPEs.

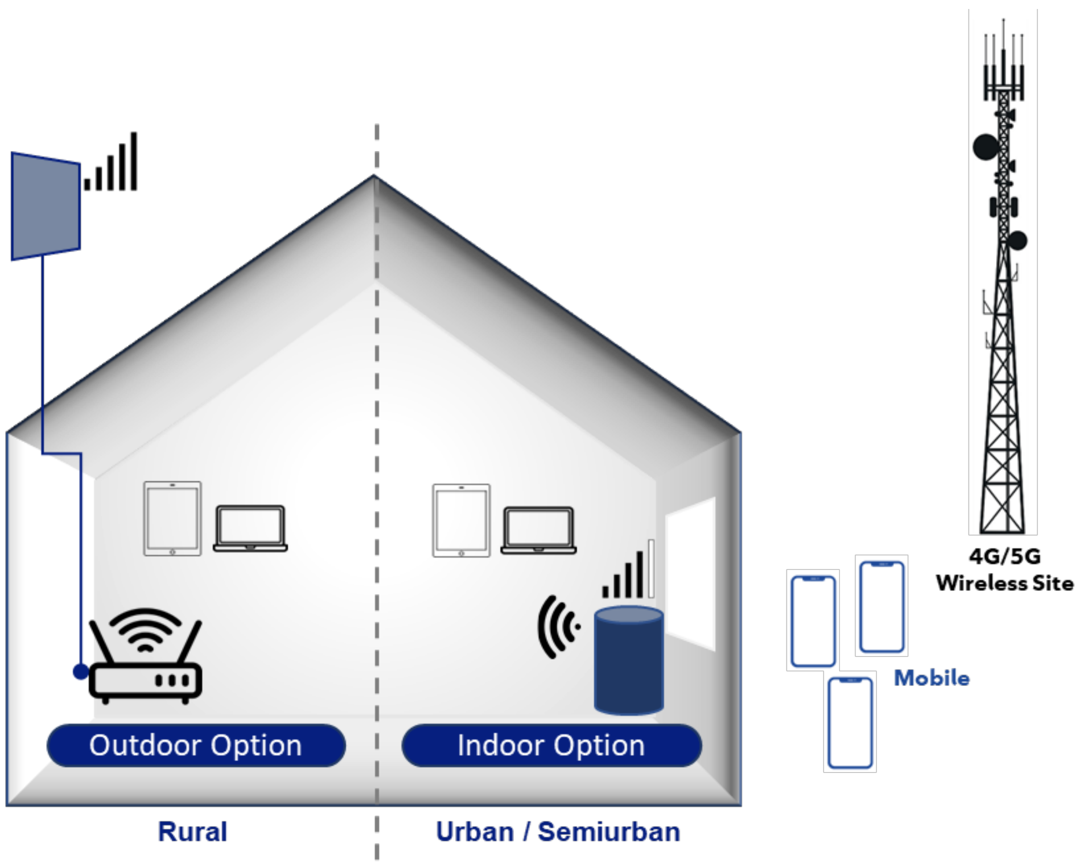

Figure 9 - Indoor & Outdoor CPE Setup

The graph in Figure 10 shows LTE high band RSRP variations observed against distance of CPE from the base station. Outdoor CPE considers an external antenna with a gain of 16 dBi. A trend is extrapolated for indoor CPE on the same graph that assumes an additional loss of 18 dB (10 dB inbuilding penetration loss and 8 dB reduced antenna gain). Assuming a cut-off at -105 dBm for target service levels, it can be deduced that Indoor CPEs reduce coverage from 8 km to approximately 1 km

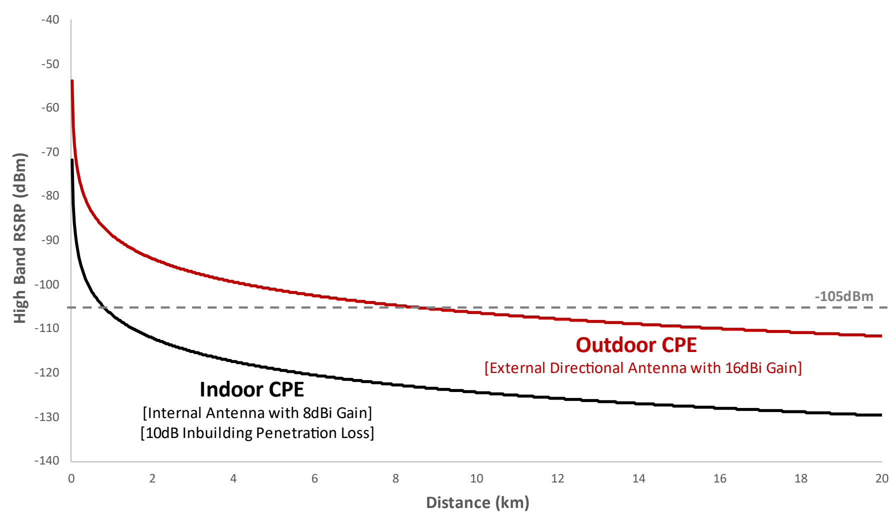

Figure 10 - Relation between High Band RSRP and distance from site

3.5. Fair Usage Policy

Across broadband networks, it has been observed that there are users with extremely high data consumption. With limited spectrum resources available on the wireless air interface, this would create capacity problems and degrade the experience for the rest of the users. Therefore, implementation of proper fair usage policies is recommended, which may be in the form of introducing:

- Data bucket plans where the users are only allowed a certain volume of data each month. Any overage after that may be charged with a higher rate
- Throttling speeds to a lower bandwidth once users surpass a certain usage each month

4. Network Management Features for FWA

As previously stated, a practical FWA solution is to deploy FWA service over 4G/5G networks. Utilizing an existing mobile network infrastructure, FWA deployment is relatively quick and cost-efficient. Despite the benefits, co-existence of FWA users and mobile users, each with their own distinct requirements brings up new challenges. It is vital to optimize the radio access network (RAN) features and parameters to ensure efficient sharing of resources between FWA and mobile users.

