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Fixed Mobile Convergence

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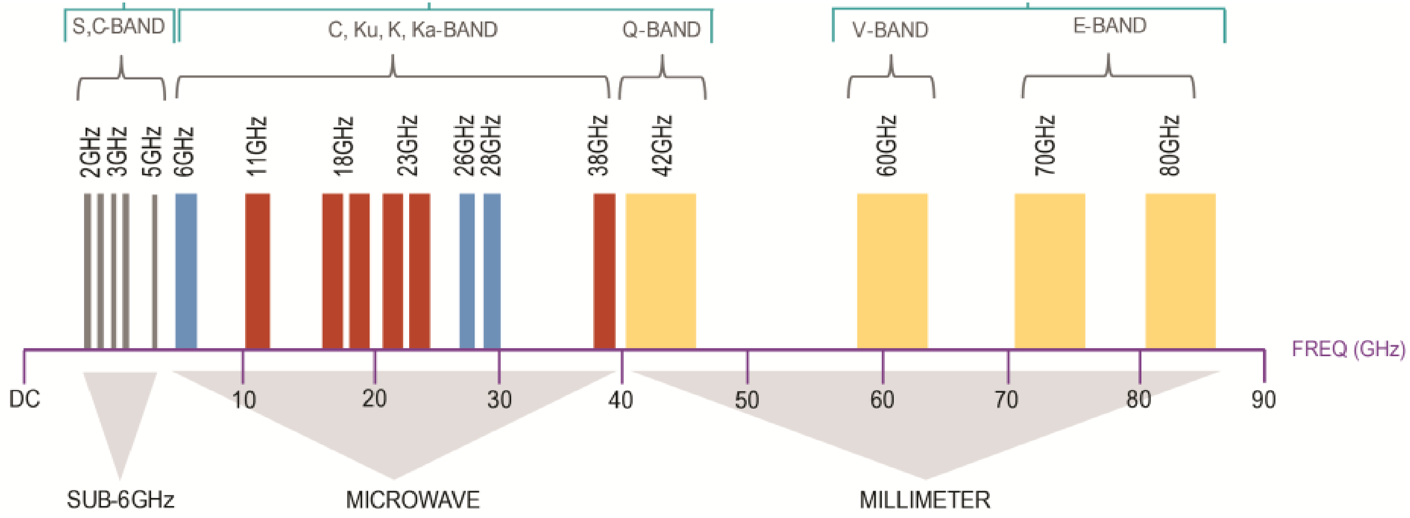
# Can a Fixed Wireless last 100m connection really compete with a wired connection – and will 5G really enable this opportunity?

**Charles Cheevers**
CTO CPE Solutions,
ARRIS

# The Importance of Wireless Physics

- Huge hype in the market at the moment around driving to new Fixed and Mobile wireless performance levels on 5G
- 5G is still being defined – and has a number of stepping stones – pre 5G, 5G-NR and 5G with full new MAC and mobility
- This paper principally focusses on some of the considerations of Fixed Wireless Access for 5G for residential applications – and what performance expectations drive wrt architecture changes
- It also touches on the sub 6GHz frequencies and in particular looks at CBRS – as a potential spectrum managed architecture to at least offer the potential to compliment 5G services in millimeter wave spectrum
- It also debates whether
    - 5G – can deliver a solution to send a FW signal into a SFU dwelling with outside or inside mounting of the Transceiver and at what distance to get Gbps speeds
    - 5G at millimeter wave needs the addition of a sub 6GHz technology to improve the reliability of the service
- Leaves the question as to how far can we go with new element array designs to create Massive MIMO and paired 100bits/Hz solutions
- Asks the question about the economics of FTTH vs Fixed Wireless Access

# Section 1.1: Wireless Spectrum Increases




| Band | Bandwidth |
|---|---|
| CBRS (3.5GHz) | 150MHz, TDD |
| 28GHz | 850MHz, TDD |
| 37~39GHz | 3GHz, TDD |
| 64~71GHz | 7GHz, TDD |

- Today, most spectrum blocks are available in 5 to 10 MHz blocks, and in some cases up to 20 MHz blocks
- High Bandwidth (mm Wave) spectrum will be available in spectrum blocks that are 200 MHz or larger
- Licensed use in the 28 GHz, 37 GHz, and 39 GHz bands
- These larger blocks will enable operators to carry significantly more traffic in a single channel, at higher speeds, and in support of many more wireless devices
- Unlicensed use in the 64-71 GHz band
- Shared access in the 37-37.6 GHz band

# The Silos of Frequencies – The Aggregate of Some/All!

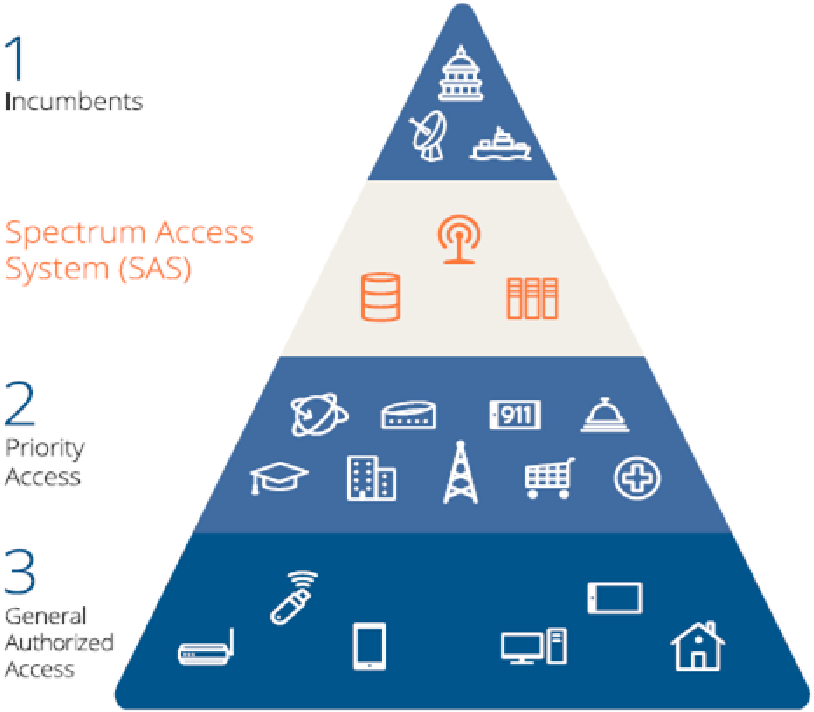
- Experimentation at the moment testing the millimeter bands in particular for range and performance in different geographic, atmospheric and terrains.
- Height and Distance of the base station to the client also are the key factors for performance
    - Non Line of Sight – typically sub 6GHz technology
    - Near Line of Sight solutions – with adaptations for being able to beamform, leverage reflections and adapt to terrain and materials
    - Line of Sight solutions – where the performance level required needs line of sight from Base Station to CPE device
- Because of this equation of Height, LOS/NLOS performance, variability of millimeter mostly LOS solutions – and the desire to get to Gbps to the home – the economics of 5G has huge challenges
    - Base Station/Cell coverage for Gbps performance – decrease in cell size increases cost
    - Self install desirability of CPE device – inside window requires smaller cell (potentially less than 50M) to have a chance of penetrating low energy Glass. Outside CPE device has more performance and stretches cell size/coverage – but is more costly on CPE, has poor ergonomics and forces technician install model like Satellite receiver
    - Does the CPE device need both millimeter wave and sub 6GHz NLOS solution – either LTE or Wi-Fi
- 5G – outside in – or inside out – or both
    - Discussions and analysis continue on whether the 5G network can emanate from the home out rather than network in… or combination of both. Different schools of thought on this – but with 60GHz growing in home usage it may be the inside millimeter solution to different outdoor millimeter wave solution

