5G Fixed Wireless Access

A Technical Paper prepared for SCTE by

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Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

List of Tables

Title **Page Number**

1. Introduction

5G radio with the new frequency bands such as C-band provides significant capacity through increased bandwidth and higher spectral efficiency potential with mMIMO. This high capacity can be efficiently utilized by Fixed Wireless Access (FWA) customers. The high radio efficiency is important for FWA services because typical FWA customers consume more data than mobile customers. The need for a 5G FWA service is high in many markets because the fiber rollouts are expensive and take time, and because 4G LTE radio capacity is typically too limited for a FWA service.

This white paper analyses 5G radio capacity, the impact of device and end-to-end optimization, the benefits to FWA provided by network slicing, and the usage of millimeter wave (mmWave) spectrum in FWA applications. The field results show that 5G radio with 100 MHz spectrum can support more than 100 FWA subscribers per cell. The experience also shows that the device (Customer Premises Equipment, CPE) and end-to-end optimization can boost FWA performance. Further capacity and even higher data rates can be provided with 5G mmWave. Existing base station sites with mmWave can offload up to 50% of sub-6 GHz traffic. The default radio scheduler implementation does not differentiate between data services (eMBB vs. FWA) but with slicing, scheduling weights and radio resource partition can be separately optimized per service. With slicing, low-latency features can be also applied and optimized selectively for FWA service.

A 5G FWA service allows mobile operators to efficiently monetize their current excess 5G TDD radio capacity without waiting for a 5G core network and standalone architecture for other new use cases. 5G FWA is an untapped capability offered by 5G radio which can be monetized today.

2. 5G Downlink Capacity Evolution

A typical mobile subscriber uses 20 GB of data per month while a fixed network subscriber uses 20 times that amount: 400 GB per month or more. Therefore, FWA services requires very high radio capacity. 5G radio enables an attractive starting point for FWA because 5G is designed to provide high capacity and high data rates.

The main solutions enabling high capacity are the new mid-band TDD spectrum and massive MIMO beamforming antenna. Figure 1 illustrates the practical 5G TDD capacity in live networks today using 100 MHz bandwidth using either single user MIMO (SU-MIMO) or multi-user MIMO (MU-MIMO). The graphs illustrate the carried traffic in terms of gigabytes per hour cell as a function of cell Physical Resource Block (PRB) loading. Each dot represents data in a single cell. A linear trendline is added to the graphs to illustrate the achievable capacity with 100% loading.

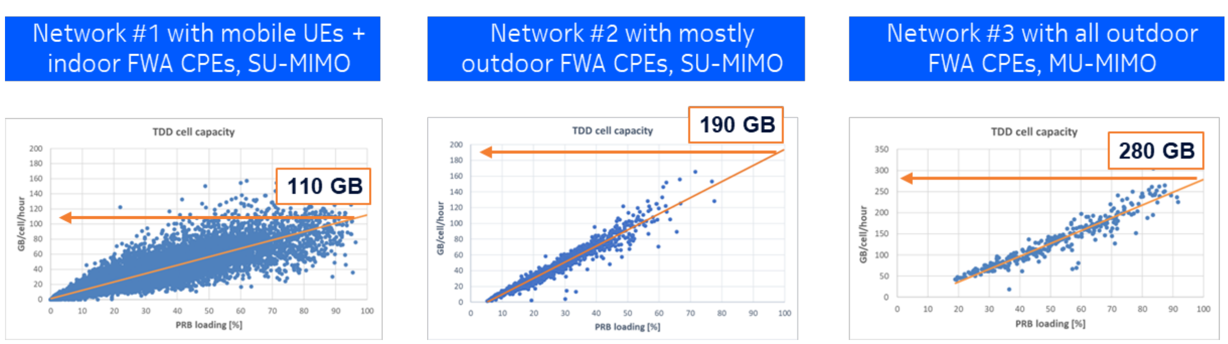


Figure 1 – 5G TDD cell capacity in live networks

The results show that current 5G with SU-MIMO supports 110-190 GB/cell/hour. Network #1 shows 110 GB/hour with mostly mobile devices and indoor FWA units while Networks #2 has relatively more FWA traffic and some outdoor units. The different types of traffic and devices can explain part of the difference in the maximum capacities. Network #3 shows that the current 5G FWA capacity can be as high as 280 GB/hour in a cell with all FWA outdoor CPEs and when MU-MIMO is enabled.

Let's then look in more detail at the steps to boost the 5G radio capacity for the FWA use case starting from the 110 GB/cell/hour baseline we see in live networks today (Figure 3). The main technology components are Multiuser-MIMO (MU-MIMO), FWA specific optimization, FWA CPE RX enhancement, and a second phase of extreme MU-MIMO with interference cancellation.

1. MU-MIMO refers to the beamforming solution where multiple devices can reuse the same resources in the time and frequency domain in the different beams. The field results indicate that MU-MIMO provides typically 50-70% capacity gains during high load (see Figure 2).

Figure 2 – 5G Multi-user MIMO gain in a live network

We assume a 50% MU-MIMO gain in the evolution steps model below.

