How will Outdoor and Indoor use of 5G Wireless Services Really Work?

Charles Cheevers

ARRIS International plc, USA

ABSTRACT

This paper will explore the 5G solutions direction from the Outside House In and Inside House Out perspectives, answering the following questions:

- What services will emerge that are outside only, versus those that are inside only?
- What happens in the hand over from one network to the next?
- What architectures are emerging?
- What solutions make sense to provide seamless connectivity?

This paper will review the use of Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) solutions as well as compare the sub 6 GHz versus millimetre wave 5G considerations. It will also explore the sensitive cost points of customer client equipment to support multiple 5G options – for both outside and inside while shedding a light on some of the key decisions ahead.

INTRODUCTION

5G Wireless Networks are being built to serve new applications. These applications must fund the development of the solutions and the infrastructure. There are four revenue or new business opportunities that will be called 5G Wireless for the rest of this paper.

1. **Fixed Wireless Access (FWA)** – The connection of wireless broadband to homes or other fixed location services. In the absence of mobile 5G services, 5G Wireless will lead with this one. The architecture trend for bringing Gbps speeds to consumers and enterprise is driving to smaller and smaller cell sites.
2. **Massive outdoor and indoor Internet of Things (IoT) connectivity** – Where everything gets connected. Narrowband IoT (NB-IOT) and existing Category M1 (CAT M1) LTE (Long Term Evolution) services will fill this growing area initially with the use of Embedded Sim (eSim) allowing economical ways for low bitrate devices to connect to low frequency LTE networks. This is already starting to appear even without the 3GPP Wireless standard being fully completed by leveraging technologies such as Long Range (LoRA) using unlicensed spectrum below 1 GHz and LTE-M.

   CAT M1 LTE is a low-power wide-area (LPWA) air interface that allows IoT and machine-to-machine (M2M) devices to connect with medium data rate *requirements. LTE-M is the simplified industry term for the LTE-MTC LPWA technology standard published by 3GPP in the Release 13 specification.*

3. **High bandwidth and capacity mobile wireless** – As the silicon technology evolves to shrink the user equipment/client side of the 5G connection, there will be increased burst and sustained speed applications to mobile devices. There is already progress in this direction on traditional LTE solutions using CAT 18 MIMO (Multiple-Input and Multiple-Output) solutions with the full 5G mobile ecosystem and handsets starting to emerge sometime after 2020.
4. **Connected Car and Connected Augmented Reality (AR)** – Vehicle to Vehicle (V2V) and Vehicle to Anything (V2X) will grow with Self Driving Car technology. The ability to support everyday life activities with AR overlay and to improve Infotainment for both mobile and fixed connections may also drive new applications as diverse as digital signage and hands free, eye glasses powered experiences.

Figure 1 – Automated Driving, Mobility Services, and Augmented Reality

Applications alone will not drive the development and deployment of the networks required to carry the additional bandwidth at the speeds required. There are a number of technical aspects to be considered from the "Outside House In and Inside House Out" perspectives as well as whether the deployments will use "Line-of-Sight and Non-Line-of-Sight" solutions.

