Fixed Wireless Access – Path to Economical Rural Broadband

GS Sickand

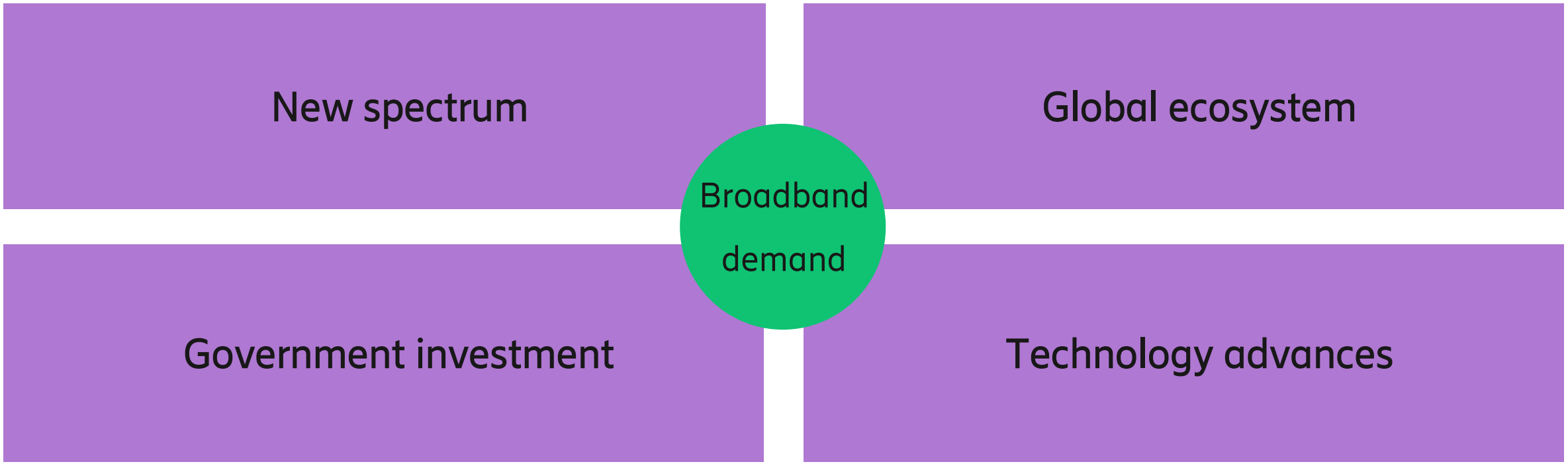
July 22th 2019

Agenda

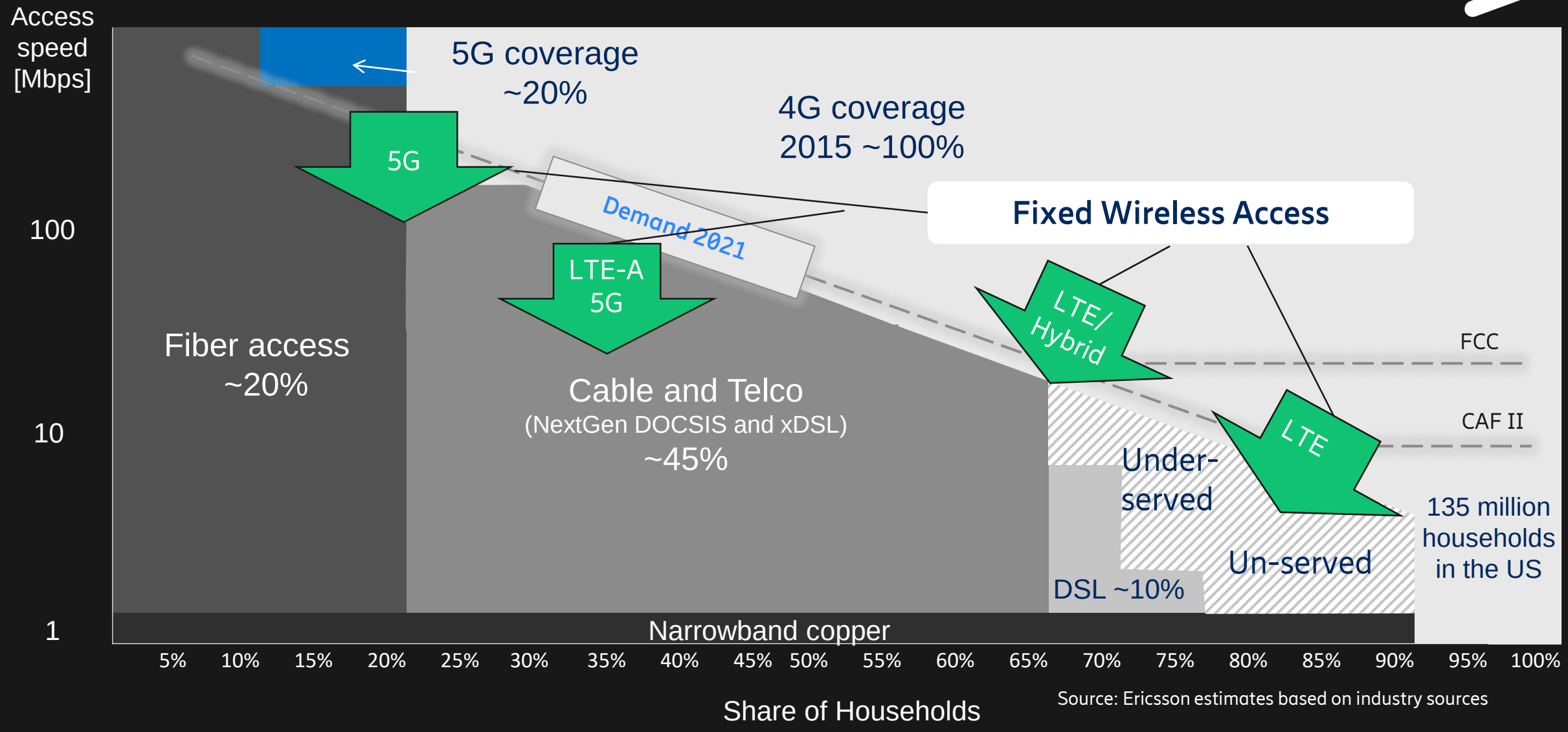
- ❑ FWA Business Overview
- ❑ CBRS Update
- ❑ Rate and Reach with CBRS
- ❑ CBRS Ecosystem
- ❑ Summary

Why Fixed Wireless Access now?

FWA momentum growing in every G – 5G and LTE-Advanced is no exception



Wireless Solutions 2021



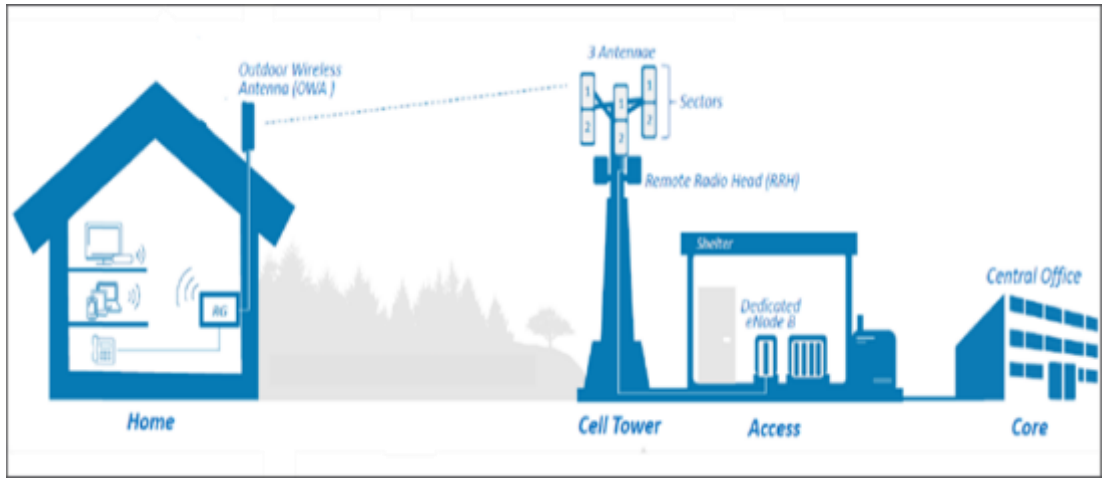
Source: Ericsson estimates based on industry sources

FWA 5 year CAGR: 37.4 % - Biggest opportunity for BB

Proven Technology – Global/Local

THE VALUE OF WIRELESS NETWORK

High level solution



Drivers and Benefits

- Alternative method to provide Home Broadband using wireless LTE network
- Solution focused on Rural broadband
- New LTE-Advanced / 5G technologies enable fiber like speeds & capacities
- Wireless eliminates maintenance headaches associated with copper and deployment challenges with fiber

Standards based technology with global ecosystem

LTE FWA – Business case

Suburban and rural

Budgetary Value*

- Suburban and Rural:
  - **$<250** Cost per Home Passed
  - 600 homes/sq. mile – Suburban
  - 10 homes/sq. mile - Rural
  - **Cash flow positive <3 years**

Performance

- **10, 25, 50, and 100** Mbps Service
- Network supports, **2 Mbps** Busy Hour Throughput per HHC with a **28%** YoY growth
- Aligned with Marketing take rates, pricing, and targeted network design metrics