2. FWA CPE performance can be optimized including CPE antenna type and CPE locations. This provides a major capacity enhancement potential. CPE outdoor antenna provides a 60% capacity gain, and its deployment can be selective based on location.

   CPEs in a weak signal area cause two challenges: 1) the data rate is low especially in the uplink, and 2) the CPE consumes more downlink resources because of the high power required. As shown in Figure 3, a 29% capacity gain can be expected by moving weak signal CPEs to a better position (7dB signal level improvement assumed). 62% capacity gain was seen by using outdoor antennas for weak signal CPEs (15 dB signal level improvement assumed).

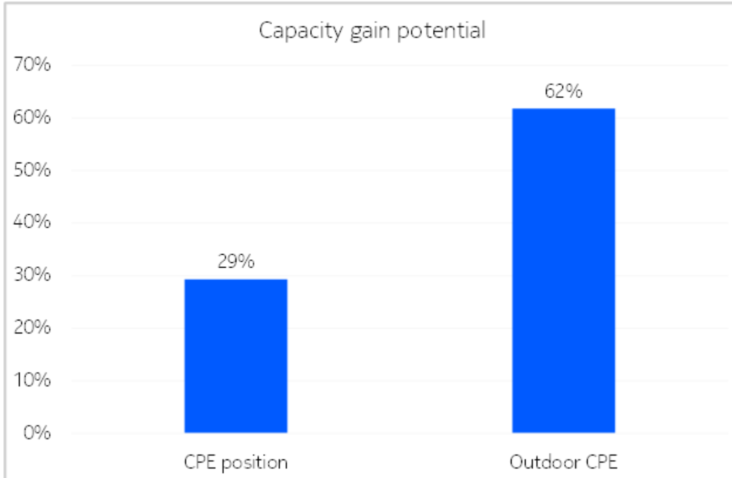


Figure 3 – Capacity gain due to CPE optimization

We assume in the following capacity evolution analysis a 40% gain due to outdoor CPE antenna based on the signal level statistics collected from an indoor FWA CPE.

3. FWA optimization in the radio network refers to multiple solutions for specifically optimizing the FWA service including beamforming, packet scheduler, traffic steering and slicing. We assume here 20% gain from FWA optimization.

4. CPEs with 8RX receiver can boost capacity by 10-15% according to measurements.

5. Extreme MU-MIMO refers to the further enhancement of MU-MIMO for minimizing interference between co-scheduled devices with Zero-Forcing algorithms. We assume here 25% gain.

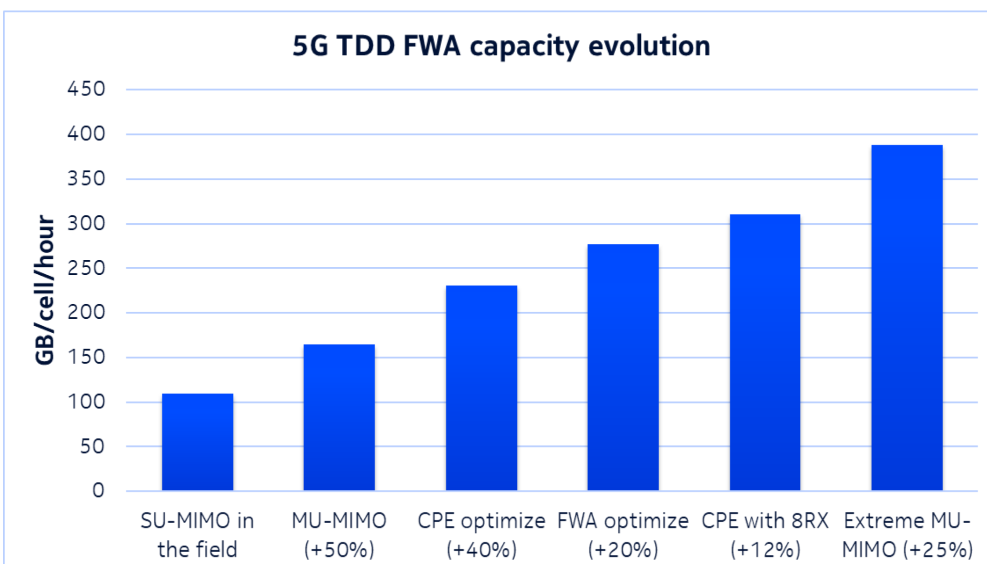


Figure 4 – 5G TDD FWA cell capacity evolution steps

When combining these steps together, the expected cell capacity will grow from the current lowest figure of 110 GB/cell/hour to approximately 390 GB/cell/hour.

Figure 5 illustrates the maximum number of FWA subscribers per cell assuming that the average usage is 500 GB/month, maximum 90% cell loading is allowed during peak hour, with the peak accounting for 10% of the daily traffic which are typical figures in the current FWA deployments. The typical FWA subscriber data usage is 300 – 500 GB/month currently. The results show that up to 150-200 FWA subscribers can be supported with a single 5G TDD sector using 100 MHz bandwidth.