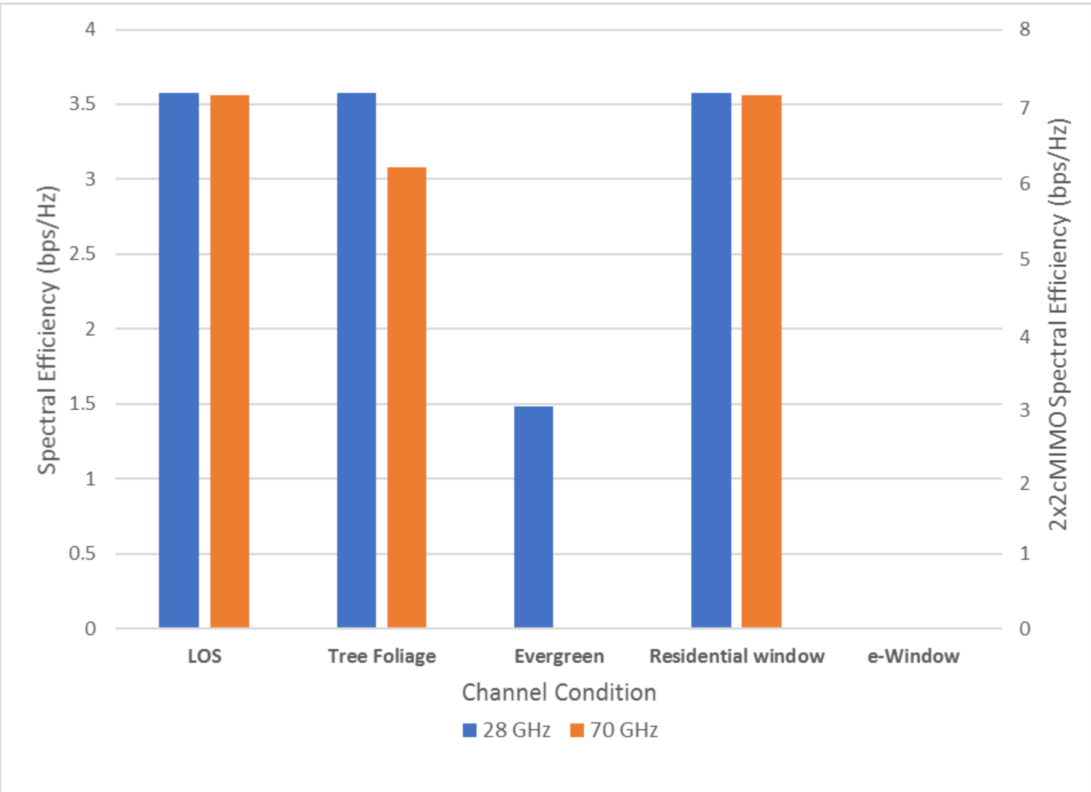
THE TOWER, MAST, LIGHT POLE, EXISTING INFRASTRUCTURE AND SMALL CELL STRATEGY

This one remains one of the key aspects of the success of the rollout of 5G services. Millimetre wave solutions move more naturally to light poles for both cell size and mounting of base stations. They also drive more to outdoor consumer premises equipment (CPE) devices to counteract the issue of the loss encountered through walls and particularly windows. However, some solutions like Multiple Dwelling Unit (MDU) to MDU work well economically from a high tower mount or top of MDU locations for millimetre wave. Traditional sub 6 GHz LTE and Wi-Fi technologies will also naturally move to a more of a small cell approach – still leveraging Non-Line of Sight economics, but splitting to smaller cells to increase the bandwidth to the user equation.

The use of existing wired network infrastructure for the location of new wireless small cells is also under investigation. For example, in the cable industry Hybrid Fibre Coax (HFC) networks are being considered to support the addition of attached in-line small cells at various demarcation points on the HFC plant. The Coax plant also supports powering for attached devices and has built in backhaul capabilities making it a potential low CAPEX and OPEX small cell host. Possible small cell locations include the Fibre Node, Amplifier locations or even at the Tap distributions to 12 or less single unit, stand-alone, houses. Expect to see a mix of high monopole and top of MDU cell sites and smaller cell in fill sites to connect to revenue generating services.

USA-based outdoor issues to consider include:

- 33 metre poles in housing subdivisions struggle to get the coverage required for Line of Sight solutions ‘Flesch (1)’
- The attenuation differences between 29 GHz and 2.9 GHz through various foliage and tree types. As an example, penetration through millimetre wave pine trees with hard and angular leaves, and pinecones – make it almost impossible to transmit any distance from the Base Station ‘Flesch (1)’
- The spectral efficiency of millimetre wave is affected severely by foliage and different window types with real problems at higher frequencies like 70 GHz to penetrate through evergreen tree and e-windows with double glazed gas filled panes (Figure 2) ‘Flesch (1)’
- Rain and snow both influence propagation and reduce the range with higher frequency and higher modulation ‘Flesch (1)’