Time to Revenue

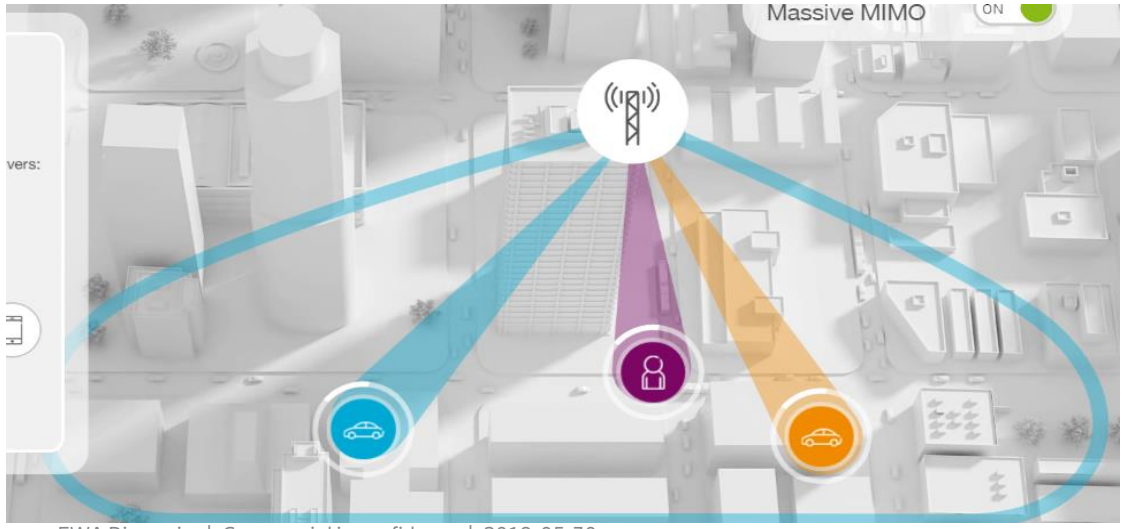
- Network Deployment can begin as soon as the 3.5GHz spectrum usage is enabled by FCC's SAS/ESC certification

Fixed LTE in 3.5GHz: A viable solution and a profitable venture

* Subscriber growth assumed 10% to 33% in 5 years, 3.5 GHz CBRS spectrum; assumes 60 MHz spectrum

Fixed wireless technology

Massive MIMO - beamforming

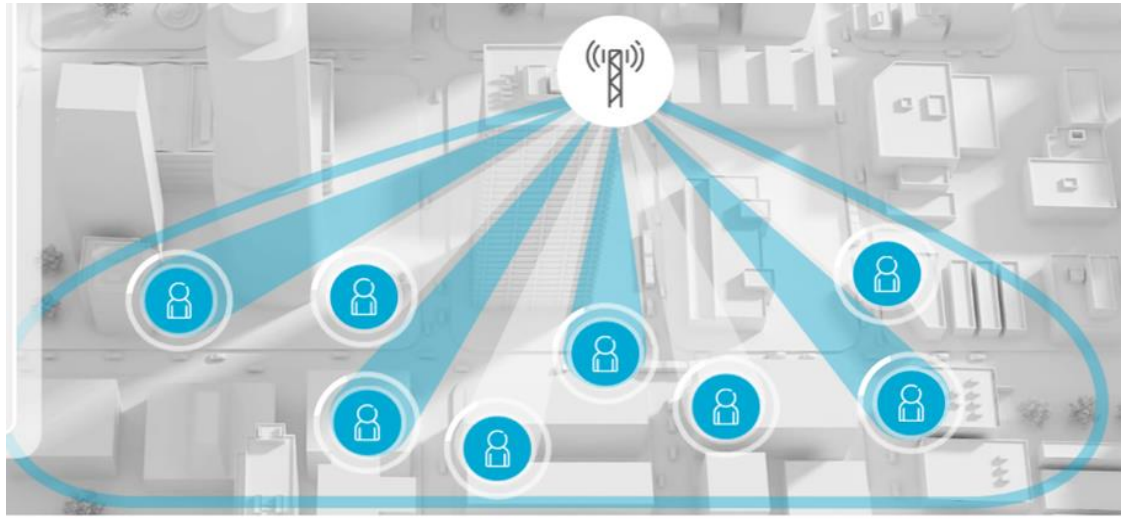


- Traditional cell sites project radio waves in a fixed predefined pattern – similar to a flood light

- Massive MIMO cell sites project radio in narrow beams directed to the users – similar to a spot light
- Multiple beams can be created which will dynamically adjust to user locations & usage
- The end result is an increase in signal and a reduction in interference from other users in the sector – improved throughput to each user in the sector

Fixed wireless technology

Multi-User MIMO



- Sector capacity in a traditional cell site is shared amongst all of the users of the cell site

- With Multi-User MIMO, sector capacity resources can be re-used across multiple users in the same sector
- The end result is an increase in sector capacity due to the re-use of resources across multiple users – creating virtual sectors within a single sector

Spectrum Update

Key FWA spectrum

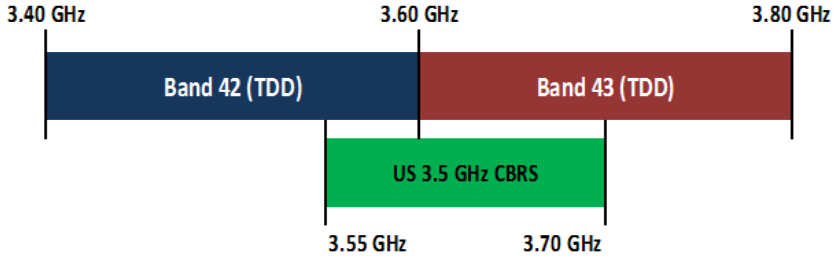
Frequency	Benefits	Challenges	Availability
2.5 GHz	– ~200 MHz of licensed spectrum – Best propagation amongst TDD spectrum – US ecosystem available today – Highest predictability due to licensed spectrum	– Cost of acquiring spectrum – Majority of spectrum in populated areas is owned	– Now
3.5 GHz CBRS	– 150 MHz of spectrum – Global LTE ecosystem – Good balance between propagation, power and reuse – Interference managed via SAS (Spectrum Access System)		– 2H-2019 as defined by CBRS ecosystem certification timelines
5 GHz	– 555 MHz of spectrum	– Propagation challenges - Maximum of 36 dBm EIRP – Mostly proprietary solutions – Prone to interference due to contention based access method	– Today
5.9 GHz-6.425 GHz	– 500 MHz of spectrum	– Will likely follow unlicensed framework established for 5 GHz, lobbying FCC to balance licensed and unlicensed	– Estimated 2022
24 GHz – 39 GHz	– Channels of 100 MHz possible	– Significant challenges - propagation	– Outdoor CPEs with NSA Estimated mid-2020
57 GHz – 71	– 14 GHz of spectrum	– Significant challenges - propagation	– Partially Today;

3.5GHz (CBRS) is the most viable FWA option considering coverage / capacity tradeoffs

3.5 GHz (CBRS) – innovation band

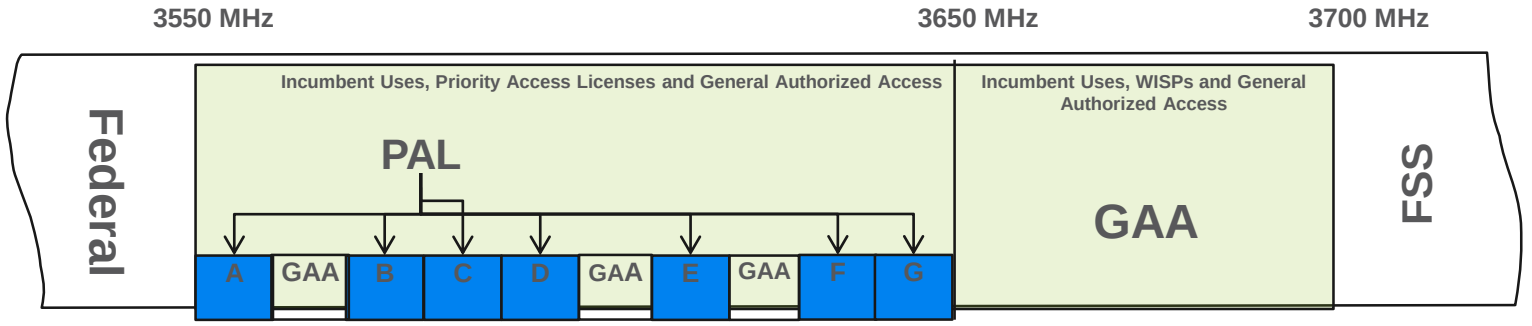
150mhz of shared spectrum to spur innovation