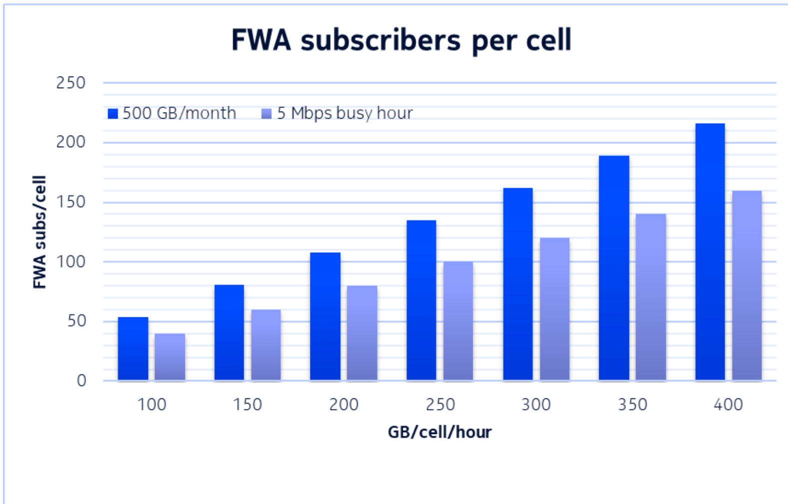


Figure 5 – 5G TDD FWA subscribers per cell

3. Uplink Capacity Evolution

This chapter provides insights into 5G uplink capacity illustrating typical spectral efficiencies that are currently seen, and showcasing advanced technologies that can further improve the uplink capacity in the future.

3.1. Uplink SU-MIMO baseline

The median uplink spectral efficiency among radio networks today is 2.2 bps/Hz when using SU-MIMO (Single User MIMO). This is illustrated in Figure 6 below.

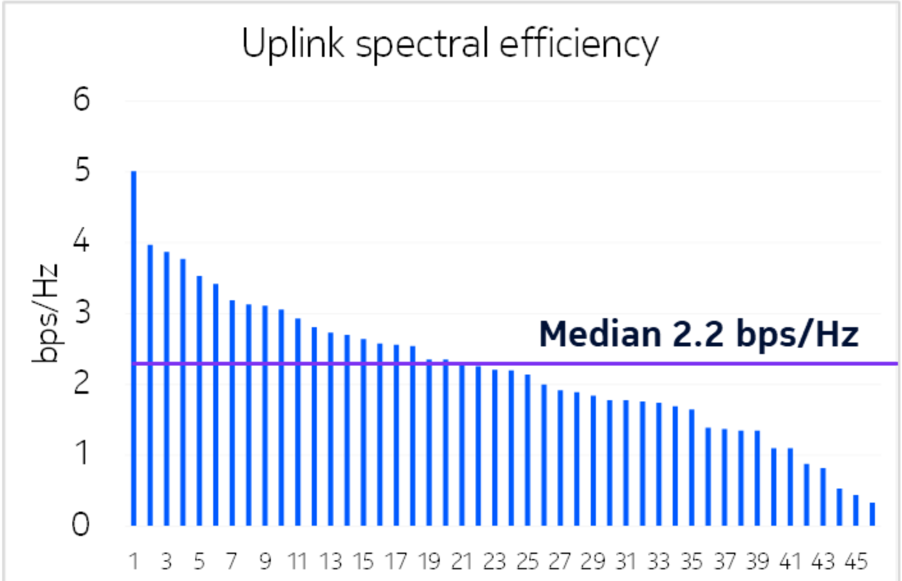


Figure 6 – Uplink Spectral Efficiencies in Networks Today (SU-MIMO)

3.2. Uplink MU-MIMO

In terms of number of subscribers supported, SU-MIMO median spectral efficiency shown above would translate to 21 users per cell with 10 Mbps uplink, with assumptions as shown in Table 1. With MU-MIMO, the spectral efficiency is estimated to increase to 5.4 bps/Hz which would mean that 50 users can be supported at 10 Mbps.

Table 1 – Number of Subscribers Supported in Uplink vs MIMO technology

MIMO Scheme	SU-MIMO	MU-MIMO
Spectral Efficiency	2.2 bps/Hz	5.4 bps/Hz
Cell Throughput (100 MHz TDD carrier)	52 Mbps	125 Mbps
User Activity	25%	25%
Average Throughput of 10 Mbps User	2.5 Mbps	2.5 Mbps
Number of Users Supported at 10 Mbps	21 Users	50 Users

Figure 7 shows an example comparison of uplink data volumes achieved with MU-MIMO and SU-MIMO. It illustrates that the uplink data volume increases by more than 70% with MU-MIMO activation even as the PRB loading goes down. The spectral efficiency is increased by a factor of 2.5.