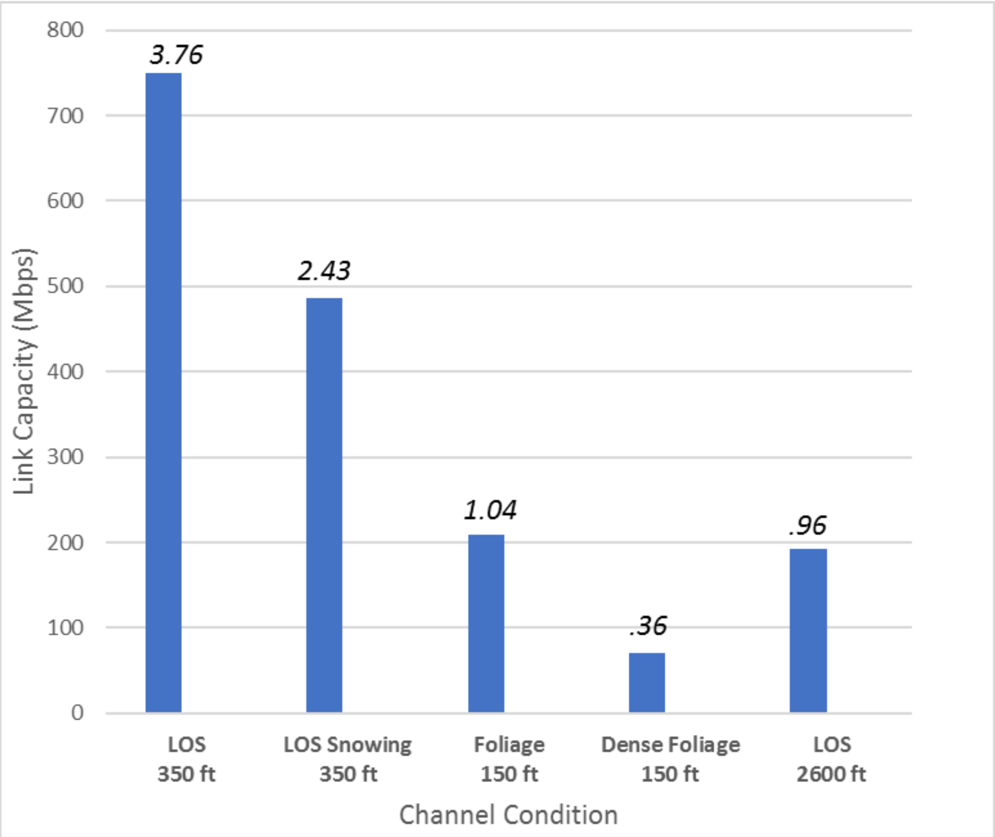


Figure 2 – 28 GHz vs. 70 GHz Spectral Efficiency

The physics of sub 6 GHz LTE applied in FWA solutions to the home typically requires an outdoor antenna to be used to mitigate 9-35dB signal loss of outdoor and indoor walls. This increases the overall OPEX and CAPEX of the FWA solution yet is typically still good for sparse and large cell site connections. What it gains in coverage it typically loses in speed and bandwidth capabilities.

The Outside Inside Discussion – Sub 6 GHz

In a cable network, the macro cell to smaller cell is a well understood direction. These cells can be added to the DOCSIS network to be included in the Wi-Fi and/or CBRS/LTE in the HFC.

> *CBRS stands for Citizens Broadband Radio System. The CBRS band comprises 150 MHz of 3.5 GHz shared spectrum. Historically these frequencies were primarily used by the U.S. government for radar systems.*

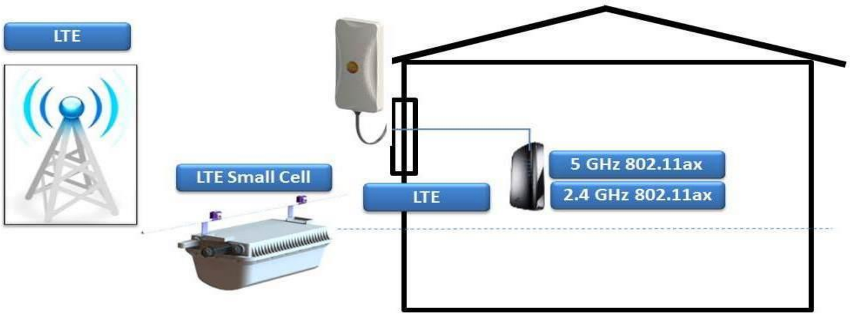


Figure 3 – Sub 6 GHz

The problem is starker with the use of high capacity millimetre wave spectrum where the cell size typically must shrink because of LOS requirements. Even high 33 to 66 metre tower locations still typically require outdoor transmit & receive (Tx/Rx) antenna solutions to make it work reliably and economically viable.

To try and increase the bandwidth to the client, the cell sizes shrinks to a point where a common architecture now being looked at is to add the cell to light poles or other mounting points less than 50 metres from the CPE device. Some of our testing has shown that in Single Family Unit Housing (SFU) Estates to achieve Gbps millimetre wave speeds to the consumer 25 metre or less cell sites may be required serving 8 or fewer homes.

The Outside Inside Discussion – mmWave

These types of solutions require getting to very small cell size and leveraging light poles closer to the single-family unit home. There's a clear opportunity for MDUs. As well as an opportunity for service providers to use their own wired plants.