150 MHz Spectrum Overlaps Global Bands 42 & 43

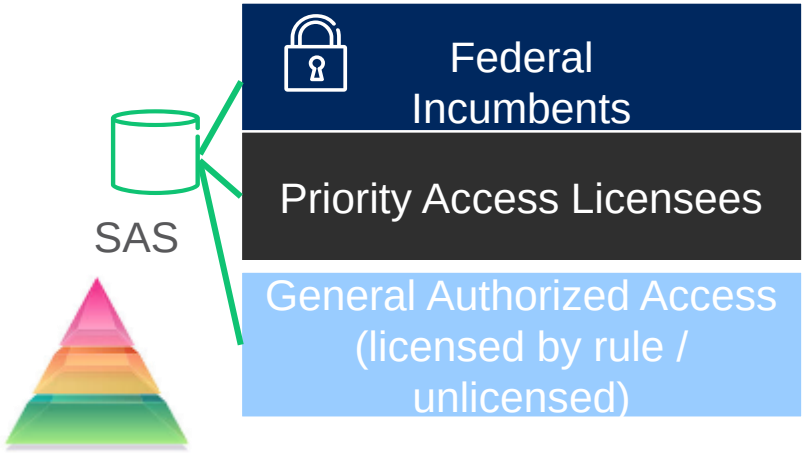


3GPP B48 – CBRS TDD

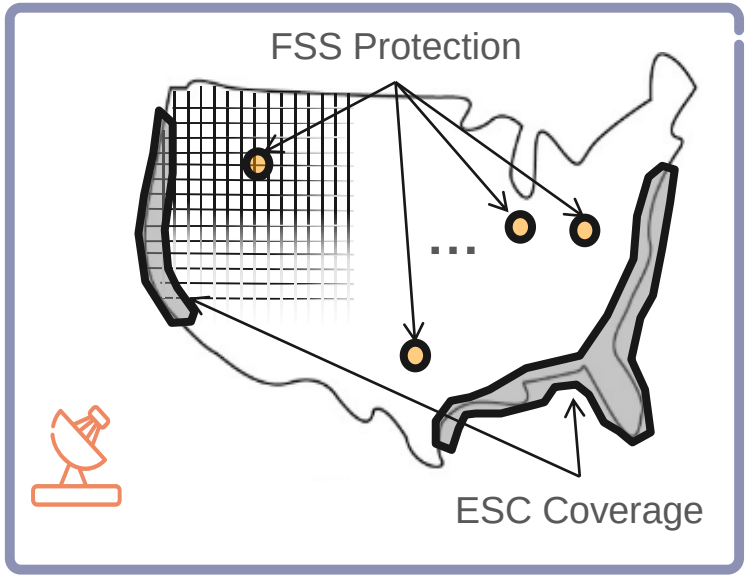
Spectrum Band Structure



Spectrum Band Architecture



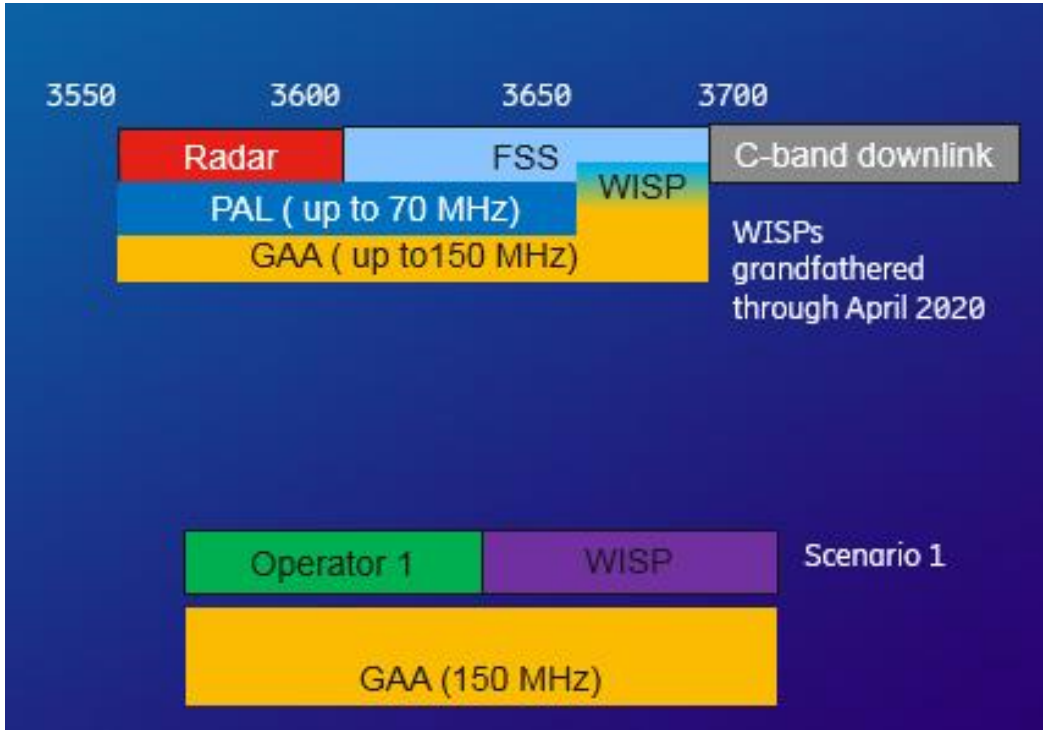
- **150 MHz** of shared spectrum
- Spectrum Access System **(SAS)** provides spectrum management
- **Incumbents** – Naval radars that use the band infrequently; FSS; WISPs
- **Priority Access** – finite term license for interference protection
- **General Authorized Access** – no license required, SAS authorization for unprotected usage



Spectrum challenges

The value of wireless network

CBRS

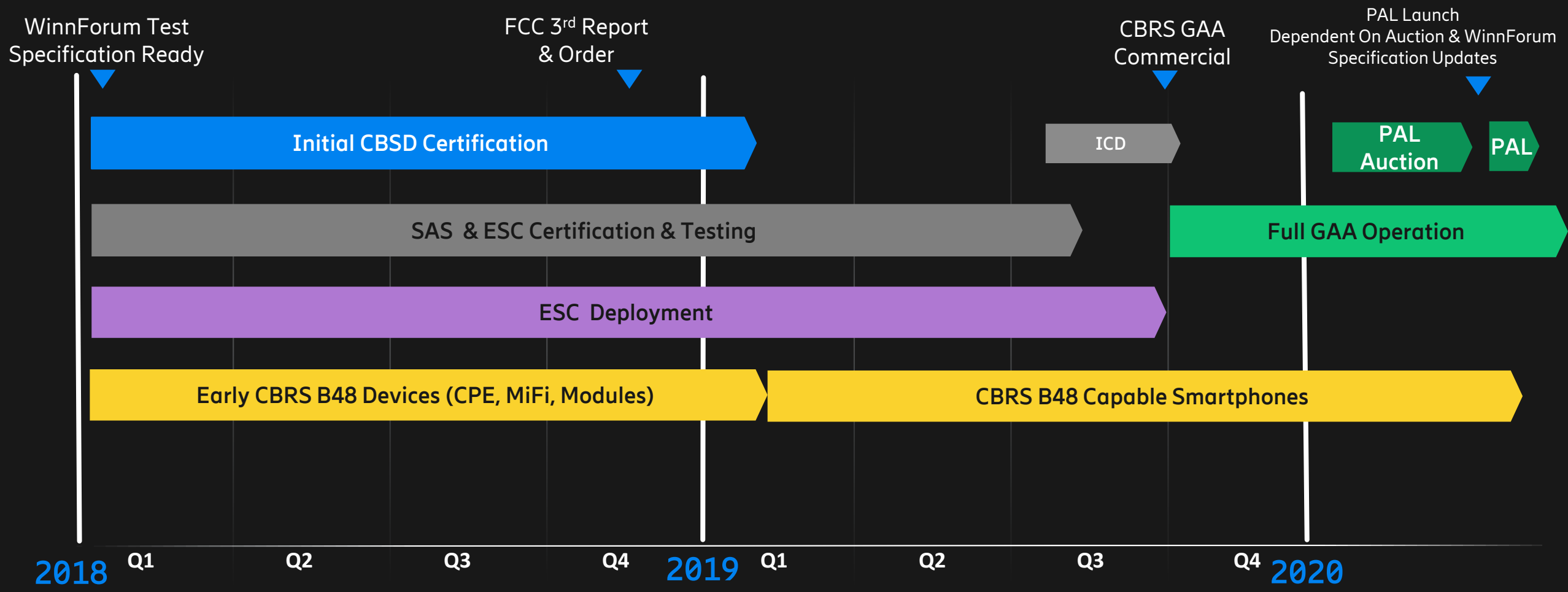


Spectrum Mechanics

- PAL
  - Total of 70 MHz (7x10 MHz licenses) - Confined to 3550-3650 MHz
  - PAL frequency assignments made by SAS
- GAA
  - Access to entire band of 150 MHz provided no active PAL or incumbents.
  - In rural areas, if no-body uses PAL, then all 150 MHz goes into the GAA pool.
  - Up to 80 MHz when all PALs are utilized