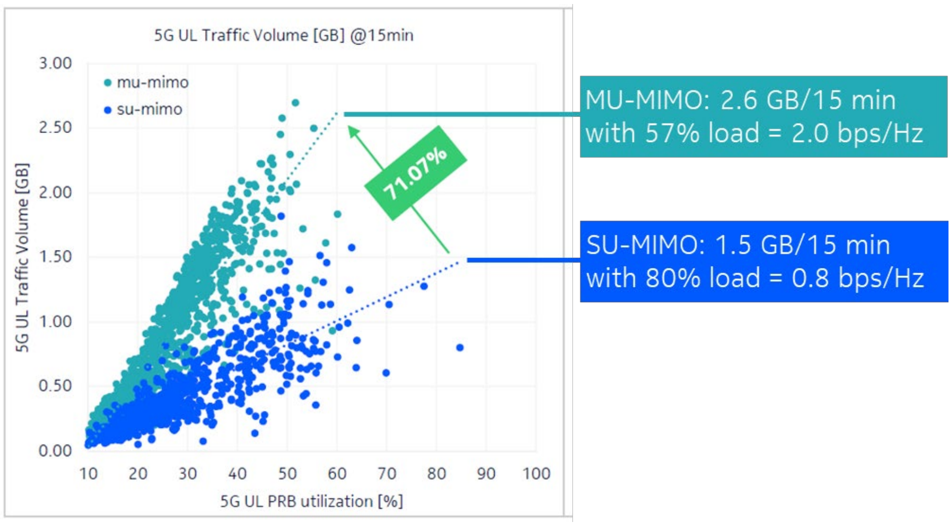


Figure 7 – Capacity Gain of Uplink MU-MIMO

3.3. UL-MIMO impact on user data rate

One benefit of 5G over LTE is that in uplink 5G devices support 2 transmit paths compared to only 1 transmit path in LTE. Therefore, 5G supports rank 2 UL-MIMO (Uplink MIMO) whereas LTE devices only support rank 1. Although standardized since Rel10, in practice there is no UL-MIMO in LTE, and it has always been limited to UL-CA which also has had little success.

In NR, NSA UEs always needed to have 2TX (one for the uplink LTE leg, one for the UL-NR leg). It means that for existing devices UL-MIMO has also become feasible in NR SA (Standalone) operation. Currently UL-MIMO is limited to NR TDD but it is forecasted to also be supported for NR FDD in the future.

Figure 8 shows UL-MIMO gains achieved with a regular UE in drive tests. With 64QAM, the UL-MIMO the user throughput gain was +61%, and with 256QAM the gain was +52% when compared with rank 1 throughput.

Field Performance (NR, cmW TDD, 64TRX, n77, 100MHz)	NSA (1Tx) Concurrent	SA (2Tx) Concurrent	
Drive Route 1, TCP Uplink Single UE Throughput 64QAM, Average, 1086 gain %	~3.4% (SSB: 82.7 Mbps, 1086: 85.4 Mbps)	~8.7% (SSB: 126.7 Mbps, 1086: 137.7 Mbps)	+61% 2TX gain
Drive Route 1, TCP Uplink Single UE Throughput 256QAM, Average, 1086 gain %	~11.1% (SSB: 86.3 Mbps, 1086: 95.9 Mbps)	~11.7% (SSB: 130.6 Mbps, 1086: 145.9 Mbps)	+52% 2TX gain

Figure 8 – 5G UL-MIMO gain in field tests

3.4. 5G Uplink 3-layer CA

3-layer uplink CA (Carrier Aggregation) combines UL-MIMO solution described above with Uplink CA and is specifically designed for FWA use cases, see Figure 9. This solution will initially be available for FDD+TDD CA scenario, however 3GPP Release 17 also defines the TDD+TDD solution.

The solution extends FR1 TDD + FDD uplink Carrier Aggregation so that UL-MIMO can be used in the TDD carrier for devices that are capable of 3TX transmission.

It is expected that this solution will provide the following improvement of peak throughput compared to 3GPP Release 15 uplink CA solution:

- +75% uplink throughput improvement (100 MHz TDD + 10 MHz FDD)
- +65% uplink throughput improvement (100 MHz TDD + 20 MHz FDD)

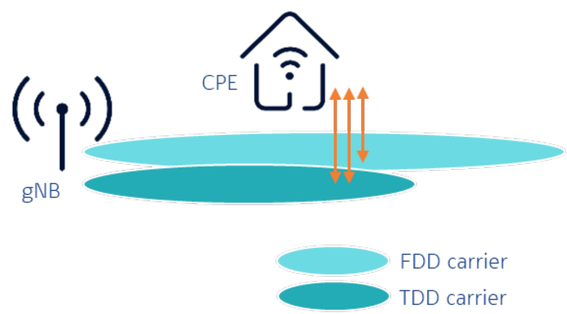


Figure 9 – 5G Uplink 3-layer CA Solution

Additional 5G uplink capacity evolution solutions are discussed in Chapter 5.

3.5. Uplink Throughput Evolution Summary

Table 2 summarizes the estimated 5G uplink capacity evolution steps in terms of cell throughput gain and user peak throughput gain.