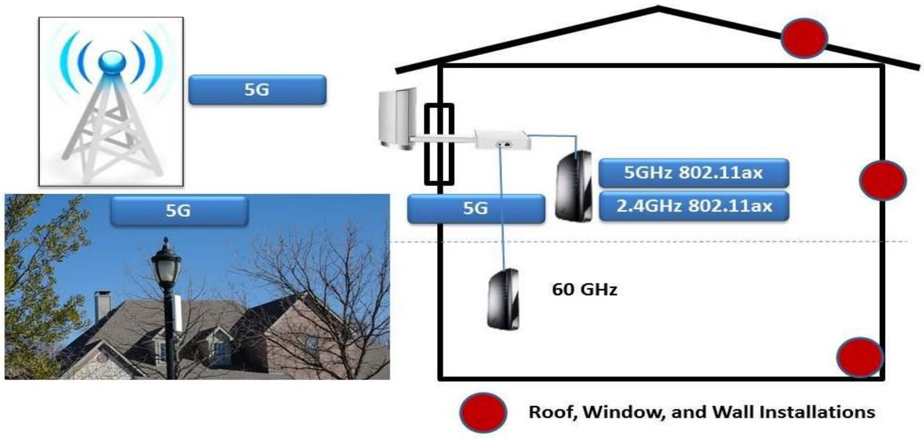


Figure 4 – mmWave Success Requires Roof, Window, and Wall Installations

Choose Your Weapon – Sub 6 GHz versus Millimetre Wave

5G deployment is likely to be a combination of **<u>both</u>** sub 6 GHz and millimetre wave to get the reliability required for FWA and mobility services.

5G mmWave	5G Sub 6 GHz
24 GHz – 90 GHz	Wi-Fi, LTE / CBRS, LoRA, and NB-IoT
• Lots of new spectrum • Performance >>Gbps – 128 Gbps in 60 GHz alone • Line of Sight – mostly • Range does not like walls, windows, or conifers! • Reliability is lower	• Wi-Fi and LTE and new Shared Spectrum CBRS • Performance >Gbps • Non- Line of Sight • Range – Ranges from multiple Km to Wi-Fi sectors • Reliability is high

Table 1 – Range or Performance

THE INSIDE OUTSIDE STRATEGY

This approach has been discussed more in recent times with the overall direction of smaller cell architectures. The idea is to support a small cell or home cell approach at the end leaves of the service provider's network. The implementation typically manifests itself as placing a Wireless Home Cell in the consumer's home to support both in and out of home Wireless Connectivity services. It tries to support many convergent applications:

1. In home Wi-Fi and Licensed Spectrum connectivity for best wireless solution
2. Surrogate connectivity for others outside the house leveraging immediate wired backhaul on the consumers ISP GW device
3. The better HomeSpot/Community Hotspot experience augmenting Wi-Fi with licensed spectrum
4. Easy connect of eSIM or other authenticated and authorized devices from an LTE or 5G Wireless Cell
5. Offload home and close to home bandwidth to lower power home cell from the outside Pico or macro networks and
6. To get 5G services 'inside' the home millimetre wave bandwidths do not penetrate deep enough into the home and struggle to connect to one device inside the outer wall/window

The Inside Outside Discussion – Sub 6 GHz

One short term option that seems to make sense particularly with Shared Spectrum solutions like CBRS in the US is to add a Femto-Cell to the home. This provides the ability to offload the Macro network and provide convenient SIM based authorization for services. The Home Cell could then contain both Wi-Fi and LTE support which can be found today in many LTE deployments.

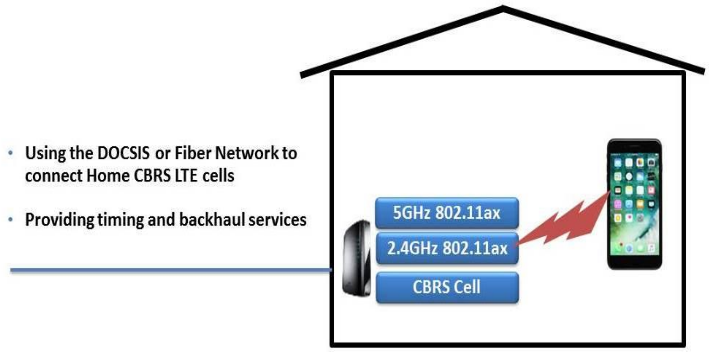


Figure 5 – Sub 6 GHz Connections to the Home

Using the DOCSIS or Fibre Network to connect Home CBRS LTE cells provides timing and backhaul services. The home gets a CBRS 3.5 GHz LTE Pico Cell. The operator supplied phone connects on a CBRS frequency. There's potential to work with a Mobile Virtual Network Operator (MVNO) partner. And there's future potential to offer Neutral Host Home Cell – and offload the MVNO partner macro network.