GAA Is a Low risk Option For Deployment Of FWA Application

CBRS Timeline Estimate



CBRS Evolution To NR

Expect CBRS To Support NR (NSA) by end of 2019

CBRS Alliance commenced work on NR standards extensions started 2018.Q4

3GPP working on new band definition **n48** for 5G NR

Devices to support CBRS will come later

Provides Future Expansion To Adjacent Bands

3.7 – 4.2 GHz - C Band DL

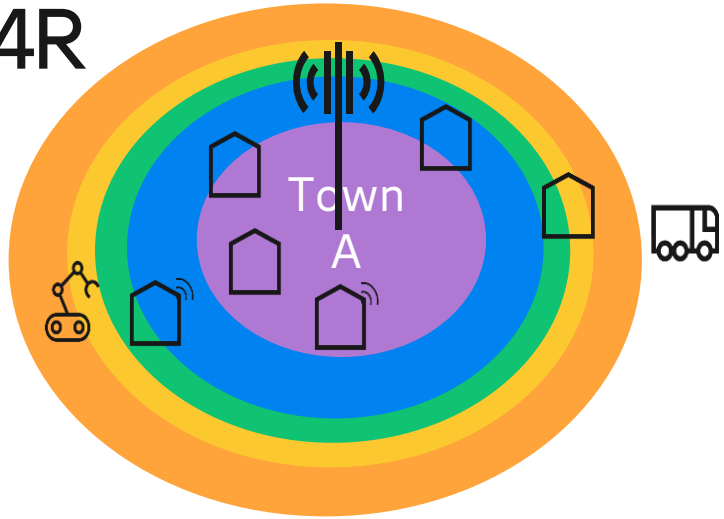
3.45 – 3.55 GHz (Currently under study by NTIA)

NR - The Future Of The CBRS Band

Rate and Reach with CBRS

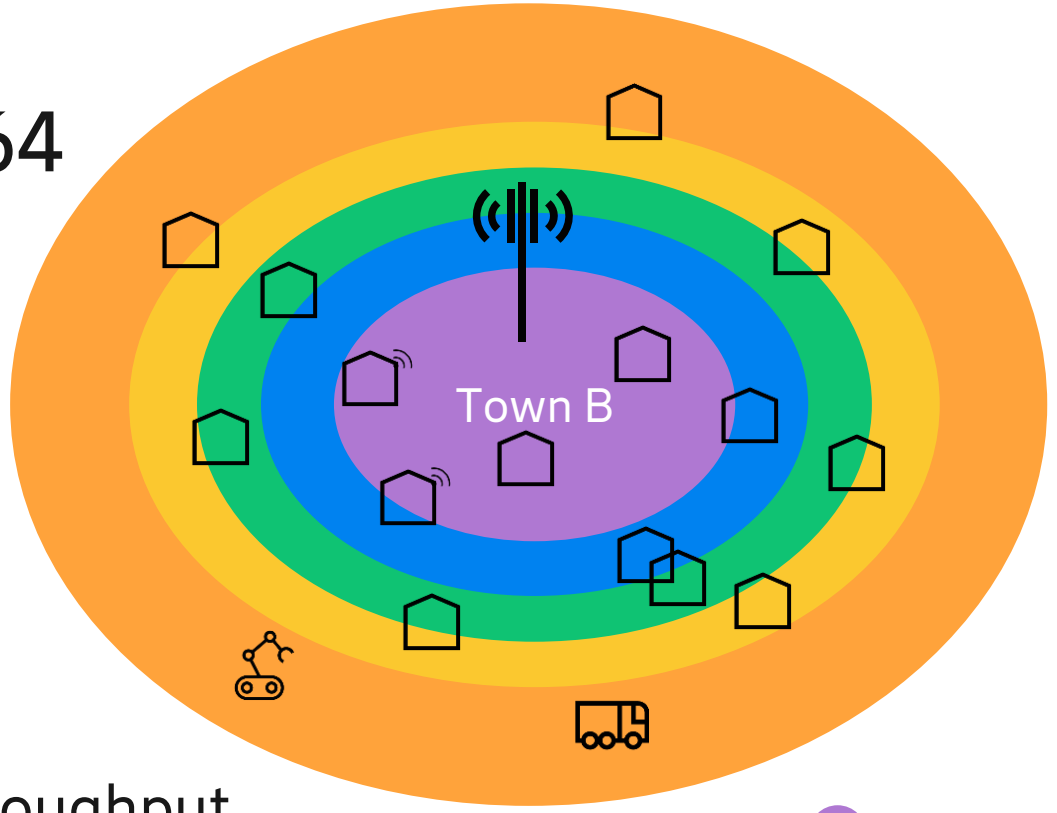
CBRS Cell Coverage – Rural

4T4R



- 100 Mbps, 7 Miles
- 50 Mbps, 9 Miles
- 25 Mbps, 9.5 Miles
- 10 Mbps, 10 Miles
- IoT coverage

64T64



- 100 Mbps, 9 Miles
- 50 Mbps, 11 Miles
- 25 Mbps, 12 Miles
- 10 Mbps, 13 Miles
- IoT coverage

Network Throughput

=

Cell Density x Available Spectrum (New Spectrum / Existing Spectrum) x Spectral Efficiency

Coverage shown with 3.5Ghz, 3x20 MHz, LoS TDD Frame config 2. Actual results vary based on clutter, terrain and other conditions

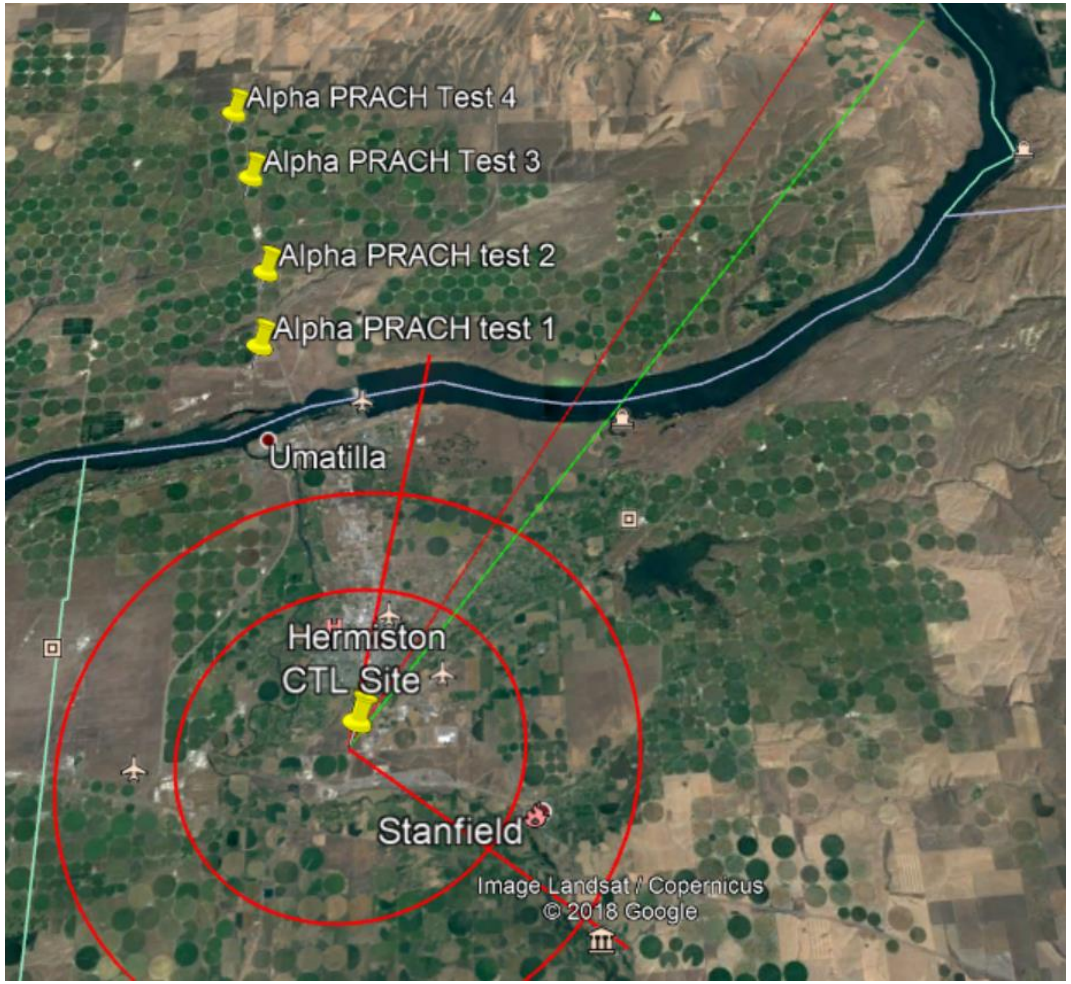
Multiple rate services supported on the same cell site

Peak Sector Throughput, Average Sector Throughput and Busy Hour Throughput

- Peak Throughput
  - CPE is in great SINR conditions. The CPE gets all available LTE resources.
- Average Throughput
  - CPEs are distributed throughout the cell under various RF conditions. LTE resources are shared amongst all CPEs
  - Used to dimension the network for capacity planning
- Busy Hour Throughput
  - Average measured Backhaul throughput divided by number of Homes connected. Based on industry trends and wireline industry input, it is currently 2 – 3 Mbps per Home.