4.1. FWA Recognition in the RAN

As part of 4G/5G security architecture, the identity of users is not visible by design within the access network. Temporary identities are used instead with the mapping to the users' permanent identities known only by the core network. For the RAN to apply customized treatment, FWA users and FWA traffic must be identified. Within 3GPP specifications framework, there are several techniques that can be implemented in the core network to assist the RAN in identifying FWA traffic.

4.1.1. UE-level Identification

To support FWA user management in the RAN, the core network can assign a planned UE-specific ID to FWA users and signal the value to the RAN every time the FWA user connects to the network.

4.1.1.1. Subscriber Profile ID (SPID)

The SPID, also known as RAT/frequency selection priority (RFSP) index, is typically assigned to specific subscriptions such as FWA. When received by the RAN, it is mapped by the radio base station to locally defined configurations designed to apply specific FWA strategies.

4.1.1.2. Network Slicing

One of the fundamental features of 5G is the concept of network slicing. A network slice is an end-to-end logical network consisting of a subset of network resources configured by the operator to serve a specific business requirement (e.g., MBB, FWA, WPN). The network slice is identified by the user, RAN and core through a single network slice selection assistance information (S-NSSAI) value. With the RAN, network slices are mapped to logically separated radio resources designed to ensure the requirements of each network slice.

4.1.2. Bearer/Flow-level Identification

In 4G/5G networks, the most fundamental unit for Quality of Service (QoS) is a single end-to-end data stream that is called “bearer” in 4G and “QoS flow” in 5G. For customized FWA QoS treatment, FWA bearers/flows should be identified and configured with distinct QoS parameters compared to mobile bearers/flows. Even within FWA bearers/flows, there might be a requirement to distinguish between them. For instance, each FWA CPE may have two different bearers/flows: one for user data traffic and the other for CPE remote management.

Among the most important QoS parameters linked to each bearer/flow are the QoS class identifier (QCI) for 4G, the 5G QoS identifier (5QI) for 5G and the allocation and retention priority (ARP) used for both 4G bearers and 5G QoS flows

4.1.2.1. QCI/5QI

The QCI/5QI is an identifier that combines multiple QoS characteristics such as packet delay budget, packet error loss rate, priority and whether the bit rate is guaranteed or not. In addition to standardized QCI/5QI values, the operator can configure operator defined QCI/5QI values to meet service requirements. Within the RAN, the configured QoS (based on the QCI/5QI value) is mapped to internal RAN features and parameters to satisfy the required QoS of each bearer/flow.

4.1.2.2. ARP

ARP parameters dictate the desired QoS level of a bearer/flow during admission and preemption decisions. ARP parameters include a priority level, preemption capability and preemption vulnerability. At the time of network congestion, ARP configuration determines if a new bearer/flow with a higher ARP priority can be admitted at the expense of preempting an existing bearer with lower ARP priority. To protect mobile subscribers during overload periods (e.g., special events), operators may assign FWA bearers/flows with ARP priority lower than that of the mobile bearers/flows

4.2. Carrier Management

Cellular networks are typically deployed using overlaid multi-layer frequency bands. Depending on the operator's spectrum assets, the number of layers may vary. However, the layers are traditionally categorized into either capacity layers or coverage layers. A capacity layer is usually a higher frequency carrier with large bandwidth and advanced MIMO capabilities, but with limited wireless coverage. On the other hand, a coverage layer is a low frequency carrier (e.g., sub-1GHz) that can provide wide-area and deep indoor coverage; however, these layers typically have smaller bandwidths and basic MIMO capabilities and hence limited capacity.

To improve radio resource utilization and spectral efficiency, several carrier management techniques can be utilized within the RAN to ensure the subscribers are being served by the best carrier(s).

4.2.1. Limiting FWA Utilization of Coverage Layers

One of the key characteristics of FWA service is the stationary CPE. Before selling the service, the operator must perform a serviceability check and during the installation, especially for outdoor CPEs, a professional installer ensures the CPE is being served by the planned carrier. It is highly recommended to have FWA served primarily by the capacity layers as shown in Figure 11. The benefit is twofold: First, capacity layers are more suited to accommodate the high traffic demand of FWA. Second, the scarce resources on the coverage layer can be available to mobile users in weak coverage.

Utilizing SPID, the operator can configure customized FWA settings for both idle mode reselections and connected mode handovers that are different from default settings used by mobile users.

For idle mode control, the RAN sends dedicated camping priorities for the capacity layers (excluding the coverage layers) to the FWA user every time the connection is released. These dedicated priorities are used by FWA users instead of the broadcasted priorities used by all other users. If the dedicated priorities are valid, the FWA user (re)selects the best carrier among the capacity layers only.

In connected mode, the RAN is in control of steering the users between different carriers. In general, handovers between layers are triggered for various reasons e.g., RF based session continuity, load balancing, and priority based layer control. For FWA users, it is preferred to keep them on capacity layers. This can be achieved by restricting handover from capacity layers to coverage layers. However, even then if an FWA user lands on a coverage layer, either due to poor high band coverage or as the only available carrier during maintenance, RAN features can be configured to trigger the FWA user to handover back to capacity layers once they are available.