The Inside Outside Discussion – Home Cell

Expanding the Home Cell further there is a choice of power for LTE radios. Two possible examples to consider:

- 125mW EIRP which can cover the home and ~10m outside the home – affording connection to handsets on the street or better performance at range for the consumers LTE enabled devices
- 1W EIRP which can cover the home and 3+ neighbouring homes as well as good street coverage

Decisions on what power device to use are determined by the cost, ergonomics of size and complexity of managing the overlapping cells.

Another common technology being explored for Inside Out Networks is LoRA. It runs in the 900 MHz frequency and affords a low-cost Macro Narrowband IoT solution from the 33 metre + Monopole – and is also capable of being used from the home. A low cost LoRA addition to the home can create a network of connection from 500 metres to 1 kilometre from the home depending on placement of the LoRA device in the home. (Figure 6)

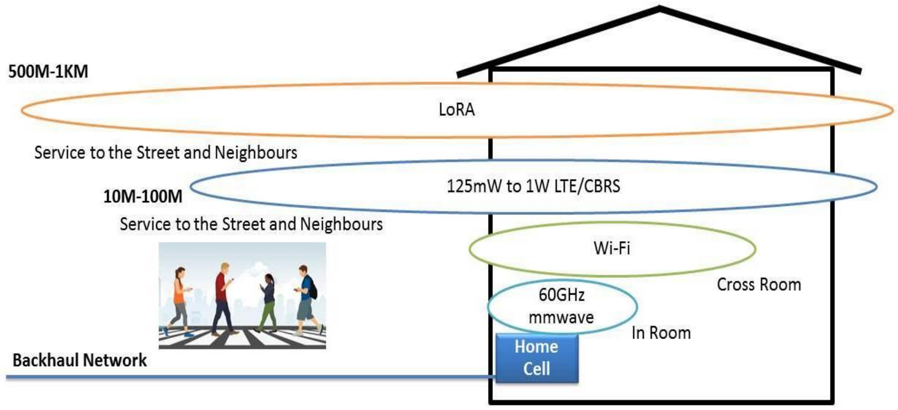


Figure 6 – Networks to the Home Cell

Questions to consider regarding Figure 6:

- Can a 5G cell operate inside the home?
- Which Sub 6 GHz opportunities like CBRS 3.5 GHz Cell and LoRA can provide outdoor coverage?
- Millimetre Wave potential, but at what cost/range?
- 60 GHz networks in the home to develop >>1 Gbps intra room wireless solutions leveraging 802.11ay technology.

Figure 8 below shows the inside out coverage of LTE small cells in the home and their potential roaming contribution at different LTE data and voice support levels. A potential visualization of an LTE based Home Cell generated network in a housing estate is given below in Figure 7. The potential does exist to get high enough coverage across homes to develop services that don't need complete coverage and can also handoff to macro networks of lower speeds or available capacity.

Figure 8 information comes from work done by ARRIS using simulations of 3.5 GHz LTE propagation in various construction types and EIRP from Femto Cell. The simulation model was also verified with actual testing of some of the construction types and foliage. It assumes a 12dB loss for foliage (on the lower side).

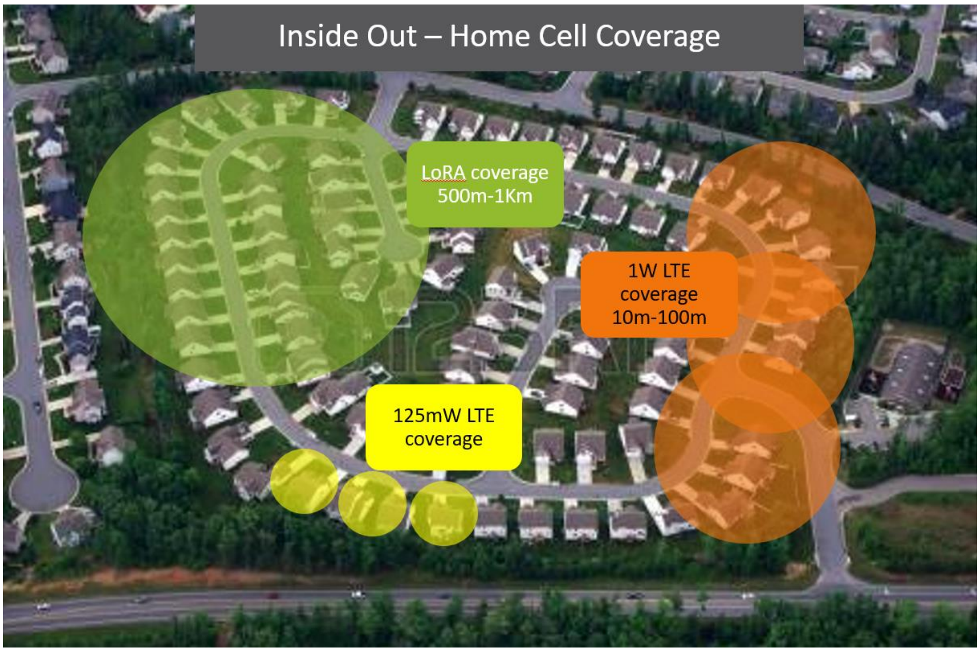


Figure 7 – Home Cell Coverage

AP Service Radius (feet) 25 Mbps (D) / 5 Mbps (U)