# Spectrum Richness:
# New BW and Bitrate Mining

| Band | Channel BW (MHz) | Bonding Limit (Channels) | Max BW (MHz) | Bitrate (Gbps) @ 7 bps/Hz | Bitrate (Gbps) @ 100 bps/Hz | Comments |
|---|---|---|---|---|---|---|
| 3.5 GHz | 10 | 7 | 70 | 0.49 | 7.0 | PAL-limited |
| 28 GHz | 425 | 2 | 850 | 5.95 | 85 | 42.5 Gbps/ch* |
| 39 GHz | 200 | 15? | 3000 | 21 | 300 | 20 Gbps/ch* |
| 70 GHz | 1250 | 5? | 7000 | 49 | 700 | 125 Gbps/ch* |

*Assumes 100 bps/Hz due to Massive MIMO

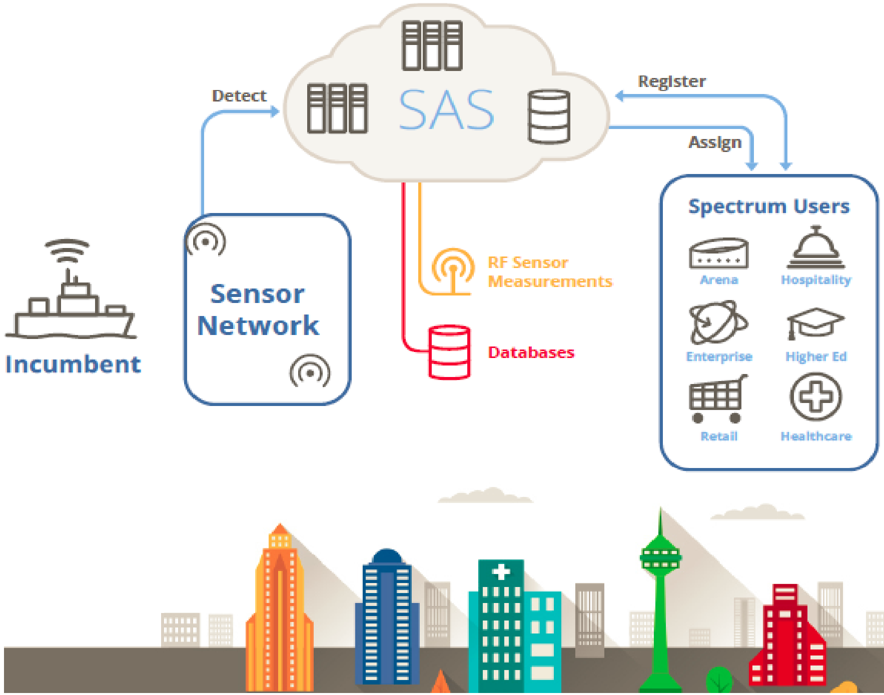
# Section 1.2: A Look Back at Sub 6GHz - 3.5 GHz CBRS Band




- 150 MHz of shared spectrum
- Low power, small cell applications
- Spectrum Access System (SAS) provides spectrum management
- **Incumbents** – Naval radars that use band infrequently
- **Priority Access** – finite term license for interference protection
- **General Authorized Access** – no license required, unprotected use
- At least 80 MHz of spectrum always available for GAA use

**CBRS does not deliver the requirements of 5G – but in combination with millimeter wave offers backup reliability**
**Offers Carrier Aggregation capability**
**In conjunction with large element arrays could offer Gbps speeds with paired arrays**

# Section 1.2: Dynamic Spectrum Allocation in CBRS



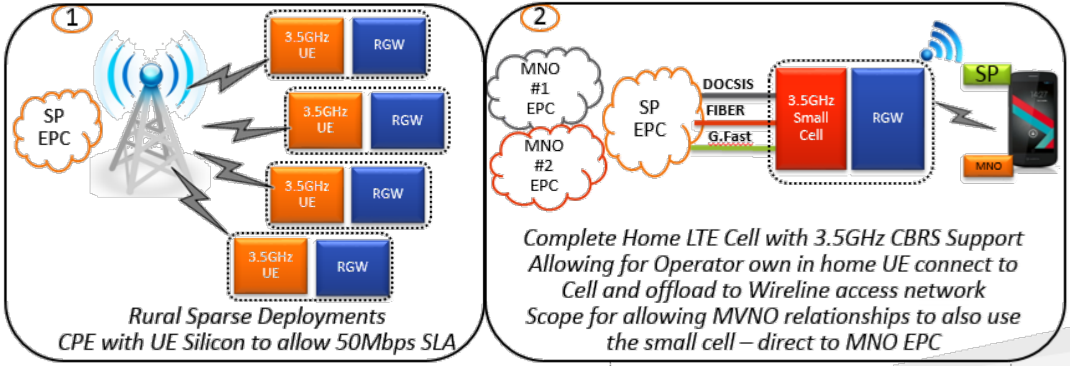

- Cloud-based for scale, extensibility, and efficiency
- Predicts RF propagation in real time
- Provides interference protection based on aggregate effects
- Employs sensing for closed loop management

**Could the SAS model targeted for CBRS and sub 6 GHz shared spectrum also be extended to support 5G small cells? Could it support the control and aggregation of sub 6Ghz with millimeter wave?**

| | |
|---|---|
| **Outdoor** | **Yes – Macro coverage** |
| **Enterprise** | **Yes** |
| **SMB** | **Yes** |
| **Residential** | **Yes** |