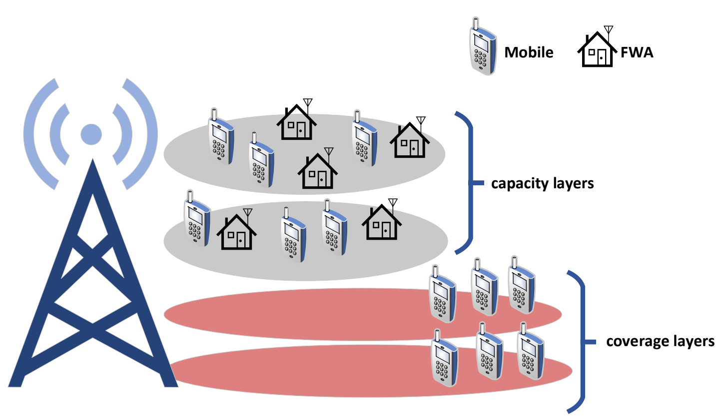

Figure 11 - FWA users sharing the capacity layers with mobile users

4.2.2. Prioritizing FWA utilization of the spectrum licensed only for Fixed Wireless Services

When the spectrum is auctioned, the license for spectrum usage may come with some restrictions. For instance, the 3.5 GHz band in Canada has been traditionally licensed for the exclusive use of fixed wireless services. Due to the importance of this band for 5G and following global trends, the Canadian government re-issued new licenses for flexible usage that allows for both mobile and fixed services. However, incumbent licensees are protected from having to transition to the new spectrum allocations for up to a 3-year transitional period in some areas.

When the operator has regulatory and/or business requirements to restrict the access of specific carriers to FWA usage only, RAN should provide a solution to support such requirements. In 5G non-standalone (NSA) networks, the access control on 5G carrier usage is performed on the 4G anchor side. In the scenario where a specific 5G carrier can only by used by FWA, 4G RAN must be configured such that 5G-capable mobile users cannot be anchored towards the restricted carrier, but can be anchored to use other 5G carriers as shown in Figure 12. To maximize radio resource utilization, 4G RAN should prioritize the FWA usage of the 5G restricted carrier and hence freeing enough resources for mobile on 4G and other 5G carriers. To further support this strategy, aggressive traffic steering mechanisms with 4G anchor carriers might be needed.

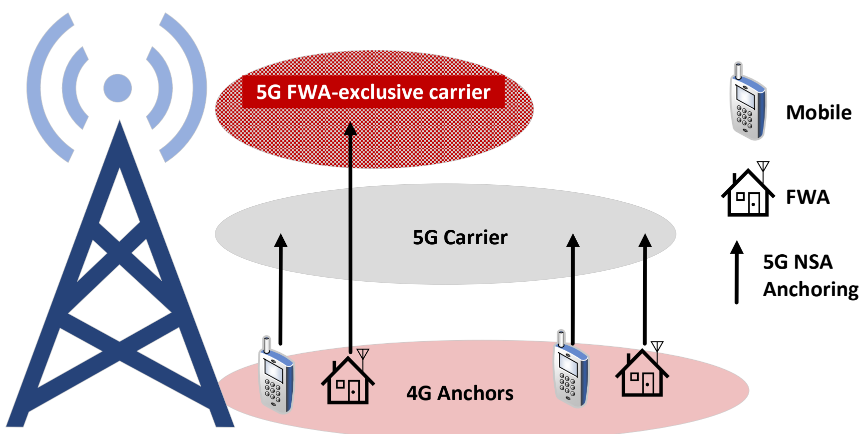

Figure 12 - FWA traffic prioitrized on FWA-exclusive 5G NSA carrier with no mobile access

4.3. Radio Resource Management

In wireless networks (point-to-multi-point communication), the radio resources are shared among all users. Radio resource management is a set of management techniques deployed in the RAN to control how the scarce radio resources are used to serve users as efficiently as possible. Radio resource management algorithms include admission control, scheduling, power control, interference management, modulation and coding schemes, MIMO, and beamforming.

4.3.1. FWA-Mobile Relative Priority Scheduling

In 4G/5G networks, the available radio resources are divided into small frequency-time units called resource blocks. The RAN node acts as a scheduler that assigns different chunks of resource blocks to different users for a data transmission time interval (TTI) of less than or equal to 1 millisecond. The scheduler needs to take a resource allocation decision every TTI taking into consideration the traffic load, the required QoS of each bearer/flow and the available resources. The scheduler's objective is to optimize network capacity and user experience. Generally, there are different scheduling algorithms such as round robin, maximum carrier-to-interference, or proportional fairness. In practice, the proportional fair scheduling is the most common algorithm that attempts to prioritize users with good radio conditions without starving users with poor radio conditions.

The deployment of FWA on a 4G/5G network is typically motivated by the fact that the radio resources are under-utilized on average. If the resources are available to satisfy the demands of both mobile and FWA users, the scheduling decision is somehow straightforward. However, at the TTI level, it is common to have high resource contention especially in the presence of bursty applications. In these scenarios, it may be preferable for the operator to configure the scheduler to protect the experience of mobile users after FWA deployment.

In addition to assigning different QCI/5QI for mobile users and FWA users, it is recommended to configure relative weights to protect the throughput of mobile users when there is high demand on resources from both mobile and FWA. The ratio between the FWA and mobile relative weights will depend on the level of desired relative experience during high resource contention. During the periods with no contention, full resource grants will be given to FWA users.

Figure 13 and Figure 14 show the statistics on a typical FWA site. While FWA users represent less than 10% of the total users, they consume more than 85% of the data traffic. Thanks to the relative priority scheduling, the throughput of mobile users is not impacted by the introduction of FWA service.