1W AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	81	217	494
2500	63	170	386
5000	63	170	386

500mW AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	63	170	386
2500	49	132	302
5000	49	132	302

250mW AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	49	132	302
2500	39	104	236
5000	39	104	236

AP Service Radius (feet) 10 Mbps (D) / 2 Mbps (U)

1W AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	135	361	822
2500	105	282	643
5000	105	282	643

500mW AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	105	282	643
2500	82	221	502
5000	82	221	502

250mW AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	82	221	502
2500	64	172	392
5000	64	172	392

AP Service Radius (feet) 100 kbps (D)/100 kbps (U)

1W AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	267	715	1627
2500	208	559	1272
5000	208	559	1272

500mW AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	208	559	1272
2500	163	437	994
5000	163	437	994

250mW AP

Size (sq ft) \ Exterior	Stone	Brick	Wood
1500	163	437	994
2500	127	341	776
5000	127	341	776

Figure 8 – LTE Range versus Performance for Inside Out Coverage

Figures 9 and 10 illustrate the overall performance in a housing development with 156 homes with approximately .75 acre lots where the house construction is mostly brick exterior. The plots show the level of expected 3.5 GHz performance with the foliage, terrain, and house types. The position of these small cell devices is not inside the home but are assumed to be located on the roof of the homes. This model was run to see if the attenuation of the indoor walls and furniture were removed would a 1W EIRP outdoor home mounted cell have a much better contribution to coverage (which it does). Equally, for something like the CBRS standard in the US – where 4W EIRP is also permissible – running the 4W model also showed good results. This strategy of using the “Home as a Tower” – is potentially useful when looking at a strand mount Small Cell strategy using aerial Hybrid Fibre Coax or Optical and a substantial portion of the network may be underground.