# Cell Supporting 3.5GHz

- Allows LTE support in all applications – Outdoor and Indoor
- With 3.5GHz allows either standalone LTE macro cell/tower or co-location with Wi-Fi
- Co-location with Wi-Fi opportunities in Outdoor, Enterprise & SMB, Residential applications
- Can support LWA solutions with support in both the AP and the Client devices
- Like any LTE network – engineering Cells for minimal overlap and deploying SON solutions for inter eNodeB handoff is also required.
- Supports providers own Handset and Mobile Network but also can potentially support a Neutral Host Cell model on 3.5GHz with supporting agreements with MNO

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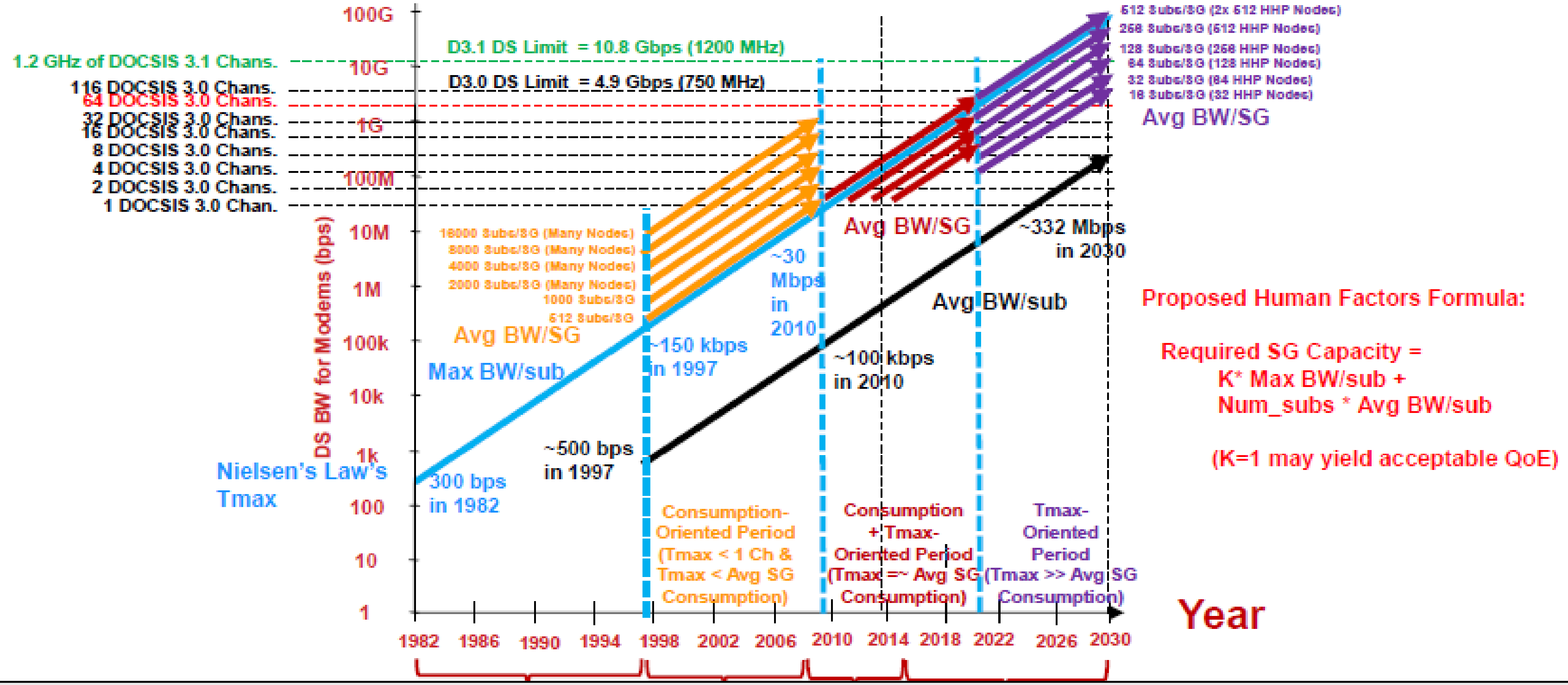
# Section 1.3: Requirements: Bitrate Demand Growth