	Peak TDD LTE DL Throughput	Peak TDD LTE DL Throughput 256 QAM	Peak TDD LTE DL Throughput 256 QAM	Average TDD LTE DL Sector Throughput Baseline + Fixed + LTE Evolution Gains	Average TDD LTE DL Sector Throughput Baseline + Fixed + LTE Evolution Gains
Assumptions	4:1 DL:UL Ratio 2x2 MIMO 64 QAM DL	4:1 DL:UL Ratio 2 x 2 MIMO 256 QAM DL	4:1 DL:UL Ratio 64T64R MU-MIMO	4:1 DL:UL Ratio 4T4R	4:1 DL:UL Ratio 64T64R
20 MHz Cell Carrier Capacity	111 Mbps	147 Mbps	720 Mbps	50 Mbps	200 Mbps
3 x 20 MHz Cell Carrier Capacity	333 Mbps	440 Mbps	1440 Mbps	150 Mbps	600 Mbps
Site – 3 sector 3 x 20 MHz Cell Carrier Capacity	999 Mbps	1320 Mbps	4320 Mbps	450 Mbps	1800 Mbps

Max Cell Range Test with 64T64R – 20 MHz



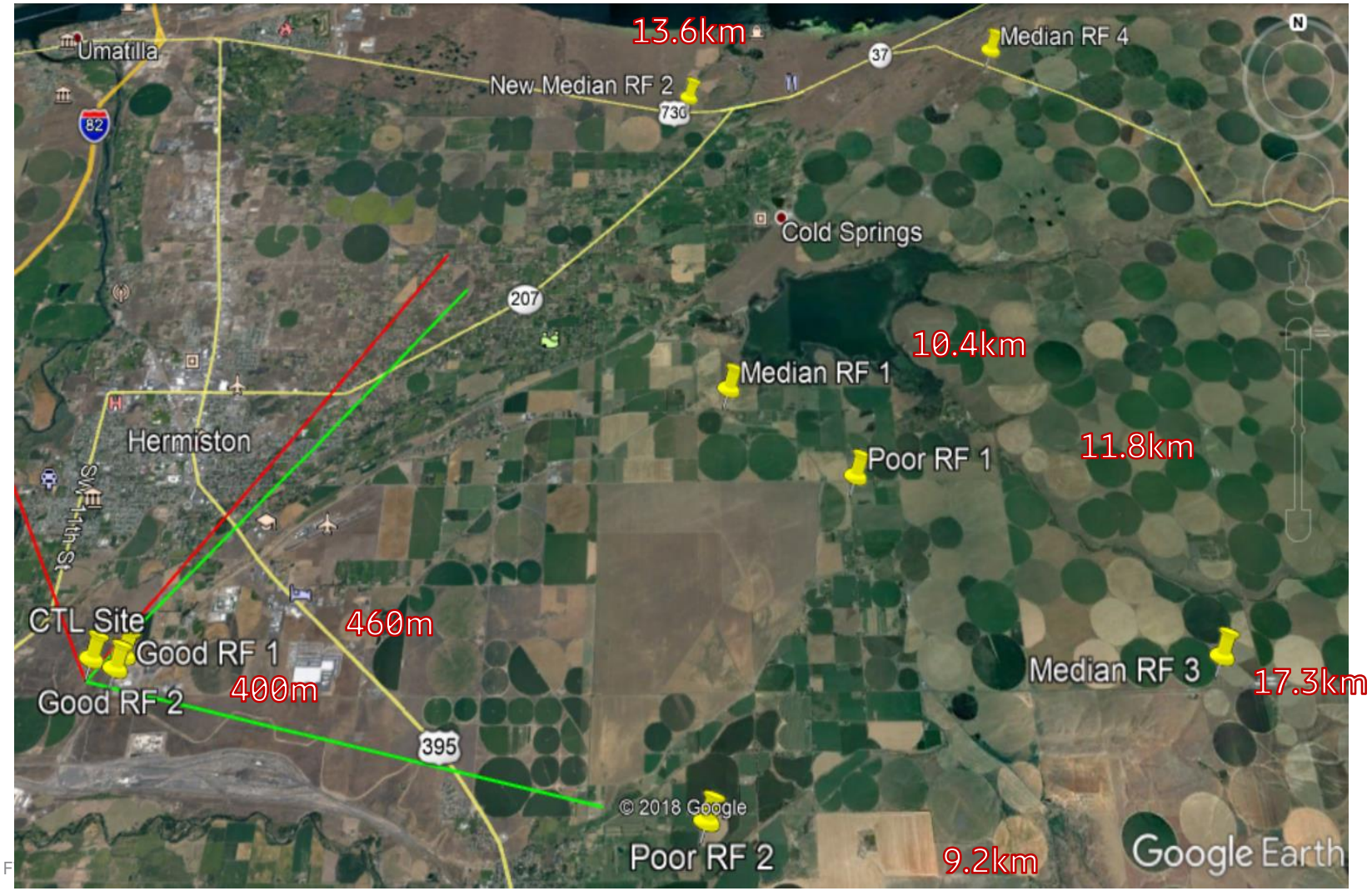
location	Location		Distance	RSRP	SNR	TCP DL	TCP UL	Latency
1	45°57'0.89"N	119°21'6.89"W	16.39 Km	-103	17	87.2 Mbits/sec	8.2 Mbits/sec	67ms
2	45°58'54.15"N	119°21'1.49"W	19.70 Km	-103	17	89.4 Mbits/sec	8.29 Mbits/sec	70 ms
3	46° 1'31.16"N	119°21'37.83"W	24.68 Km	-115	12	50.2 Mbits/sec	7.96 Mbits/sec	71 ms
4	46° 3'24.02"N	119°22'16.79"W	28.19 Km	-122	8	11.6 Mbits/sec	3.04 Mbits/sec	70 ms

CPEs can connect up to 28 Kms with LoS conditions and get good throughput

Rural 64T64R FWA Results (SU-MIMO) – One UE at a time – 20 MHz

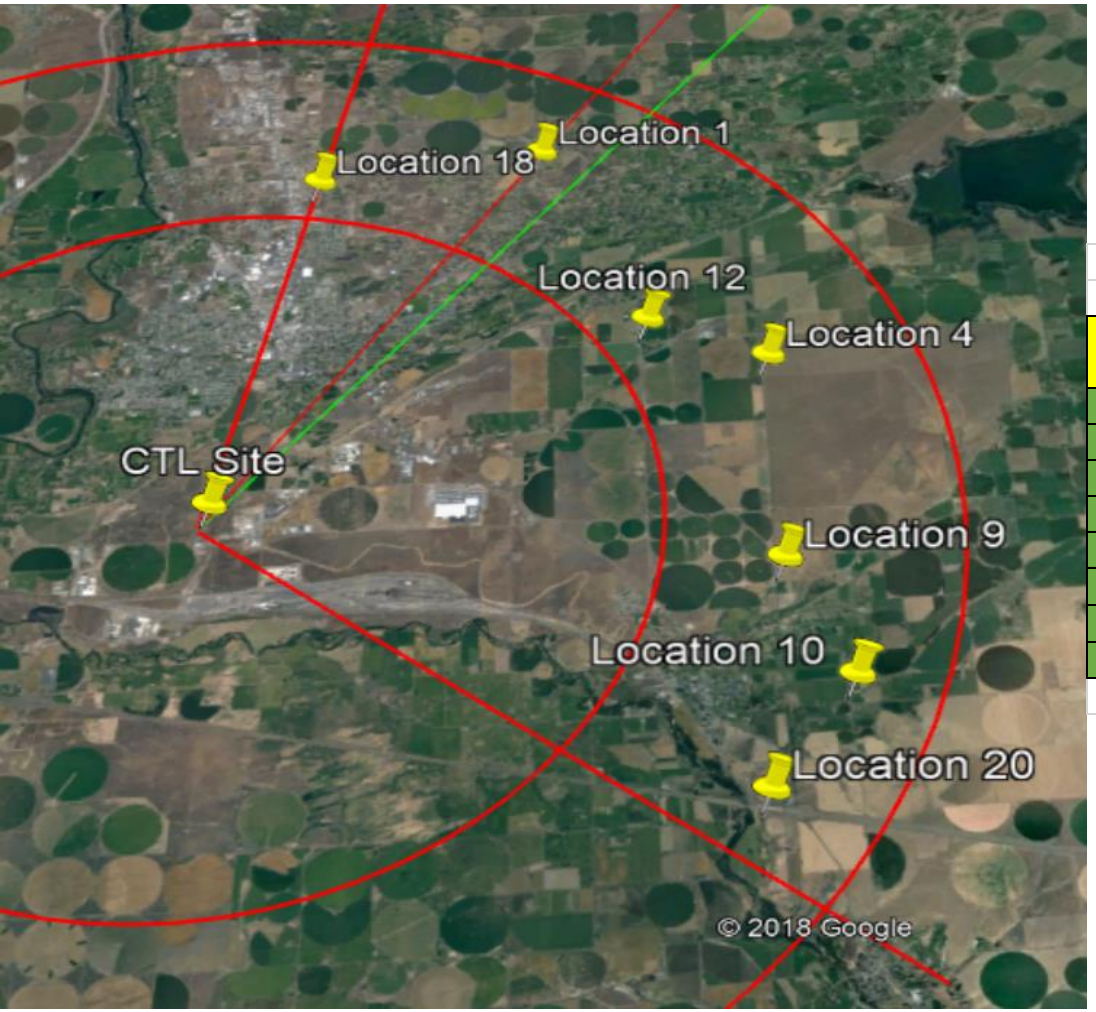
UE Number	DL Thrpt (Mbps) with SU-MIMO	UL Thrpt (Mbps) with SU-MIMO
1 (good)	86.7	8.4
2 (good)	91	8.3
3 (med)	80	8.39
4 (med)	81.3	8.3
5 (med)	73	6.5
6 (med)	54.6	8.3
7 (poor)	35.4	2.5
8 (poor)	29.2	1.96