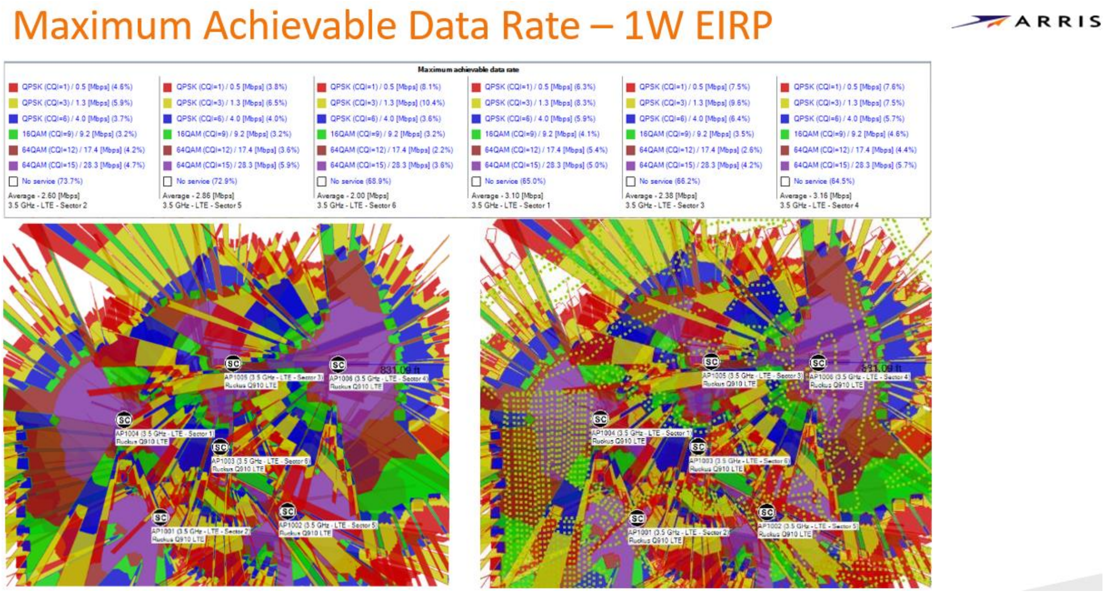


Figure 9 – DL/UL results of 1W EIRP Roof Mounted 3.5 GHz LTE Small Cell

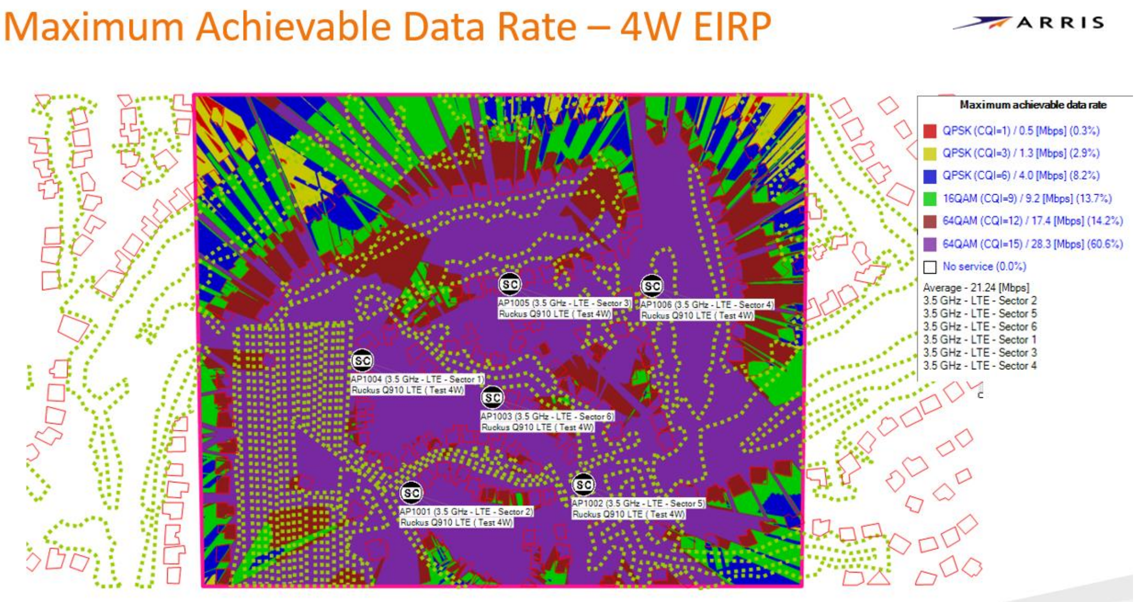
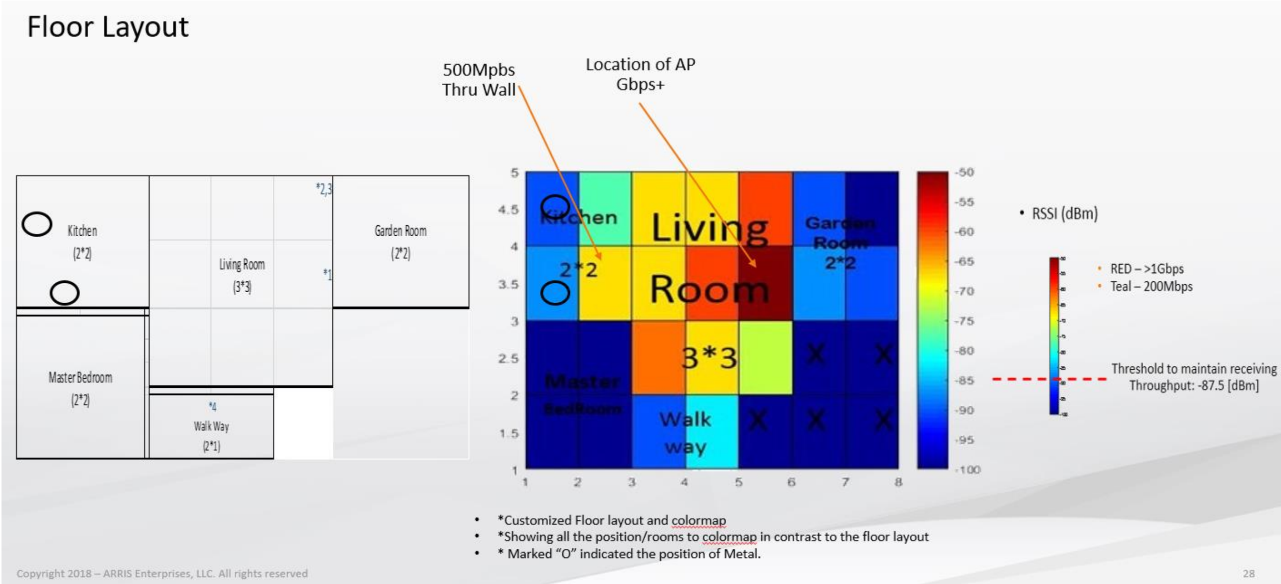