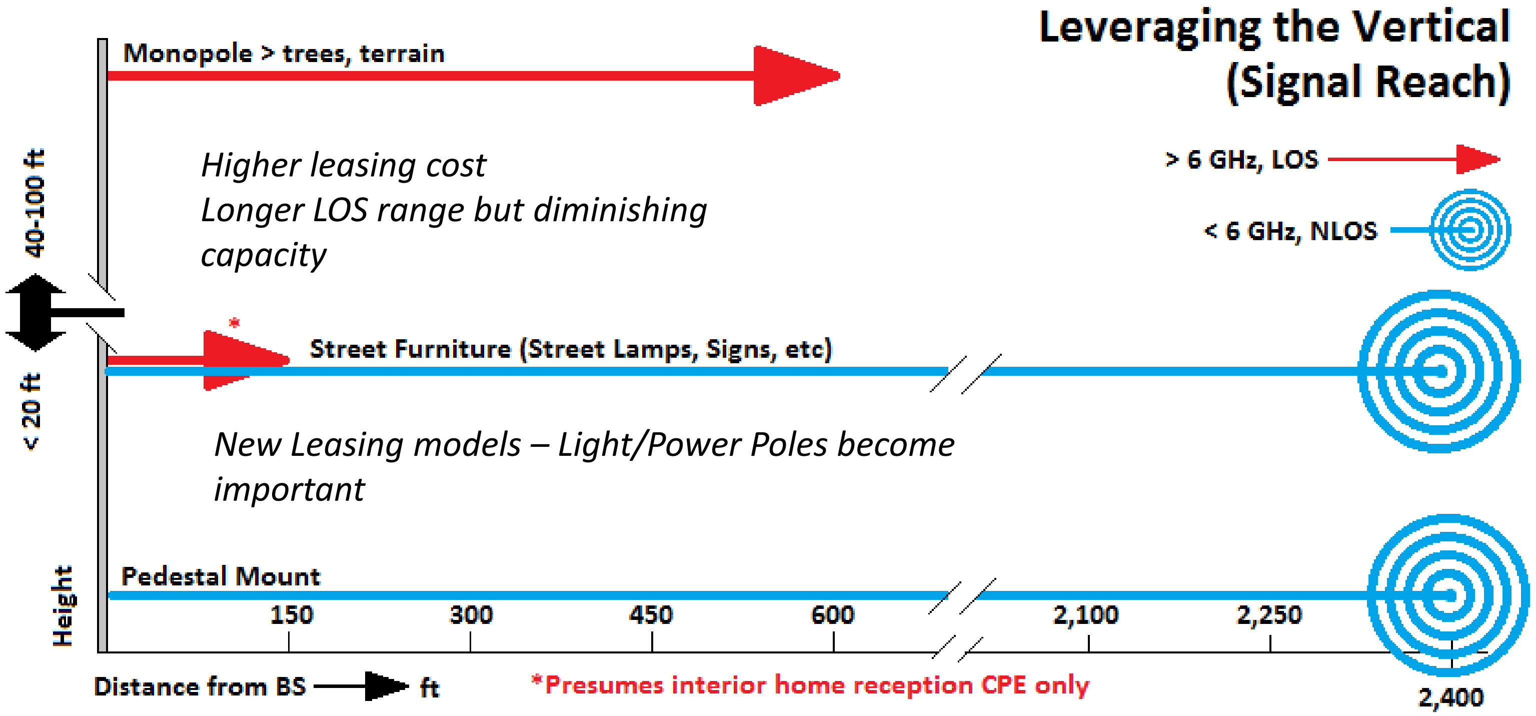



**Our Bandwidth model for Wireline access network**

**Why would FWA solutions be any different – shows that they have to be capable of doing Gbps**

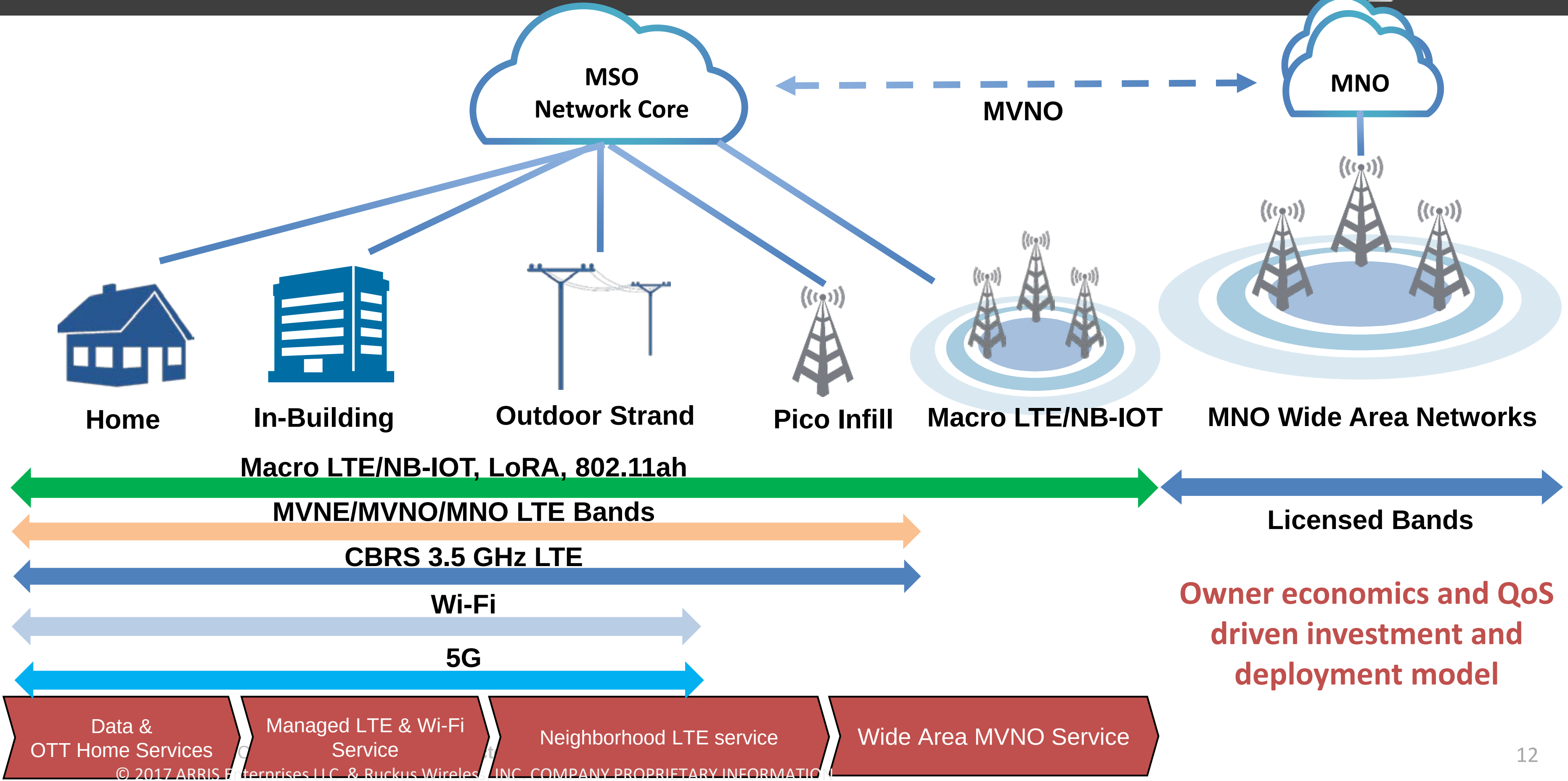
**Wireless solutions can decrease cell size and # of subscribers – as can splitting nodes in DOCSIS HFC planning**

# Section 1.3.1: Wireless Signal Reach Challenges




NLOS (blue) restricted BW is easier to deliver and install (lower height mounts and greater service radius).
LOS (red) packs an order-higher BW but, absent outside signal capture (at least 2nd story), needs to be serviced by base stations located within 50 meters (best case reception <= 200 meters).