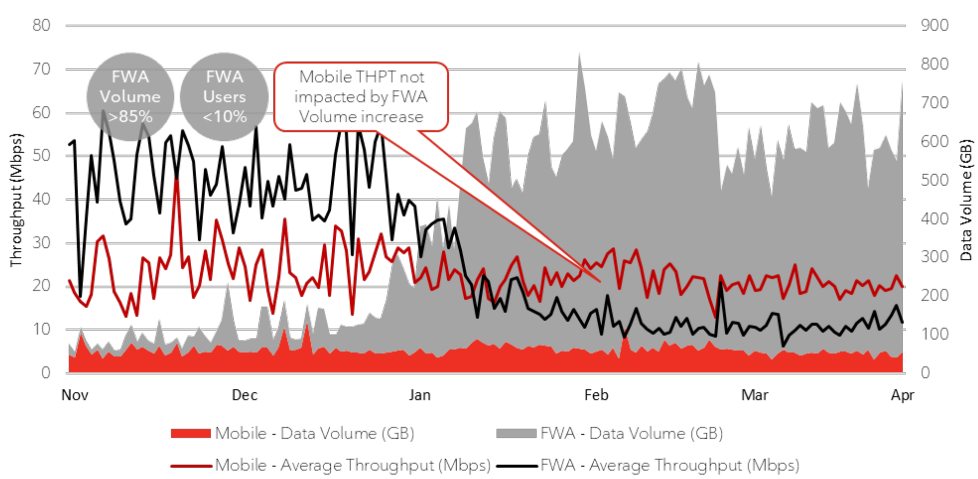

Figure 13 - FWA vs Mobile: Data Volume and Throughput

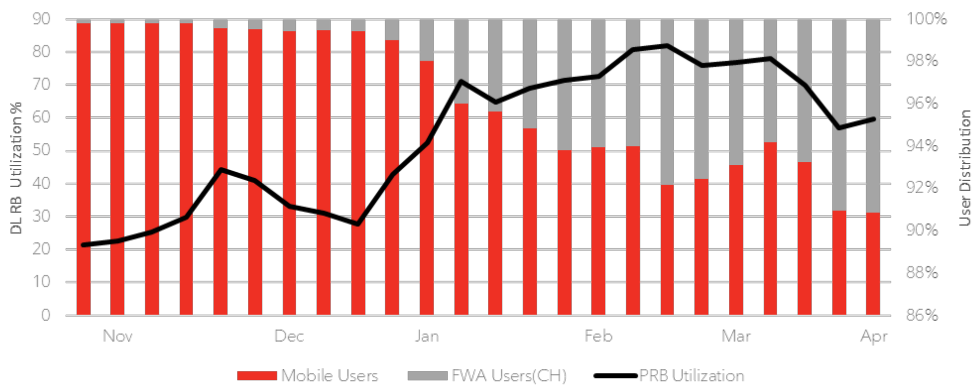

Figure 14 - FWA vs Mobile: Number of Users and Resource Block Utilization %

4.3.2. Differentiated Admission Control

Admission control is a key functionality that is used by the RAN node to decide whether there are enough resources to allow a new call or session to be adequately served without impacting the QoS of existing connections. When different services, such as mobile and FWA, are deployed on the same network, it is recommended to utilize differentiated admission control by assigning different ARP values. To protect mobile subscribers, FWA bearers/flows can be configured with lower ARP priority values.

Differentiated admission control could be achieved using differentiated blocking and/or preemption. During the periods of system resource shortage, the RAN prioritizes the admissions of mobile users with higher ARP priority over FWA users with lower ARP priority. Moreover, when preemption of existing sessions is necessary to free resources for incoming requests, the RAN prioritizes the preemption of FWA users with lower ARP priority over mobile users with higher ARP priority. The differentiated admission control preserves the accessibility and mobility performance of legacy mobile users after the introduction of FWA service in the network.

4.3.3. Differentiated Uplink Power Control

One of the mechanisms of radio resource management is the uplink power control. The RAN node controls how much power the device should use during uplink transmissions. This is typically dictated by specifying an uplink target power spectral density received by the base station known as P0. P0 is a parameter that is optimized to balance between the maximum uplink throughput and the overall network capacity. A higher P0 leads to higher signal to interference and noise ratio (SINR) resulting in higher uplink throughput, especially for users located close to the cell center. However, the trade-off of setting a high P0 value is the increase in the co-channel interference due to high power transmission by cell edge users.

If FWA devices are pre-planned to be in good/acceptable RF conditions, they might benefit from a P0 value, higher than that of the mobile users, to improve the reception of uplink transmissions from FWA, resulting in improvement in uplink throughput as well as downlink throughput due to more robust acknowledgement of downlink transmissions. Since the number of FWA users per cell are usually limited and their locations are typically near cell center, the increase in the co-channel interference has negligible impact on the SINR of mobile users on neighboring sites.

4.4. Revisiting the Battery Power Saving Features

Battery life is one of the major challenges facing mobile devices. It is a common practice that the RAN in 4G/5G networks deploy features that aim to provide battery power savings even if it comes at the expense of minor degradation in performance. On the other hand, FWA devices are usually not power-constrained and hence the settings of the power saving features should be customized in an FWA-aware RAN to alleviate any unnecessary performance degradation to FWA devices.

4.4.1. Discontinuous Reception in Connected Mode (C-DRX)

C-DRX is a mechanism that allows the 4G/5G devices to stop monitoring the downlink channel during certain reoccurring time periods, similar to entering a temporary sleep mode. For battery-operated devices, C-DRX can extend the battery life as the device has the chance to turn off some RF circuits and reduce power consumption. The trade-off is an increase in the downlink latency and a slight degradation in the user throughput which is a cost that most mobile users are willing to pay to extend their battery life.

Since FWA devices are not power constrained, there is no benefit of utilizing C-DRX and hence it is recommended that operators configure the RAN to disable C-DRX feature for FWA devices.