Rural 64T64R FWA Results (SU-MIMO) – All UEs simultaneously – 20 MHz



UE Number	DL Thrpt (Mbps) with SU-MIMO	UL Thrpt (Mbps) with SU-MIMO
1 (good)	11.1	1.8
2 (good)	11.2	1.8
3 (med)	11.2	1.6
4 (med)	11.3	0.7
5 (med)	11.5	0.74
6 (med)	10.8	2
7 (poor)	9.5	0.178
8 (poor)	5.5	0.325
Average Sector Thrput	88.2 Mbps	

8 Layer MU-MIMO Test – 64 QAM - MU MIMO

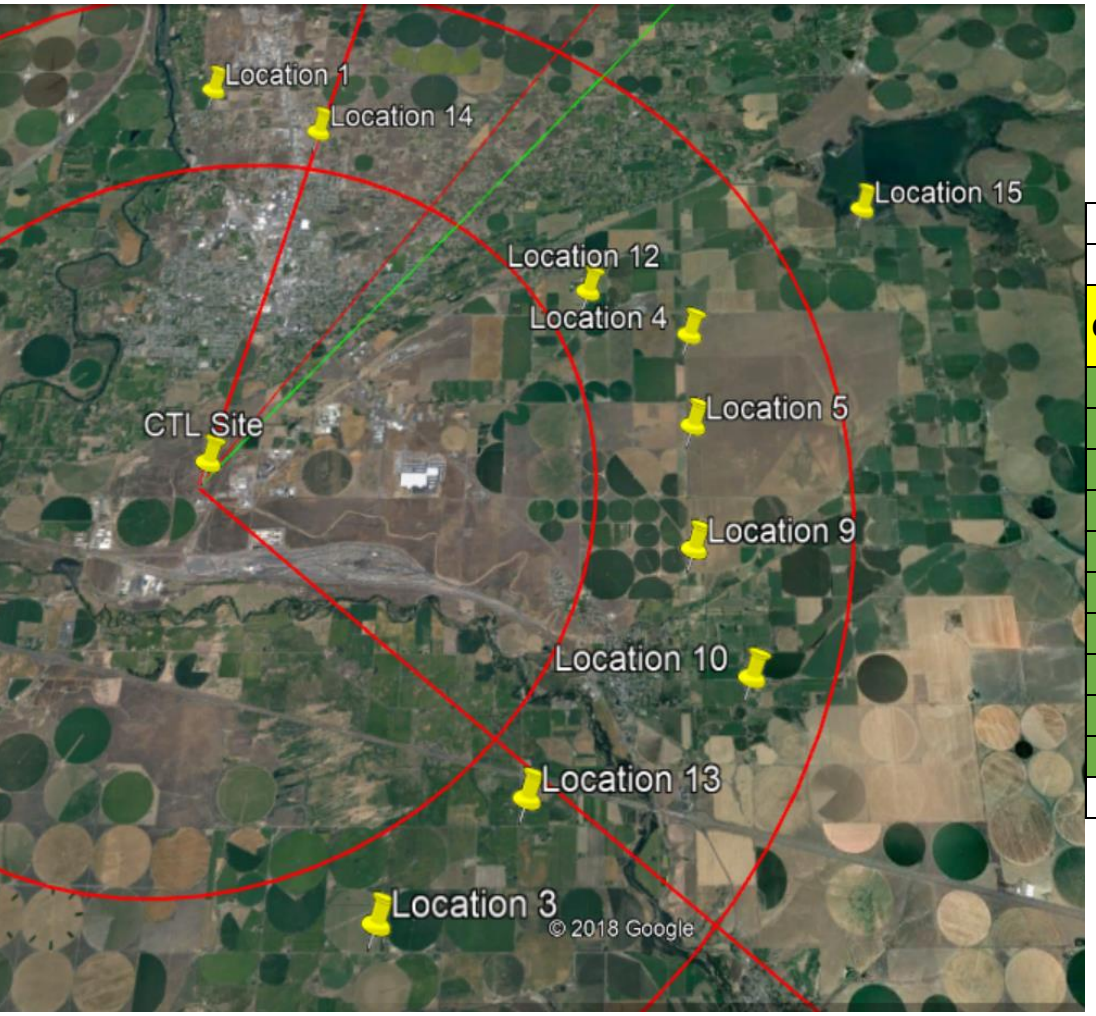


					Recorded Throughput DL (Mbps)					
CPE Test Location	Recorded SINR (dB)	Recorded RSRP (dBm)	Latitude	Longitude	Latency (ms)	1	2	3	4	5
1	16	-110	45°52'3.17"N	119°14'41.54"W	65	12.2	10.1	23.5	14.6	11.3
4	16	-108	45°49'39.58"N	119°12'17.68"W	62	32.2	31.7	29.9	29.8	30.8
20	18	-101	45.762765	-119.210077	73	42.8	35	35.6	33.7	33.7
9	18	-107	45.795122	-119.204902	70	14.8	15	16.8	14.4	15
10	16	-108	45°46'39.53"N	119°11'41.68"W	70	21.4	21.8	22.8	21.3	22.2
12	14	-112	45°50'5.93"N	119°13'33.29"W	67	27	25.4	24.9	23.9	31.1
18	17	-107	45° 51' 49.07"N	119° 17' 11.57"W	70	29.7	30.3	30.6	30.2	30.8
5	17	-109	45°48'47.39"N	119°12'16.39"W	68	30	30.6	30.3	29.8	29.6
						210.1	**199.9**	**214.4**	**197.7**	**204.5**

- Locations are between 6-8 km from Site
- Tests done with TCP

FWA average sector capacity - **64T64R** in a **20 MHz** channel is **200 Mbps**, **8 layer MU-MIMO & 64QAM**

10 Layer MU-MIMO Test – 64 QAM - MU MIMO

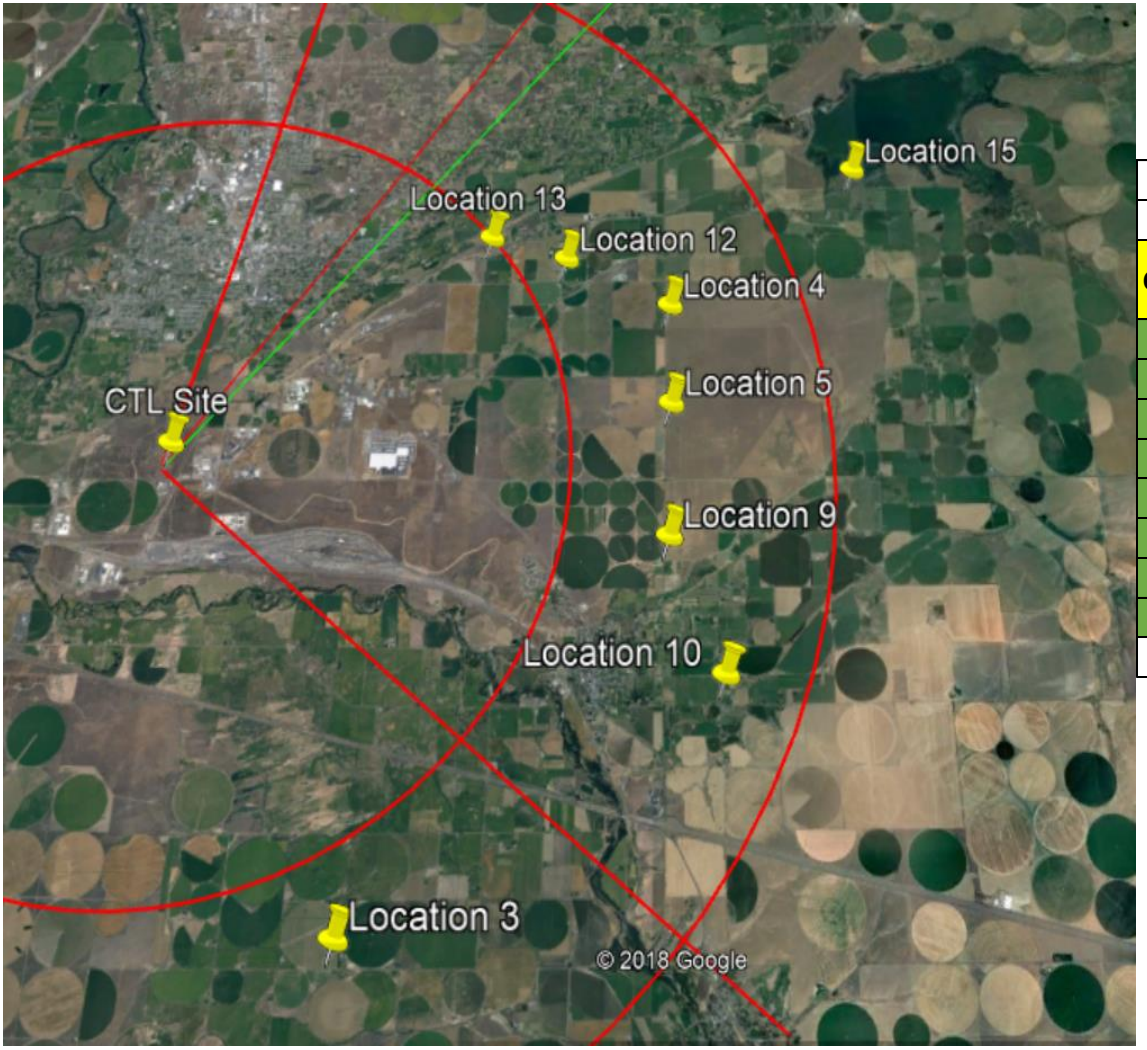


					Recorded Throughput DL (Mbps)	
CPE Test Location	Recorded RSRP (dB)	Recorded SINR (dBm)	Latitude	Longitude	1	2
4	-91	23	45°49'39.58"N	119°12'17.68"W	39.9	40.4
13	-98	18	45°45'45.05"N	119°14'9.16"W	23.3	23
9	-96	22	45°47'42.41"N	119°12'18.18"W	30.5	36
10	-91	24	45°46'39.59"N	119°11'41.73"W	38.5	38.6
12	-97	20	45°50'5.85"N	119°13'33.49"W	32.7	33
14	-98	19	45°51'49.69"N	119°17'11.69"W	28.9	26.3
5	-88	25	45°48'47.44"N	119°12'16.88"W	40.4	40.4
15	-96	22	45°50'57.40"N	119°10'0.29"W	26.7	25.6
1	-103	18	45°52'18.57"N	119°18'41.21"W	19.7	19.1
3	-99	18	45°44'52.24"N	119°15'40.08"W	22	21.6
					302.6	**304**