# Overlapping Frequencies / Range – Target Architectures



## Overlapping Frequencies / Range – Speeds

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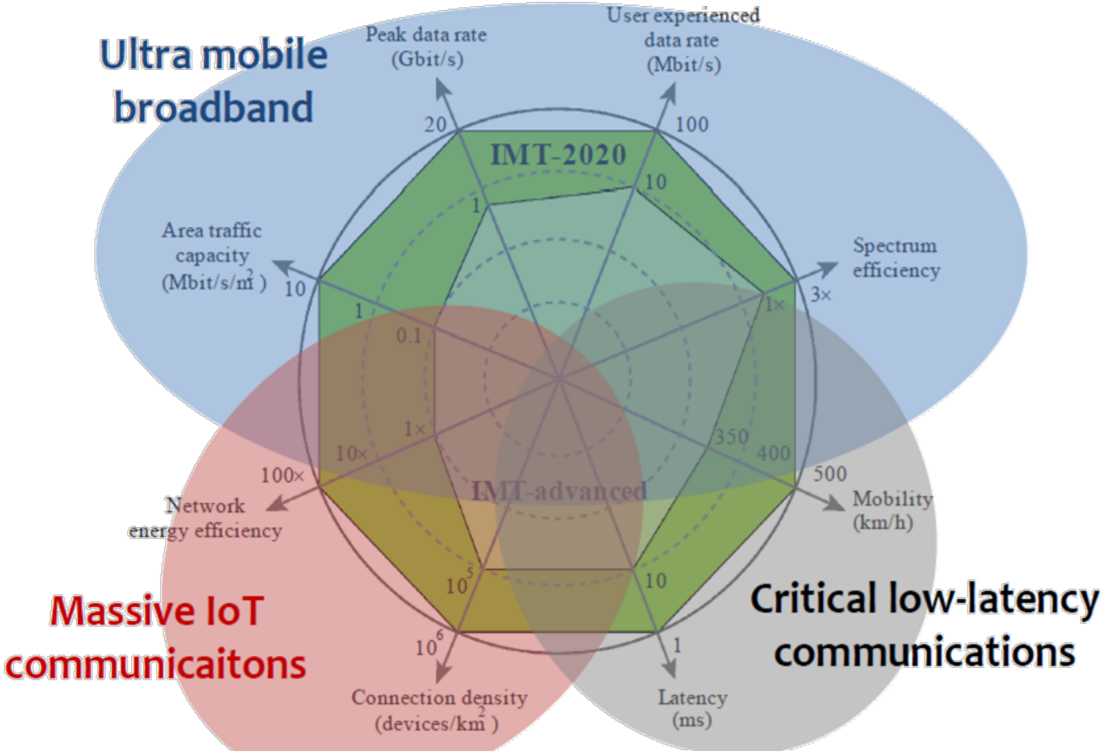
| Type | Frequency | | Speed / Coverage |
|---|---|---|---|
| LOS | *57-64GHz ; 64-71GHz* | Cell | *>>Gbps*<br>***<150m*** *Outdoor LOS ;* ***<10m*** *indoors* |
| NLOS | *Wi-Fi 2.4GHz and 5GHz* | CELL | *500Mbps*<br>***20m*** *On Property Coverage* |
| NLOS | *2.5GHz - 3.5GHz CBRS/LTE* | CELL | *200Mbps*<br>***1Km- 200m*** *On Street Coverage* |
| NLOS | *900MHz – 802.11ah LPWAN* | | *Other options*<br>*LoRA, NB-IOT*<br>*1Mbps*<br>***1000m*** *Neighborhood Coverage* |
| NLOS | *TV White Space – 802.11af* | | *Other options*<br>*LTE Anchor Band and VoLTE*<br>*1Mbps*<br>***10Km-1000m*** *Neighborhood Coverage* |

*Opportunity for Aggregation -* ***LAA***

*Opportunity for Anchor LTE channel-* ***LAA***

**1000 meters**



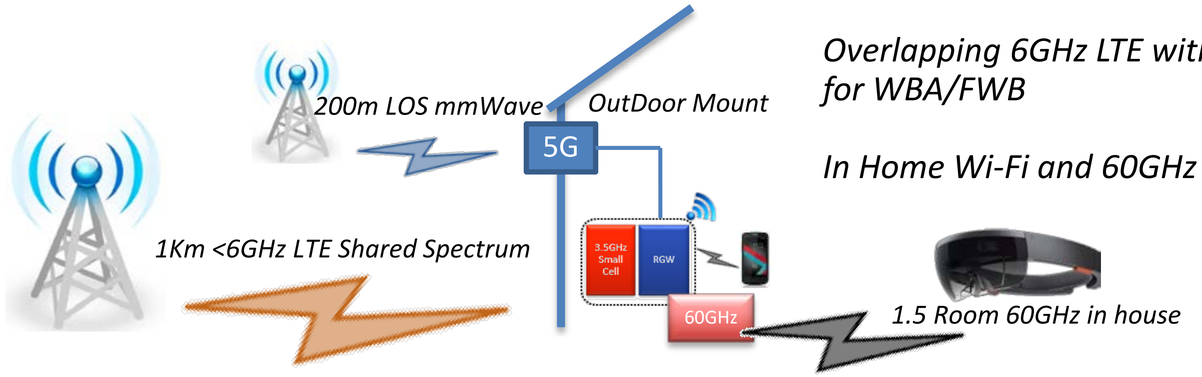

- ❑ Low Latency
- ❑ Has to do Gbps+
- ❑ Has to scale for massive IoT

*For FWA applications*

- *Gbps symmetric drives architecture*
- *Macro Tower unlikely because of range issues*
- *Street Furniture and propogation at 20ft or less for Base station and cell is the likely solution*
- *Drives opportunity for Backhaul – Fiber better than millimeter wave*

# 5G Directions and Strategies

- ❑ 5G wireless services likely to be
  - ❑ Multiple PHY strategy for across the 6GHz and higher millimeter wave frequencies. This is required to provide fallback for the non deterministic nature of LOS mmWave solutions
  - ❑ Use of lowest frequency bands for LTE anchor channels may be advantageous to any macro LTE to Pico LTE solutions
  - ❑ Combination of LOS and NLOS technologies for a single service may be needed
- ❑ Solutions that offer channel bonding, Aggregation and potential spectrum reuse in the sub 6GHz band **PLUS** use of the selective use of some or all of the 12GHz+ of 38,60,70 GHz where appropriate will prevail
- ❑ Innovation in trying to outdoor mount 5G Transceiver on home without drilling holes. There are innovations in solutions doing induction powering and Wireless pads that may improve technician install experience and give some home for self install.




*Overlapping 6GHz LTE with mmWave for WBA/FWB*

*In Home Wi-Fi and 60GHz – offload LTE*

# How Small a Cell Size Will Terrain and Economics Allow?

- For typical suburban subdivisions – the challenges are many
  - Where to locate the cell/base station
    - Desire to use street furniture vs Macro Towers
  - Getting backhaul to the subdivision
    - Desire to run Fiber vs using millimeter wave backhaul
  - CPE devices
    - Desire to use highest windows in homes
- One thesis that still does not have a satisfactory answer is that to get Gbps to a home
  - Sending a millimeter wave through a window requires a Cell < 50m
  - Street Lights in Subdivisions probably see < 10 homes on average LOS
  - Consumers hate devices on the outside – even on a window
  - Consumers don’t like terminal devices in bedrooms
  - HOA covenants also place restrictions on outside devices
- The following diagrams show a simple LOS propagation model for a random Georgia Subdivision