4.4.2. User Inactivity Timer

When the RAN detects that a connected user does not transmit or receive any data for a pre-configured duration, the UE is released to idle mode. The optimization of the user inactivity timer for mobile users is to balance between the benefits of battery life extension when the user is in idle mode and the increase in signaling traffic for frequent changes between idle and connected modes. For FWA users, a customized user inactivity timer is recommended since there are no concerns regarding power consumption.

5. Case Studies

This section will cover two case studies evaluated on the Rogers network and how their results influenced decisions on optimizing the performance of the fixed wireless access product provided to customers.

5.1. Case Study 1 – Consequences of Low Band Utilization

Fixed Wireless Access is generally an alternative to cable or fiber connectivity to the home, hence the requirements of the service are different to what a mobile UE would need. Having the FWA user served by low bands that generally have lower capacity introduces worse performance to the end user for a few reasons:

- Low bands generally serve users in poor radio conditions, hence the users utilize more resources. Adding FWA users to the pool of users on low band could lead to congestion and a negative impact on all users served by the cell.
- The lower capacity on low bands generally leads to lower end user throughputs even in the absence of congestion.
- Low bands are sometimes limited to lower MIMO configuration (using 2x2 MIMO instead of 4x4 MIMO) this essentially reduces the peak throughput by half.

These limitations on low band were observed from network and device statistics as well as from customer complaints. Due to these drawbacks, settings were introduced as discussed in section 4, to make sure FWA UEs are kept on high bands longer which resulted in improved overall experience.

In Figure 15, data collected from the CPE show that when the FWA UE is served by 700 MHz (Band 12) as the primary cell, the LTE and NR aggregated spectrum bandwidth available to the user is more than 50 MHz for just 6% of the time from the collected samples. While when the UE is served by 2600 MHz (Band 7) as the primary cell, around 70% of the collected samples show an aggregated bandwidth larger than50 MHz.

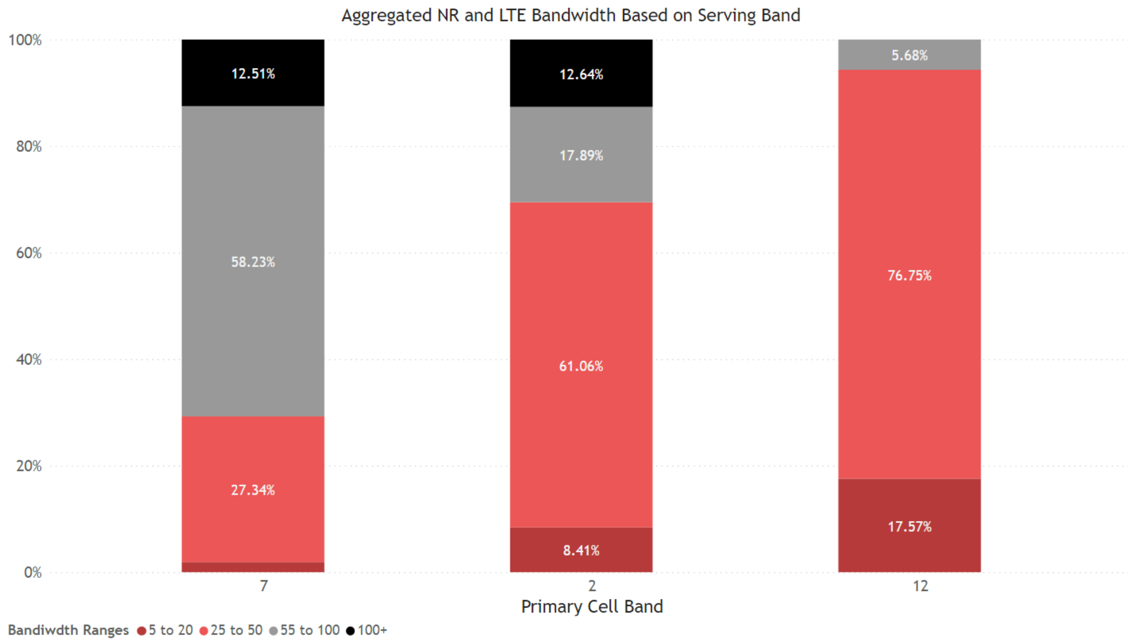

Figure 15 - Aggregated Bandwidth Based on Serving Band

From a network statistics point of view, Figure 16 shows the improvement in throughput attained on LTE and NR as a result of changes implemented to keep FWA users on high LTE bands for longer. The changes resulted in around 12% average throughput improvement for FWA users after reducing the percentage of traffic carried on low bands by 8%.