Table 2 – Estimated Throughput for 5G Uplink Capacity Evolution Steps

	UL SU-MIMO	UL MU-MIMO	UL MIMO	UL 3-layer CA 20 MHz FDD
Cell Throughput (100 MHz TDD)	52 Mbps	125 Mbps		
User Peak Throughput (100 MHz TDD)	110 Mbps		220 Mbps	320 Mbps

4. Slicing for FWA

With 5G slicing, logical networks with varying characteristics and use cases can be created on top of common 5G RAN infrastructure.

The following characteristics can be defined by operators individually per slice:

- Slice-specific Performance Management
- Radio Scheduling Priority (scheduling weight)
- Radio Resource Partition
- Radio Latency Parameters

- Radio Layer Management
- Radio & Core Security Parameters

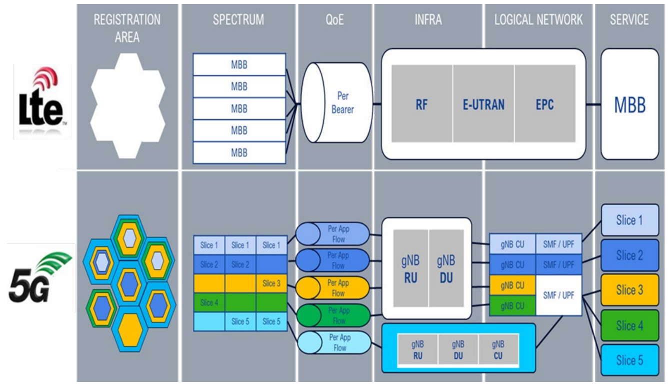


Figure 10 – 5G Slicing architecture for RAN

Slicing solution for FWA enables high performance sliced internet access services – see Figure 11 for high level architecture of the solution. Different FWA service tiers and subscriptions can be established with slicing. Slicing allows setting up various service and application category slices for FWA users, e.g. internet, voice, IPTV, streaming, gaming etc. The network load can be dynamically balanced between FWA users and mobile users, while ensuring a minimum capacity for the FWA users.

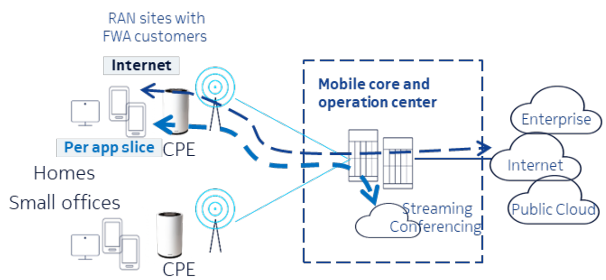


Figure 11 – 4G/5G FWA slicing end-to-end deployment

Let's look in detail the following key benefits of the FWA slicing solution inside 5G RAN:

- Enhanced radio scheduling provides dedicated scheduling weight and radio resource partitioning per slice
- Optimization of frequency layer management allowing separate mobility and handover frequency targets and thresholds
- Enhanced performance visibility with separate KPIs per slice
- Optimization of low latency services using scheduling request optimization per slice

Default radio scheduler implementation does not differentiate between data services (eMBB vs. FWA) With slicing, the scheduling weights and radio resource partition can be separately optimized per service.

Figure 12 below shows an example where unwanted FWA traffic peaks can saturate the cell capacity on a site. Slice based radio resource partitioning was applied to better balance the traffic between the eMBB and FWA services.

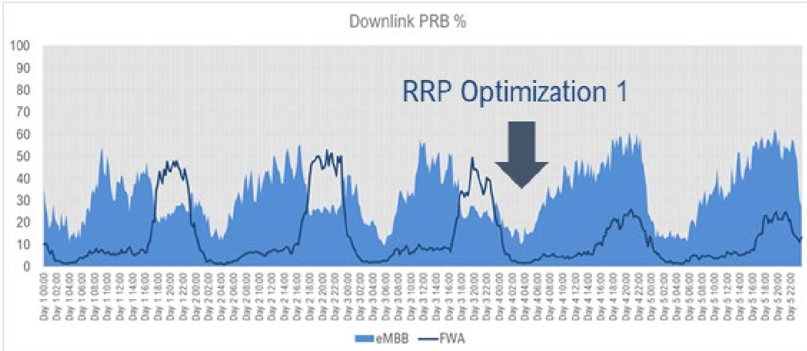


Figure 12 – Balancing traffic between eMBB and FWA slices

Another use case for slicing based radio resource partitioning is shown in Figure 13 below. Prior to applying RRP, the FWA end user experience was inconsistent resulting in highly varying downlink throughput. After activating RRP the biggest dips in the downlink throughput were eliminated.