Figure 10 – DL/UL results of 1W EIRP Roof Mounted 3.5 GHz LTE Small Cell

For millimetre wave in the home it is not practical to have a Home Cell support outside home connection. However, with the recent approval of the 802.11ay standard, the 60 GHz spectrum can be utilized in the home to support higher speeds and leverage of millimetre wave solutions. 60 GHz can certainly be used in room but with sheetrock (-7db to -9dB) dividing walls it can also be used across rooms. 802.11ad devices (rated to 1.5 Gbps) can generate higher than Wi-Fi capacities in room and even across rooms.

In actual testing performed by ARRIS of 60 GHz in home propagation with 802.11ad, there was higher than Wi-Fi performance in much of the home. Typical issues with millimetre wave were reflected from 'hard' surfaces like TVs and porcelain in bathrooms. See Figure 11 below.



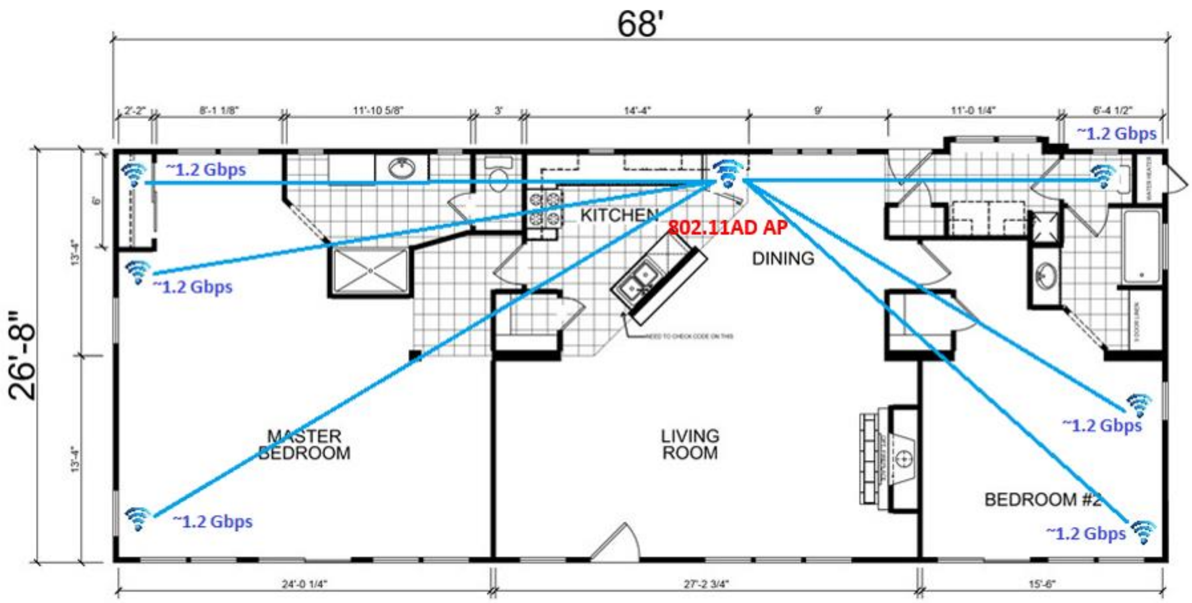


Figure 11 – In Home/Office 60 GHz Coverage

CONCLUSIONS

It will be the Wired Backhaul Network that supports these ever-decreasing 5G small cell architectures. Why? Because…

- 5G cannot exist without a Wired Network to backhaul it!
- It's important to go to ground wire as soon as possible to minimize latency

- Industry multiple network operator and service provider consolidation are driven by this requirement and convergence

Because of the latency requirements for 5G Wireless, and the availability of spectrum, it will be increasingly likely that 5G architectures will be many and varied. The likelihood of any sub 6 GHz spectrum being used for 5G services is high and the potential for architectures to have to support both sub 6 GHz for range and millimetre wave for bandwidth is highly probable. There is also scope for adding inside out schemes for leaf Home Cells on wired networks. Whether these deploy as first stage or final stage elements of the new 5G Wireless world, we will see in the coming five years of rollouts.

REFERENCES

1. J.R Flesch et al, 2017. SCTE/ISBE Expo Technical Paper, Can a Fixed Wireless Last 100m Connection Really Compete with a Wired Connection and Will 5G Really Enable this Opportunity? pp. 24 to 41

ACKNOWLEDGEMENTS

The Author would like to thank Qualcomm, Inc. and CableLabs® for their contributions.