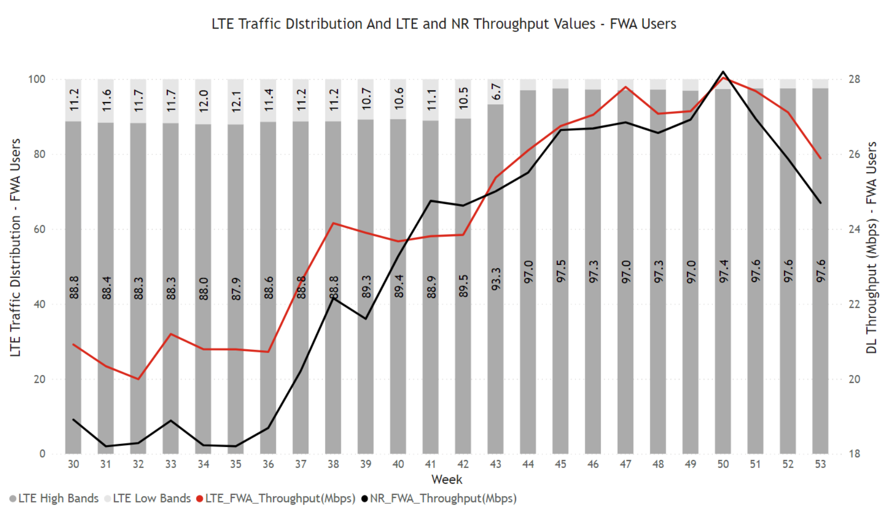

Figure 16 - FWA Network Level Statistics

5.2. Case Study 2 – Massive MIMO

Massive MIMO is a technique that utilizes an antenna array with large number of antenna elements and large number of transmitter and receiver chains [TRXs], typically significantly more than 8 [ref: Ericsson Massive MIMO Handbook]. Massive MIMO allows for improved air interface performance by enabling advanced beamforming, which can improve antenna directivity. In addition, massive MIMO facilitates the use of Multi-User MIMO (MU-MIMO) which can expand the capacity of the air interface by allowing the RAN node to schedule multiple users to utilize the same time and frequency resources, provided the users are sufficiently spatially separated. Massive MIMO is mainly used with an active antenna system, where the radio and the antenna are integrated into a single unit.

Massive MIMO active antenna systems are mainly used with NR TDD bands that are generally in frequency ranges greater than 2.5 GHz. As the frequency increases the optimal size of each antenna element in the array reduces allowing for the use of larger arrays while maintaining or even reducing the overall size of the antenna. In addition, for TDD, having a reciprocal channel allows for more accurate channel estimation and therefore, further improves gains from the use of massive MIMO antennas. Network statistics show that with massive MIMO antennas, a higher average spectral efficiency is achieved for FWA users. Figure 17 shows the median spectral efficiency for FWA users estimated from network statistics is 22% higher for Massive MIMO deployments compared to non-Massive MIMO deployments.

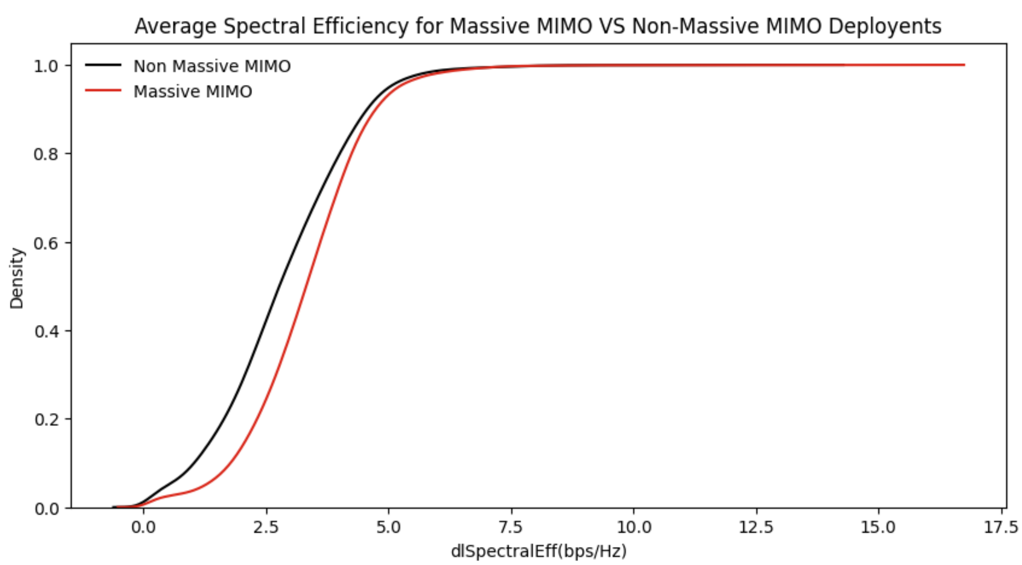

Figure 17 - Average Spectral Efficiency of Massive MIMO vs Non-Massive MIMO

MU-MIMO is expected to be more efficient for FWA users compared to mobile users since they have a higher data consumption rate and remain static. If there are more than two FWA users served by a particular cell and are sufficiently isolated to satisfy MU-MIMO conditions, those UEs will almost always satisfy the conditions. To observe this, network KPIs were analyzed to compare a set of nodes that predominantly serve FWA users and other nodes that serve mobile users and evaluate the difference in their cell capacity and MU-MIMO usage. Figure 18 shows sites predominantly serving FWA users utilize MU-MIMO 7% of the time while for sites with Mobile users this value is under 1%.