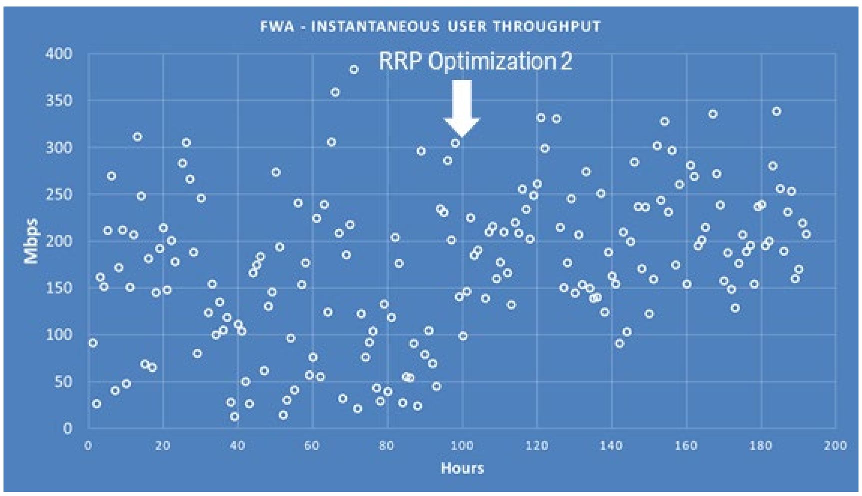


Figure 13 – Average DL throughput (Mbps) before and after enabling RRP

Regular network counters do not give sufficient visibility between handset and CPE performance. With slicing, the network and device performance can be differentiated, resulting in an enhanced view per service, as shown in the example of Figure 14.

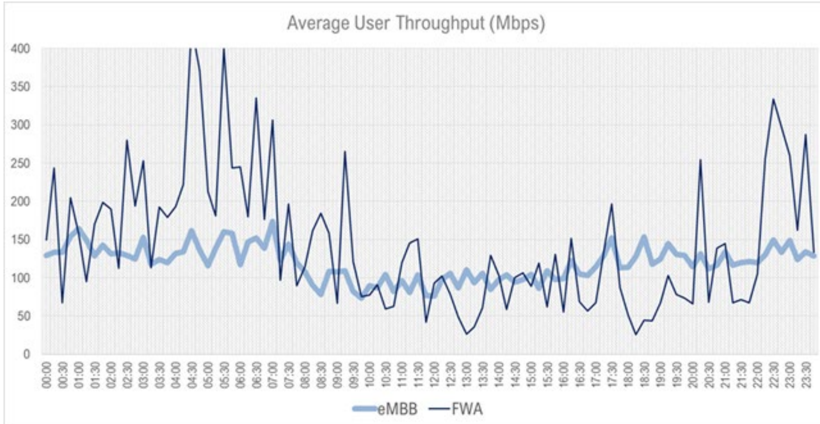


Figure 14 – Average user throughput view for FWA slice

Slicing enables application and optimization of low latency features selectively per service.

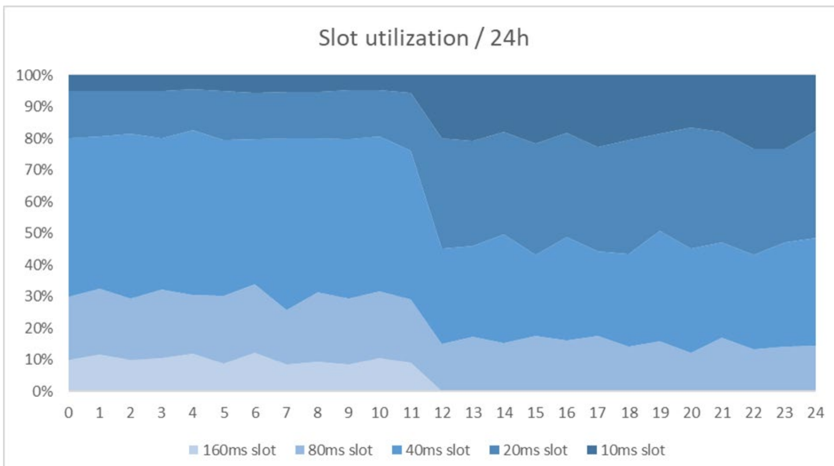


Figure 15 – Impact of low latency feature application on slot length statistics

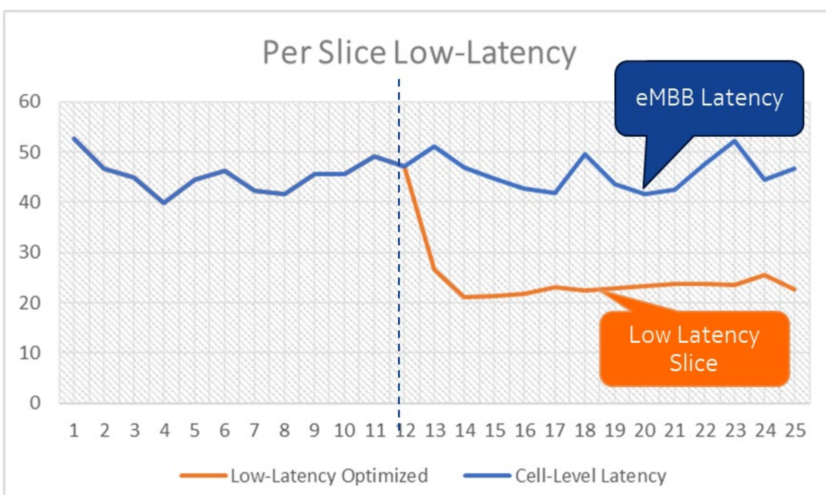


Figure 16 – Low latency optimized slice example

5. mmWave for FWA

Using mmWave bands for smartphones is challenging due to coverage limitations. The average share of mmWave availability in dense urban areas is 2-3% which is very low compared to mid-band TDD share of 60-70%.