- Locations are between 6-8 km from Site
- Tests done with TCP

FWA average sector capacity - **64T64R** in a **20 MHz** channel is **300 MBPS**, **10 layer MU-MIMO & 64QAM**

8 Layer MU-MIMO Test – 256 QAM - MU MIMO

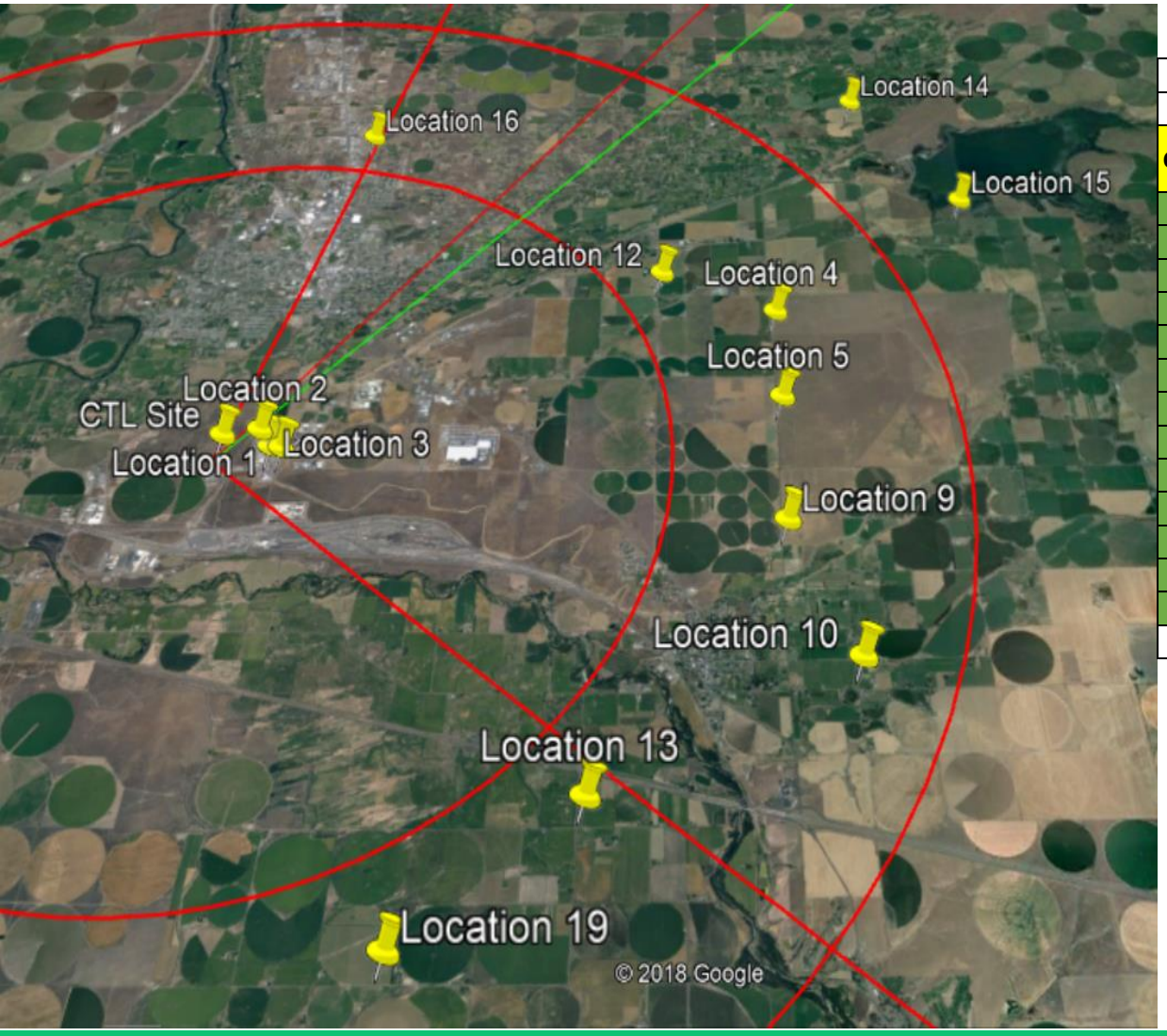


					Recorded Throughput DL
CPE Test Location	Recorded RSRP (dB)	Recorded SINR (dBm)	Latitude	Longitude	1
9	-108	16	45°47'42.41"N	119°12'18.18"W	38
15	-107	18	45°50'57.40"N	119°10'0.29"W	28.4
3	-104	16	45°44'52.24"N	119°15'40.08"W	32.8
13	-99	19	45°50'18.13"N	119°14'29.01"W	40.9
4	-105	18	45°49'39.58"N	119°12'17.68"W	51.3
5	-98	20	45°48'47.44"N	119°12'16.88"W	15.8
10	-102	19	45°46'39.59"N	119°11'41.73"W	38.4
12	-106	17	45°50'5.85"N	119°13'33.49"W	28.6
					274.2

- Locations are between 6-8 km from Site
- Tests done with TCP

FWA average sector capacity - **64T64R** in a **20 MHz** channel is **250-275 MBPS**, **8 layer MU-MIMO & 256 QAM**