# Section 1.3.1: Line-of-Sight mmWave Delivery Challenges




mmWave LOS: Going vertical to gain clear access to service footprint

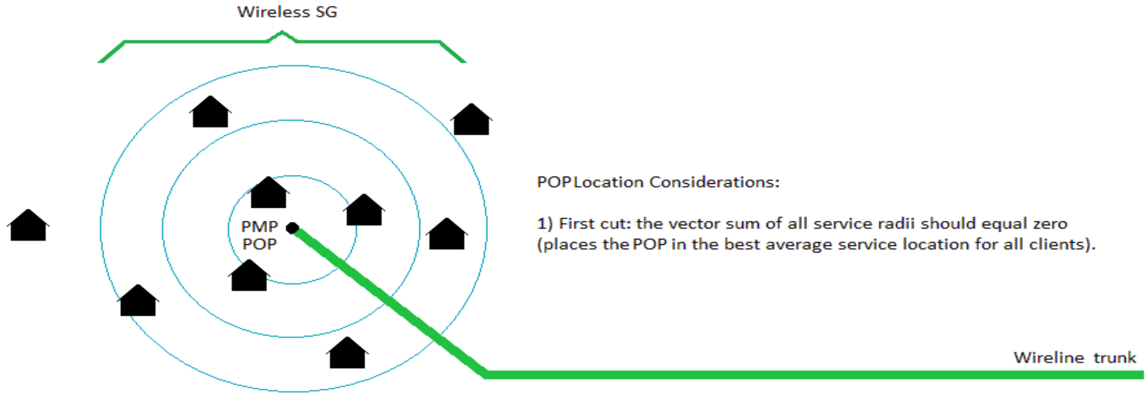

**Extremely hit and miss wrt number of homes served from location**
**Street light models have problems of overgrown trees**
**Can be rolled out incrementally – but initial investment to target 10-20 homes**

# Section 1.3.1: Tower density, LOS (left), NLOS (right)


**Single NLOS may have coverage but wont have the bandwidth**

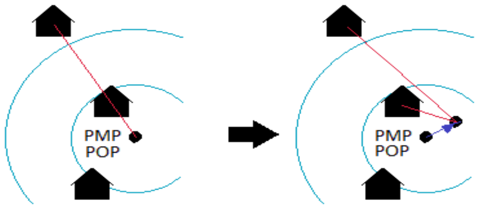
**Potential deployments initially on NLOS sub 6GHz for lower density and add millimeter wave in-fill Street furniture cell when subscriber counts increase?**

# Section 1.3.2: NLOS POP Setting and Adjustment




POP Location Considerations:

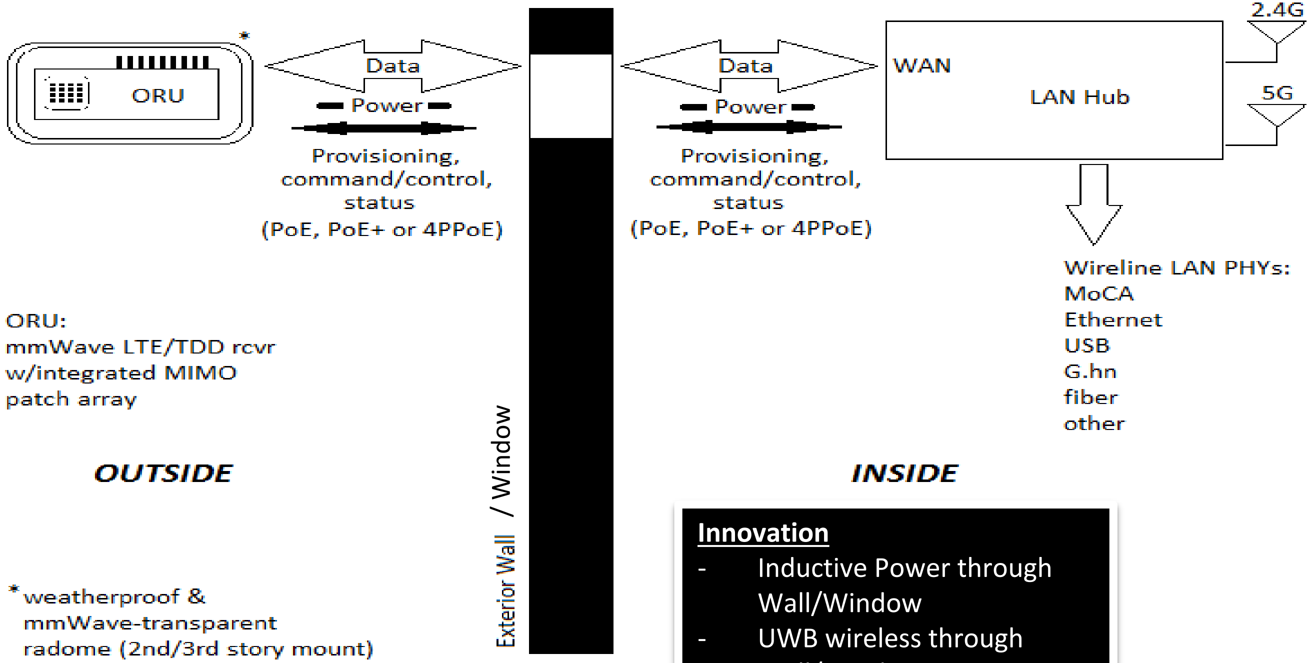
1) First cut: the vector sum of all service radii should equal zero (places the POP in the best average service location for all clients).




2) Offset the POP along a line orthogonal to the average vector between the two closest clients in azimuth, until that displacement is at least twice the angular resolution of the antenna MuMIMO array. Confirm against all remaining clients after move and iterate this for any newly created vector overlay until all look angles are appropriately diverse. This insures best bonded channel spatial re-use for each of the clients, maximizing their connectivity bitrate.

**NLOS POP placement is an exercise in geometry, without much consideration for environmental impediments. You start by determining the cluster service group size, centering the POP to balance propagation losses and then fine-tune the offset by examining look angles to all clients such that best azimuth diversity is achieved.**

# Section 1.3.3: Home Implementation for LOS Millimeter Wave Reception Anticipating 200 Meter Service Radius




**Innovation**

- Inductive Power through Wall/Window
- UWB wireless through Wall/Window

**The outside inside problem:**

**Assuming you need an outdoor Analog Transceiver with indoor Baseband, innovation exists in trying to get solutions to power through walls/window and send UWB wireless through Wall/Window**

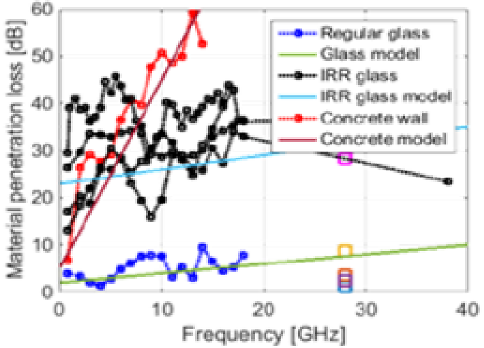
# Section 1.4.1: Signal Penetration Potential of Various External Home Materials, by Frequency

| Residential 1 | |
|---|---|
| Material | Loss |
| Vinyl siding | ~6-7 dB |
| Stone siding | ~35 dB |
| Window glass | ~10 dB |
| Plastic blinds | ~2 dB |