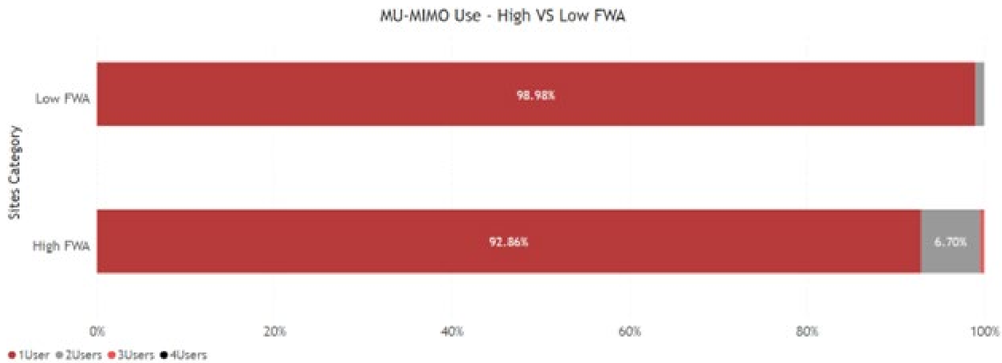

Figure 18 - MU-MIMO Usage: All FWA Nodes vs Mobile Nodes

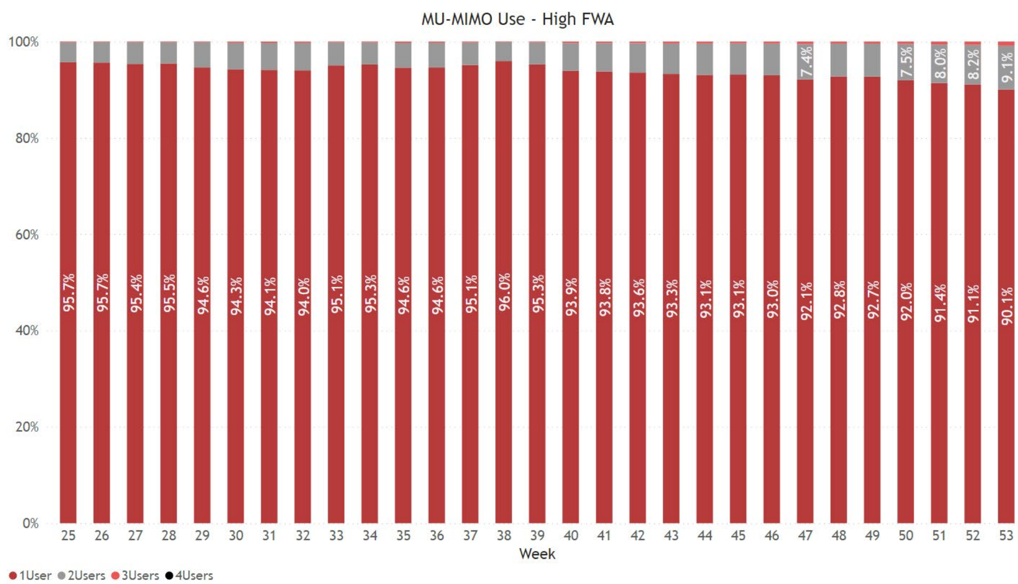

Figure 19 - MU-MIMO Usage Trend for FWA Serving Nodes

6. FWA: Lessons Learned, Prospects & Future

This section serves to summarize the best practices discussed in this paper and translate them into practical approaches and lessons learned. It then evaluates how FWA is also a valid use case for the urban environment and what is upcoming in context of the Canadian market.

6.1. FWA Recommendations

As operators continue to onboard more customers onto their 4G/5G networks and they tackle through issues, more clarity is achieved in terms of customer behavior and experience, traffic trends, installation issues, CPE issues, network management and impact of network features. Some of the key challenges broadly categorized with recommendations on how to address them are listed below.

- **Coverage Qualification:** To ensure customers are only onboarded where there is sufficient coverage available that can provide the desired service levels. This will avoid adding users on cell edge and/or low band, that will have greater impact on network resources and provide poor customer experience. It will also prevent failed truck rolls or technician visits to remote locations where there is no coverage available. Coverage qualification also helps with determining the dominant best server at customer locations and can guide field technicians to position and orient the CPE for best results. The following steps are recommended:

- Conduct proper link budget analysis as per network configuration to determine required RSRP thresholds. This will define the minimum signal strength customers will need to have at their locations
- Use industry standard propagation modelling tools to determine serviceable areas and best server
- Continuously invest in updating & tuning propagation models and in latest geo datasets

- **Capacity Evaluation:** To ensure customers are only onboarded where there is sufficient capacity or headroom available on best server cells. Many operators choose to calculate an absolute number that can be supported on each of their sites based on the most common configuration found on their networks and use that as a reference. While this may be sufficient for high level planning, it is not the preferred method for actual customer onboarding especially when the network is being shared with other services such as mobile which may be more significant for the operator. Operators are recommended to be more surgical about it and define a framework around capacity evaluation at cell level using methodologies like the one discussed in this paper and incorporate it into their serviceability process. To accommodate that, some best practices include:
  - Continuously monitoring the network for congestion
  - Define appropriate congestion thresholds, could be based on PRB utilization or any other performance KPI. Different markets (urban vs rural) can be addressed differently
  - Prioritize network build or upgrades where congestion is observed or fast approaching
  - Analyze traffic trends for seasonal variations and year over year growth. It is recommended to account for those when calculating available headroom to avoid future congestion and customer churn

- **Maximizing Spectral Efficiency**: This is essential for efficient utilization of network resources. While coverage and capacity checks during serviceability evaluation also helps with improving spectral efficiency, some network strategies can help further improve this as seen with the case studies discussed in this paper.
  - Use of Massive MIMO radios capable of MU-MIMO and beamforming. It helps with reducing interference and re-using resources amongst users sufficiently isolated within the same cell coverage
  - Using outdoor CPEs with high gain directional antenna, especially for cell edge users. This helps with reducing interference and improves uplink performance, prevents excessive low band utilization, and gives better coverage reach and experience to cell edge users

- **Network Management Features**: Many operators are offering FWA services on infrastructure, spectrum and network assets that are shared with mobile users. Depending on the operator's strategy and primary business, traffic balancing and prioritization becomes critical. Operators may choose to implement network features that prioritizes Mobile traffic to ensure FWA usage does not adversely impact critical mobile services. Some of the practices that have proved valuable are:

- Steering FWA traffic to high band capacity layers, and away from low bands that are generally reserved for cell edge mobile users and are also limited to lower order MIMO configurations
- Relative priority scheduling and differentiated admission control for mobile users over FWA users that protects the mobile experience as congestion on the cell increases due to FWA traffic
- Implement fair usage policies such as data caps, throttling or limited bandwidth plans to protect network from heavy users

It is important to note, not all features that work for Mobile use cases will work for FWA users as well. Operators need to work out customized settings for their FWA setup. E.g., FWA users can have higher differentiated uplink power control because they are less likely to cause adjacent channel interference or using battery saving features such as C-DRX and inactivity timer may not be useful for FWA users because these devices are not power constrained.