13 Layer Test – 256 QAM - MU MIMO

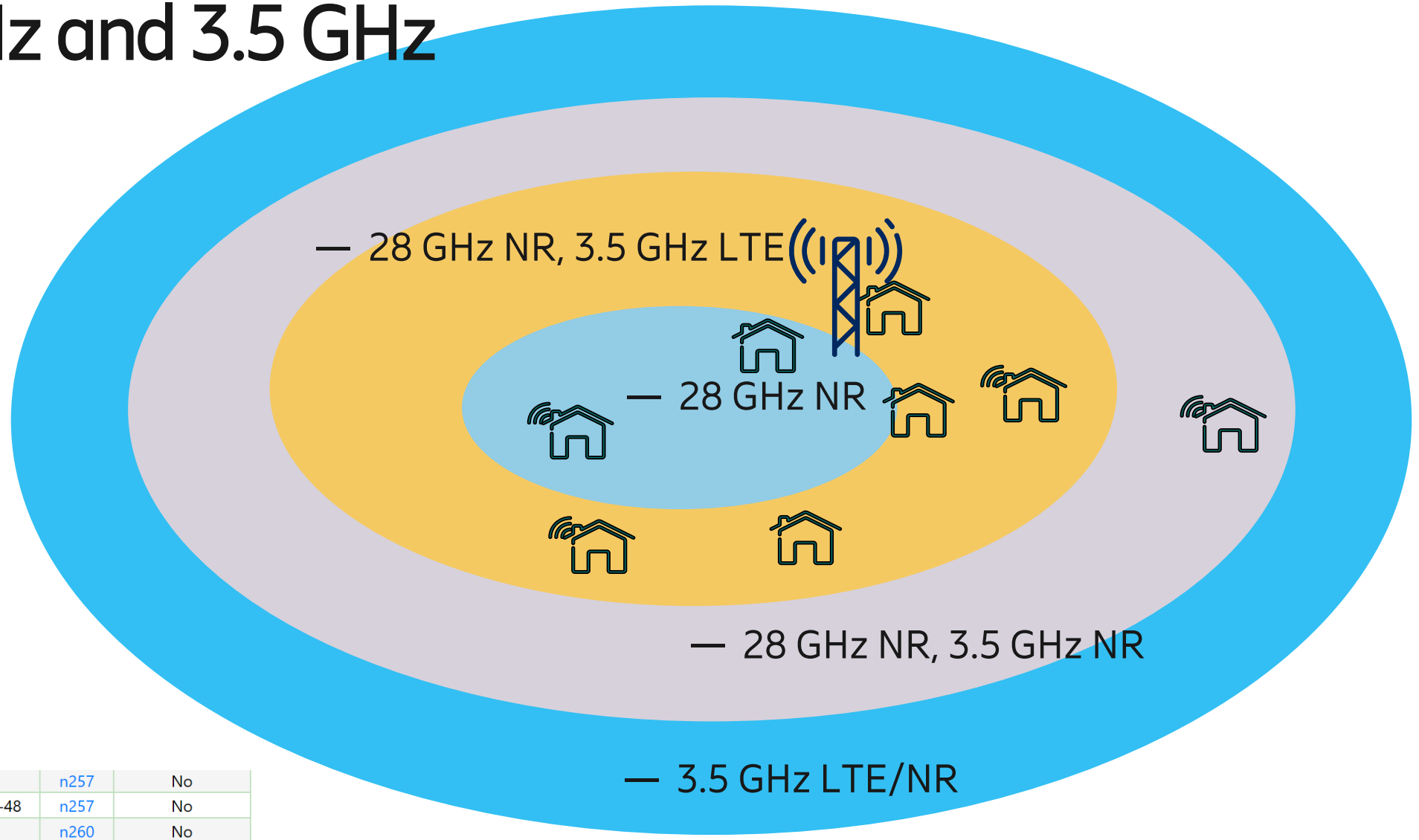


					Recorded Throughput DL (Mbps)		
CPE Test Location	Recorded RSRP (dB)	Recorded SINR (dBm)	Latitude	Longitude	1	2	3
9	-108	16	45°47'42.41"N	119°12'18.18"W	27.9	27.8	29.6
1	-76	24	45°48'21.00"N	119°17'25.00"W	33.9	35.4	35.4
15	-107	18	45°50'57.40"N	119°10'0.29"W	29.3	30.3	27.4
13	-103	14	45°45'45.05"N	119°14'9.16"W	25.7	23.3	23.9
19	-104	16	45°44'52.24"N	119°15'40.08"W	19.2	18.7	18.7
14	-109	15	45°52'18.57"N	119°11'9.65"W	14.6	14.1	14.4
2	-72	24	45°48'31"N	119°17'41"W	54.8	54.5	54.7
3	-77	25	45°48'21.95"N	119°17'32.032"W	42.4	42.5	42.1
4	-105	18	45°49'39.58"N	119°12'17.68"W	34.9	43.4	43.4
5	-98	20	45°48'47.44"N	119°12'16.88"W	34.8	33.1	33.9
10	-102	19	45°46'39.59"N	119°11'41.73"W	7.44	27.2	11.6
12	-106	17	45°50'5.85"N	119°13'33.49"W	38.4	37.9	36.9
16	-96	20	45° 51' 49.69"N	119° 17' 11.69"W	26.3	25.3	25
					389.64	413.5	397

- 10 Locations are between 6-8 km from Site
- 3 Locations are between 400-500 m
- Tests done with TCP
- Results can be improved as there were winds which affected the throughput.

FWA average sector capacity - **64T64R** in a **20 MHz** channel is **400 MBPS**, **10 layer MU-MIMO & 256 QAM,** proof point that 400 MBPS is possible

28 GHz and 3.5 GHz

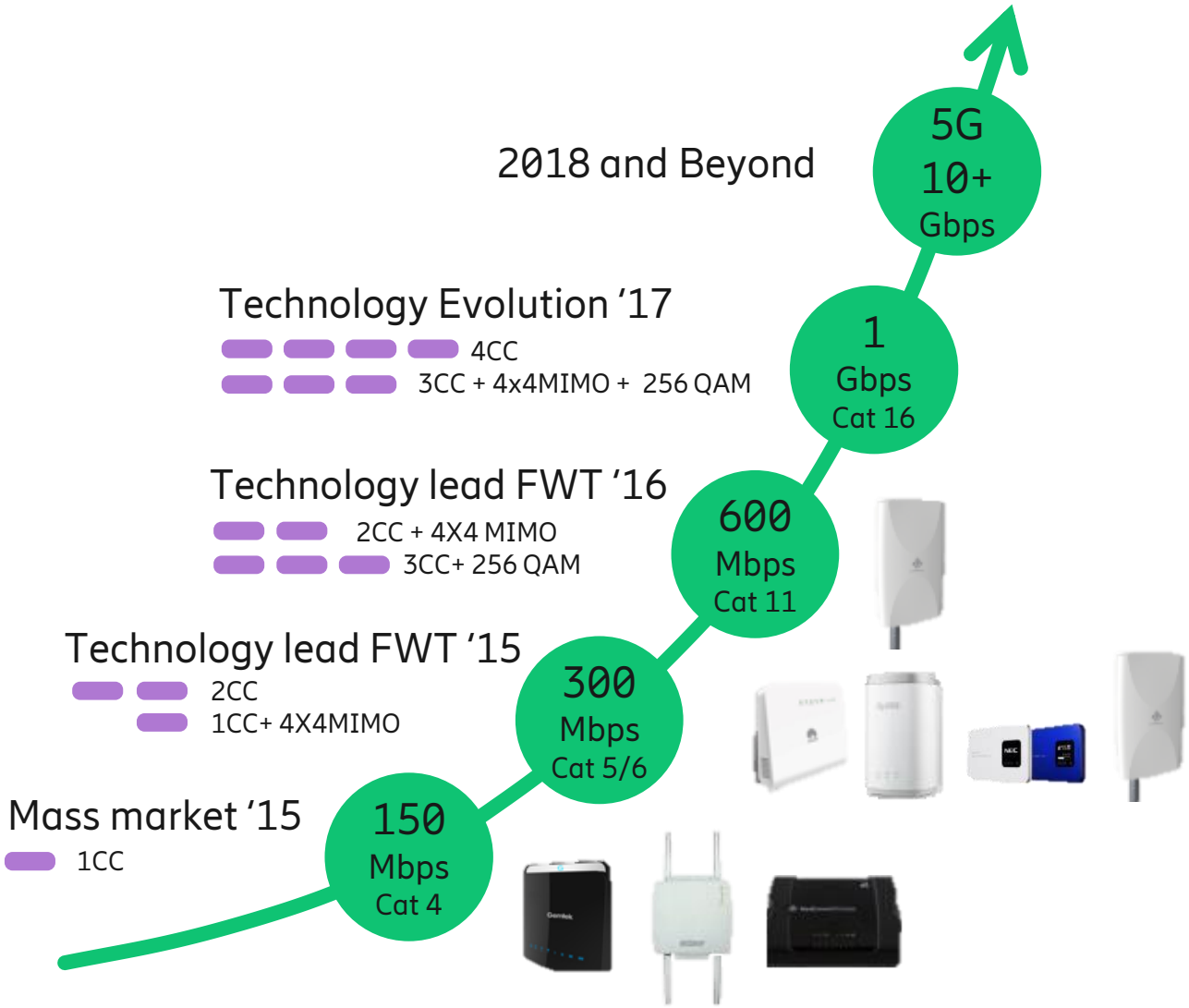


DC_48_n257	48	n257	No
DC_48-48_n257	CA_48-48	n257	No
DC_48_n260	48	n260	No
DC_48-48_n260	CA_48-48	n260	No

28 GHz DL in combination with mid-band or low band can give better DL coverage

Ecosystem

LTE FWA device evolution



- Global ecosystem forming around 3.5 GHz
- Proprietary devices are expensive and never achieve global scale
- Global scale w/LTE options is keeping price lower
- Typical CPE price levels:
  - $150-$200 indoor
  - $200-$400 outdoor
- Technology support:
  - Devices with 4x4MIMO, 3CC, 256 QAM available now!!

CBRS Chipsets and devices

Chipsets

Available Devices

QUALCOMM

SDX20/SDM 845 – CS Oct 2017

Cat 18 DL/Cat 13 UL (1.2 Gbps/150 Mbps)

Inter and Intra Band CA for CBRS

12 MIMO Layers with DL 5xCA

QComm MTP

SIERRA WIRELESS

BEC TECHNOLOGIES

GCT

GDM 7243QT – CS July 2017

Cat 7 (300 Mbps UL/100 Mbps DL)

Limited CA Capabilities

IODT in Progress

- Chipset capable of Cat 18 DL/Cat 13 UL, but no B48 device available today
- Commercial Devices with Max Th'put dependent on ODM implementation
- ODM driven by market demand and volumes – usual min. 10s of thousands qty

BEC CPE Roadmap for CBRS

BEC TECHNOLOGIES

4G/LTE TDD Outdoor Router

Key Features — **BEC 6900 Series**

- **MIMO antenna for maximum bandwidth and service coverage**
  - Embedded directional & Optimize antenna design
  - Vertical / Horizontal / Dual-Slant polarization antenna technology
- **Gigabit LAN/PoE and Gigabit Ethernet WAN**
  - 1 - Gigabit WAN Interface
  - 1 - Gigabit LAN Interface with complaint IEEE 802.3at (PoE+)
- **Designed for challenging/rugged deployments**
  - IP-67 hardened enclosure with industrial-grade components
  - GORE ® Vent for pressure equalization, humidity, and air flow
  - Operating temperature: -40°C to 65°C (-40°F to 140°F)

	6900-R15 Category 6	6900-R18 Category 6	6900-R20 Category 12	6900-R21 Category 12
Chipset	Qualcomm	GCT	Qualcomm	Qualcomm SD
TDD Bands	B41	B42/43/48	B41/42/43/48/46	B41/42/43/48
Antenna	2x2	4x4	4x2	4x4
CA	2xCA	2xCA	3xCA	3xCA
Availability	NOW	Sampling	Aug./2018	Q4/2018

Summary

- Customers are demanding more robust broadband services and capabilities
- Fixed wireless has become a solid solution to meet growing bandwidth needs
  - Changes in technology
  - Availability of new spectrum
  - Growth of larger ecosystems
  - Government investment
- FWA has strong business case with more rapid time-to-revenue
  - As broadband provider
  - As MVNO
- Many operators worldwide are finding ways to successfully put in place a FWA solution

Thank You!

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