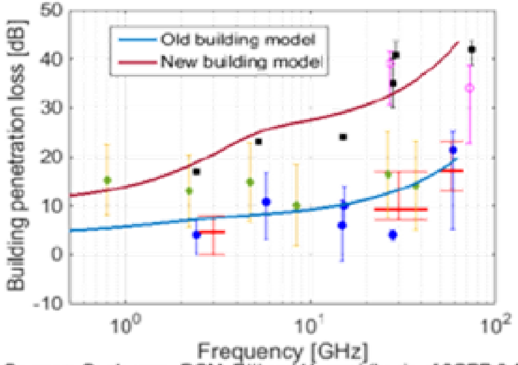
| Residential 2 | |
|---|---|
| Material | Loss |
| Plywood | ~8-10 dB |
| Hollow sheetrock | ~1-2 dB |
| Wood exterior wall/panel | ~10 dB |
| Brick exterior | ~30 dB |
| Metal doors/window frames | high |

| Residential & Commercial | |
|---|---|
| Material | Loss |
| Commercial Tinted Window | 10-20 dB |
| Clear glass | 2.5 dB |
| Residential Home Exterior | ~9 dB |

- Results consistent with other industry sources




Sources: Samsung and Nokia

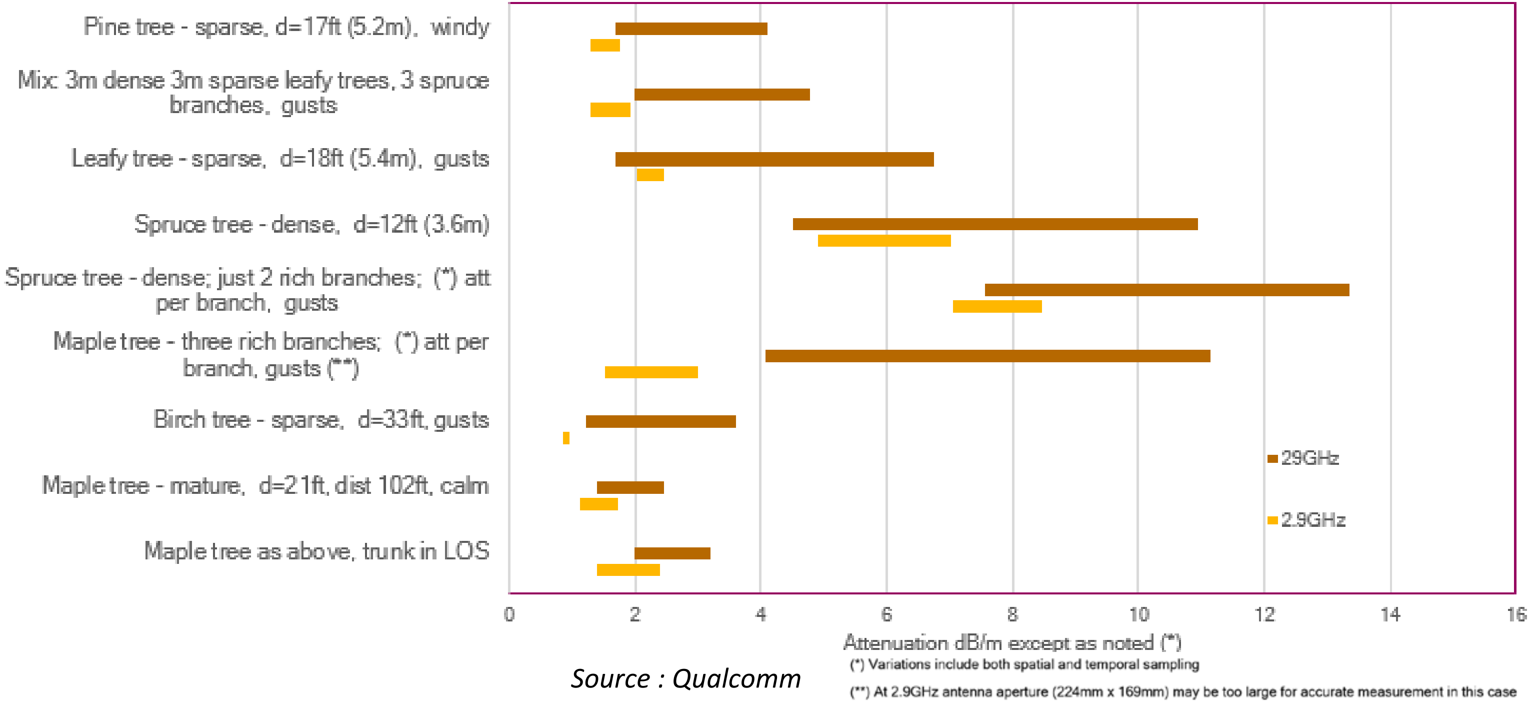



Sources: Qualcomm, DCM, E/// and Huawei (basis of 3GPP & 5GTF O2I model)

**Will millimeter wave go through Walls or Windows?**

**Ironically, tinted windows and low energy windows present 20dB loss challenges**

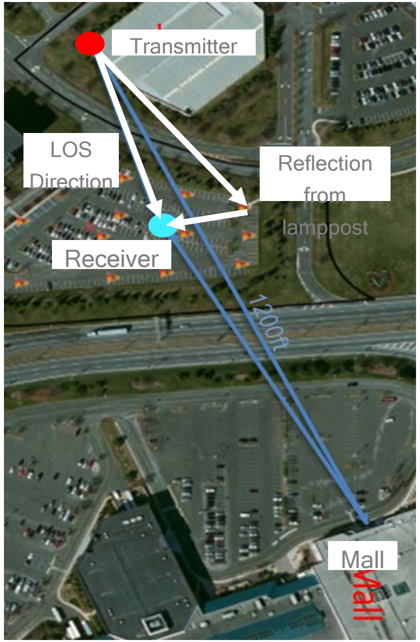
# Section 1.4.1: Effect of Tree Foliage on Signal Propagation both sub-6 GHz and Near Millimeter Wave




*Source : Qualcomm*

**Evergreen Trees have highest attenuation to 29GHz**

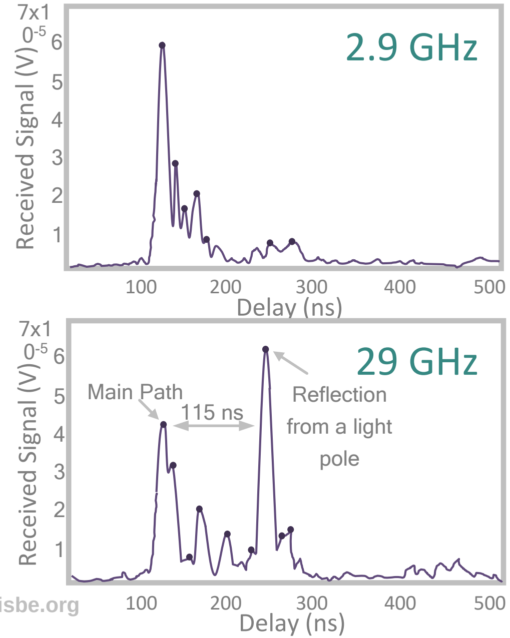
# Outdoor mmWave Propagation Measurements