However, mmWave can be attractive for sub-urban FWA even when using existing sites to deploy. Typically, an operator has access to more spectrum bandwidth on mmWave bands (400-800 MHz) vs midband TDD (up to 100 MHz). High gain CPE antenna technology can be used to optimize the mmWave link budget even for Non-line of sight (NLOS) propagation conditions.

Nokia has demonstrated throughput of 3.5 Gbps at 6 km distance. Therefore, in Line-of-sight (LOS) conditions, premium fiber-like service can be offered over distances of 6 km or more. Even in areas with high foliage, typically more than 100 users can be reached in LOS conditions from the existing base station sites.

A suburban case study was conducted to illustrate the potential to offload sub-6 GHz traffic to mmWave using existing macro base station sites and considering the realistic propagation conditions. 3-sector mmWave deployment was assumed with 30 m antenna height. The study assumed a 17 dBi outdoor rooftop antenna for the home CPE. The results are shown in Figure 17 for two different downlink service levels: 100 Mbps and 500 Mbps. In cases with a 1 km inter-site distance, mmWave connection is available in 50-65% of households. In cases with a 1.4 km inter-site site distance, mmWave offloading with 100 Mbps service still works for 45% of households.

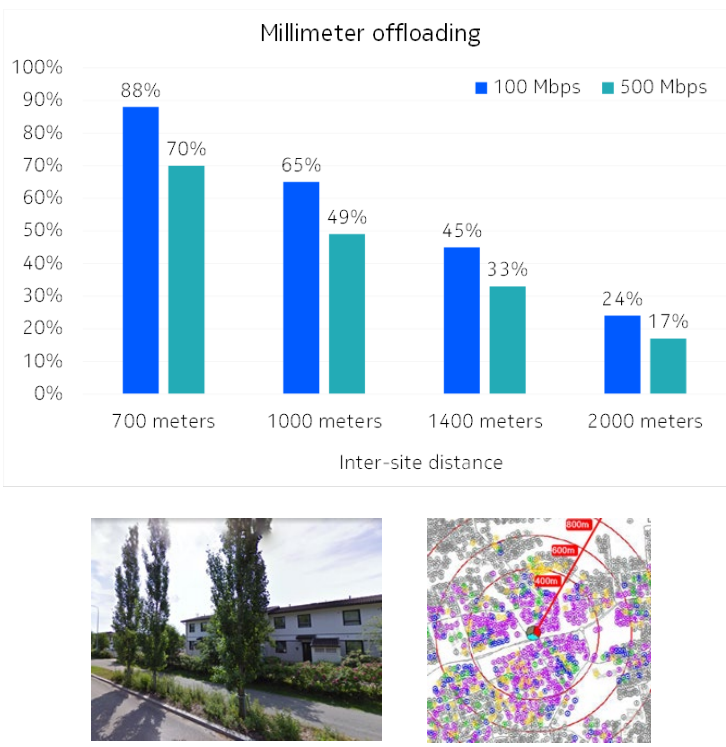
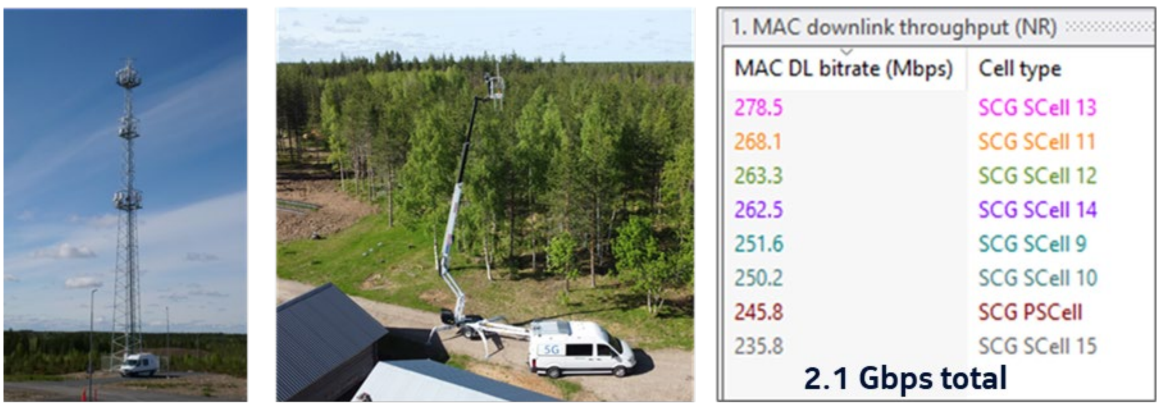


Figure 17 – Percentage of households that can be offloaded to mmWave from existing macro sites

Similarly, another measurement campaign with high gain mmWave CPE antenna was executed in a suburban environment with limited foliage but mostly NLOS propagation conditions. The results showed that throughputs of 700-800 Mbps can be achieved consistently over distances of 500 meters from the base stations with extensions even up to 900 meters demonstrating efficient offload capability to mmWave.