- **Device Selection & Installation**: Operators tend to select devices that are more acceptable by customers and have an attractive form factor. However, that often results in reduced capabilities of devices. Some important factors to consider related to FWA devices are:
    - Select CPEs capable of supporting latest 4G/5G features and enhancements
    - Deploy managed devices as it provides visibility to customer experience
    - Prefer outdoor CPEs over indoor for better spectral efficiency
    - Consider professional installs of outdoor CPEs that are securely mounted at sufficient heights to achieve line of sight and are oriented accurately towards the base station of the best server. This allows operators to control which part of the network (cells) traffic is added to. Improper or sub-standard installation may defeat the purpose of improving spectral efficiency

6.2. Urbanization of FWA

While the focus of developing FWA services has been on rural areas to serve unserved or underserved communities, 5G opens-up the potential for increased adoption of FWA in urban areas as well, where the demand for high-speed internet continues to grow.

High population density leads to a greater demand for broadband connectivity in a confined area, which can be efficiently addressed by FWA, especially in areas where wired infrastructure is either unavailable due to cost and implementation challenges or is outdated and difficult to maintain. Fewer physical components involved in FWA enable its rapid deployment, making it an attractive option for meeting immediate connectivity demands. Since last-mile connectivity to users is wireless, it causes minimal disruption to existing urban infrastructure.

Despite that, for FWA to be successful in urban markets and be competitive to the cable broadband offerings, its success largely depends on:

- Providing throughput speeds comparable to cable broadband
- Provide reliable indoor coverage
- Use convenient indoor devices as physically mounting outdoor CPEs may not be possible for multi dwelling units or urban environments
- Offer competitive pricing

As technology continues to evolve and 5G networks become more widespread, FWA is likely to play an increasingly important role in meeting the digital demands of our expanding urban centers.

6.3. Future Developments in FWA

The future of FWA appears to be promising, with several developments and prospects on the horizon. As 5G deployment gains momentum with operators in Canada, FWA stands to benefit from its expanded coverage and greater network efficiency, extending its reach to more underserved communities and communities previously only served with 4G.

A key feature introduced with 5G is network slicing that particularly benefits the FWA use case. It allows providers to partition their network into virtual end to end slices, each of which can be tailored to specific applications and user needs. This ensures optimized performance and quality of service for FWA and other services sharing network resources. Operators have been trialing this feature and are now expected to start implementing it.

The forthcoming 3800MHz auction in Canada also holds the promise of making additional capacity bands available, presenting a valuable opportunity to address FWA congestion concerns and empowering operators to improve the quality of services offered to FWA consumers.

Next on the horizon are prospects of using millimeter-wave (mm-Wave) technology for FWA. Its immense capacity, ultra-high speeds, and minimal latency, achieved by using large channel bandwidths, holds tremendous promise for FWA applications. However, the adoption of mm-Wave does come with its challenges, particularly in terms of coverage and propagation. In building penetration, foliage or propagation losses are extensive which makes it infeasible for FWA in non-line of sight conditions. The mm-Wave spectrum in Canada is yet to undergo auction, and while some operators are conducting trials, widespread implementation remains to be seen globally.

7. Conclusion

FWA isn't a threat to fiber or vice vera, rather the two complement each other. In context of bridging the digital divide and depending on an operators' broadband strategy, some key FWA deployment scenarios that emerge are:

- Quick turnaround to reach underserved communities via FWA, while fiber build follows. 5G infrastructure developed for FWA will gradually progress to cater mobile growth in the area once the fiber infrastructure is developed
- Customers in served communities that can compromise on performance and are on a budget. Key opportunity for operators is to utilize unused wireless capacity during non-busy hours
- Businesses that demand backup connections or an alternate to a wired connection
- Address residential customers in urban areas where wired connection is not available or outdated

With the ever-increasing demand of broadband connectivity and finite resources on the air interface that are usually shared with other services such as mobile, service providers continue to face challenges of providing fast, reliable, and consistent speeds to their customers along with sufficient capacity during busy hours. The paper has tried to identify best practices and recommendations that would help operators continue successfully on this journey and truly help bridge the digital divide in our communities.

Abbreviations

FWA	Fixed Wireless Access
MBB	Mobile Broadband
CRTC	Canadian Radio-television and Telecommunications Commission
LTE	Long Term Evolution
CA	Carrier Aggregation
CPE	Customer Premises Equipment
MIMO	Multiple Input Multiple Output
MU-MIMO	Multi-User Multiple Input Multiple Output
SCTE	Society of Cable Telecommunications Engineers
SPID	Subscriber profile ID
RAN	Radio access network
RFSP	RAT/frequency selection priority
RAT	Radio access technology
DL	Downlink
UL	Uplink
TDD	Time Division Duplexing
LNF	Log Normal Fade Margin
RMa	Rural Macro
S-NSSAI	Single network slice selection assistance information
mmWave	Millimeter-wave
QoS	Quality of service
PC-2	Power Class 2
PUSCH	Physical Uplink Shared Channel
SINR	Signal to Interference and Noise Ratio
CQI	Channel Quality Indicator
MCS	Modulation Coding Scheme
BLER	Block Error Rate
QCI	QoS class identifier
5QI	5G QoS identifier
ARP	Allocation and retention priority
NSA	Non-standalone
TTI	Transmission Time Interval
SINR	Signal to Interference and Noise Ratio
C-DRX	Discontinuous Reception in Connected Mode

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