A mmWave FWA field trial was conducted recently that demonstrates the potential of mmWave for providing extreme radio coverage. In the trial a sustained 2.1 Gbps downlink data rate connection was established using mmWave over a distance of 11 km. In the uplink, 57 Mbps throughput was achieved. 26 GHz mmWave band (n258) was utilized with 8 x 100 MHz component carriers and NSA architecture with LTE 2100 as the anchor band. A high gain 27 dBi antenna at 21 meters height was used with the CPE with an EIRP of 47 dBm. The gNB mmWave radio was radiating at 60 dBm power at the height of 46 meters.


1. MAC downlink throughput (NR)

MAC DL bitrate (Mbps)	Cell type
278.5	SCG SCell 13
268.1	SCG SCell 11
263.3	SCG SCell 12
262.5	SCG SCell 14
251.6	SCG SCell 9
250.2	SCG SCell 10
245.8	SCG PSCell
235.8	SCG SCell 15

2.1 Gbps total

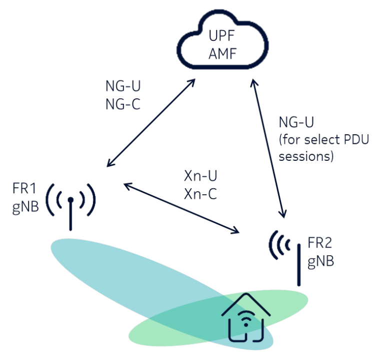
Figure 18 – Field trial results for 11 km extended range mmWave site

This achievement demonstrates the reach and connectivity speeds that 5G mmWave can deliver. It also lays the foundations for high-quality internet connectivity solutions delivered via FWA to areas where wired connections are not always possible.

5.1. NR Dual Connectivity with mmWave

A key evolution step for mmWave FWA over the next few years is FR1-FR2 NR Dual Connectivity (NR-DC) functionality which provides access to the high throughput of FR2 while maintaining the connection stability of FR1.

Figure below shows the principle of FR1-FR2 NR-DC functionality. The Primary Cell (PCell) belongs to an FR1 band (FDD or TDD) and the Primary Secondary Cell (PSCell) uses an FR2 band. The total throughput is estimated to reach up to 6-8.5 Gbps when a 100 MHz TDD carrier is combined with 8x100 MHz of FR2 spectrum in downlink.



The NR-DC functionality described above can be extended to include uplink CA as well to increase uplink throughput. Up to 4 uplink Component Carriers (CC) can be supported in FR2. In addition, FR1 Carrier Aggregation (CA) can be supported for FR1 to further increase the downlink throughput.

6. Conclusion

5G technology combined with mid-band TDD spectrum and massive MIMO antenna can provide a major boost to the radio capacity that it can support also Fixed Wireless Access services for home broadband connectivity. The analysis shows that up to 150-200 FWA subscribers per 100 MHz sector can be supported on the existing base station grid without adding new sites. High capacity on existing sites enables monetization of 5G for FWA services already today. Evolution steps were presented showing the future potential for further capacity enhancements for both downlink and uplink.

5G RAN slicing can provide several benefits to efficiently manage FWA user traffic load in the network. The radio resource can be partitioned per slice, guaranteeing the bandwidth for both mobile and FWA services. Frequency layer management allows separate mobility and handover frequency targets and thresholds for the different slices. The performance can also be monitored and visualized with separate KPIs per traffic type. Scheduling for low latency services can also be optimized per slice.

Incremental mmWave spectrum can triple FWA network capacity in NLOS conditions. It is possible to offload even 50% of households to mmWave while using existing base station sites. Combining mmWave with sub-6 GHz spectrum enables more aggressive mmWave radio planning, delivering more mmWave offloading while always providing a robust service with sub-6 GHz. In LOS conditions, mmWave enables fiber-like services over distances over 6 km, while providing enough capacity to connect hundreds of users per cell.

An extended range mmWave trial demonstrates that mmWave solutions can be an essential building block for operators to efficiently deliver widespread, multi-gigabit 5G broadband coverage to their customers in urban, suburban, and rural areas, complementing sub-6 GHz spectrum assets.

Abbreviations

bps	bits per second
CA	Carrier aggregation
CC	Component carrier
CPE	Customer premises equipment
DC	Dual connectivity
eMBB	Enhanced mobile broadband
FDD	Frequency division duplex
FWA	Fixed wireless access
GB	Gigabyte
LOS	Line of sight
MIMO	Multiple-input multiple-output
MU-MIMO	Multi-user MIMO
NLOS	Non-line of sight
NSA	Non-standalone
PCell	Primary cell
PRB	Physical resource block
PSCell	Primary secondary cell
RAN	Radio access network
RRP	Radio resource partitioning
RX	Receive
SA	Standalone
SCTE	Society of Cable Telecommunications Engineers
SU-MIMO	Single user MIMO
TDD	Time division duplex
TX	Transmit

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