*Source : Qualcomm*

## Channel response from omni-directional antennas

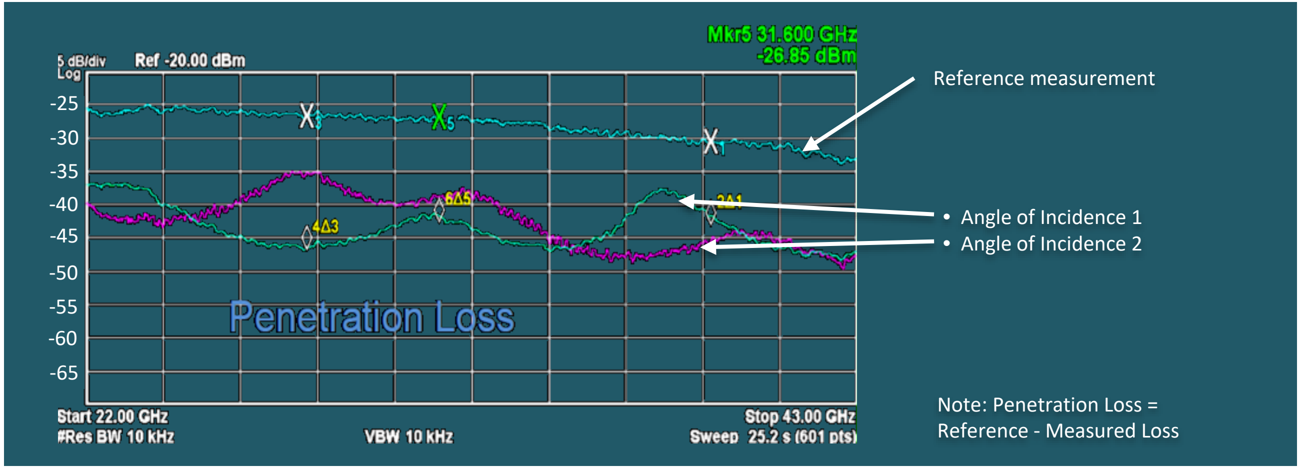
(Example measurement)




## Key mmWave observations made

- Additional reflections at mmWave band provide alternative paths when LOS is blocked
- Alternative paths in mmWave can have very large receive signal
- Small objects affect mmWave propagation more than 2.9 GHz[1] (e.g. tree branches)
- mmWave NLOS path loss exponents across frequencies not dramatically different than 2.9 GHz[2]

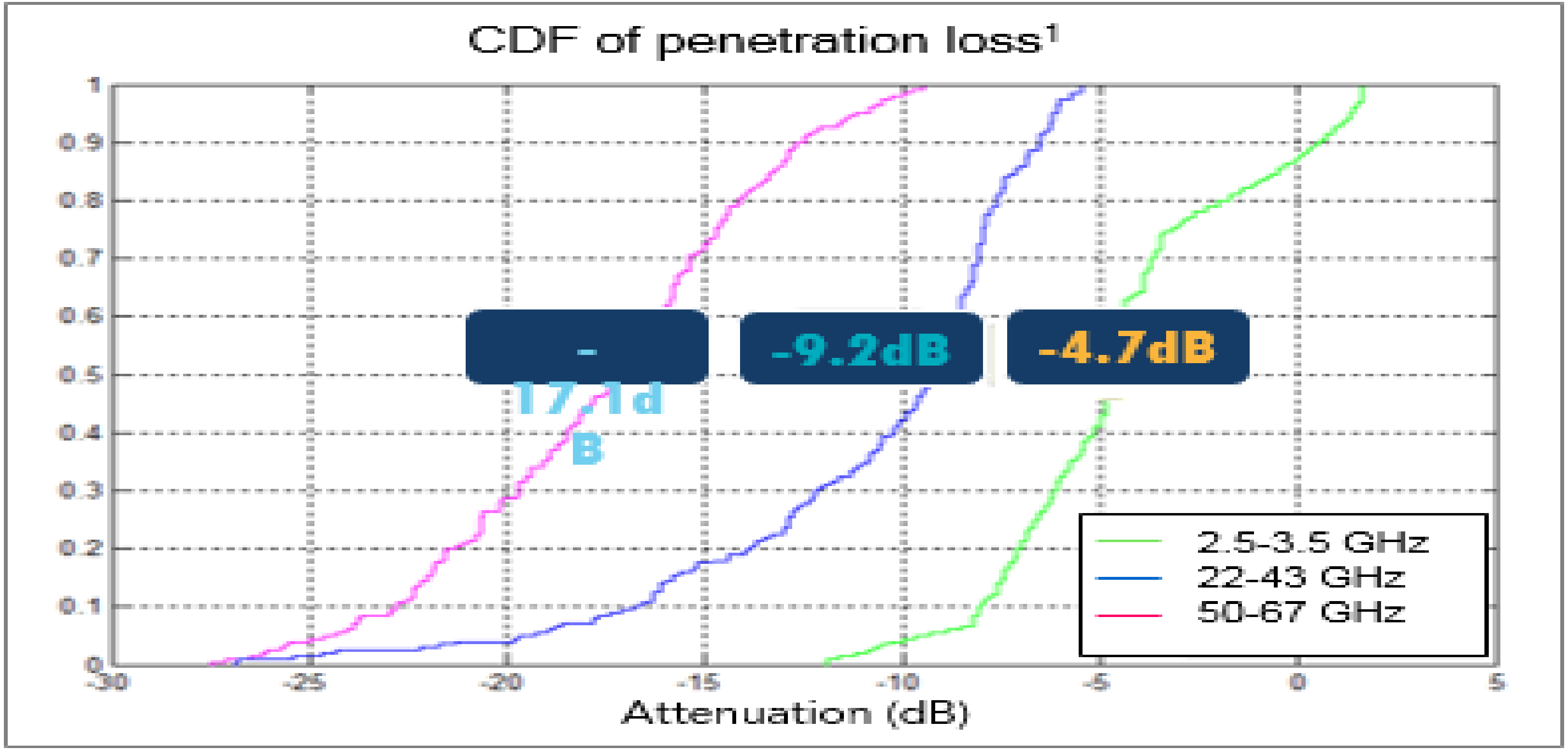
# Out-to-in Penetration Loss for a Tinted External Window




*Source : Qualcomm*

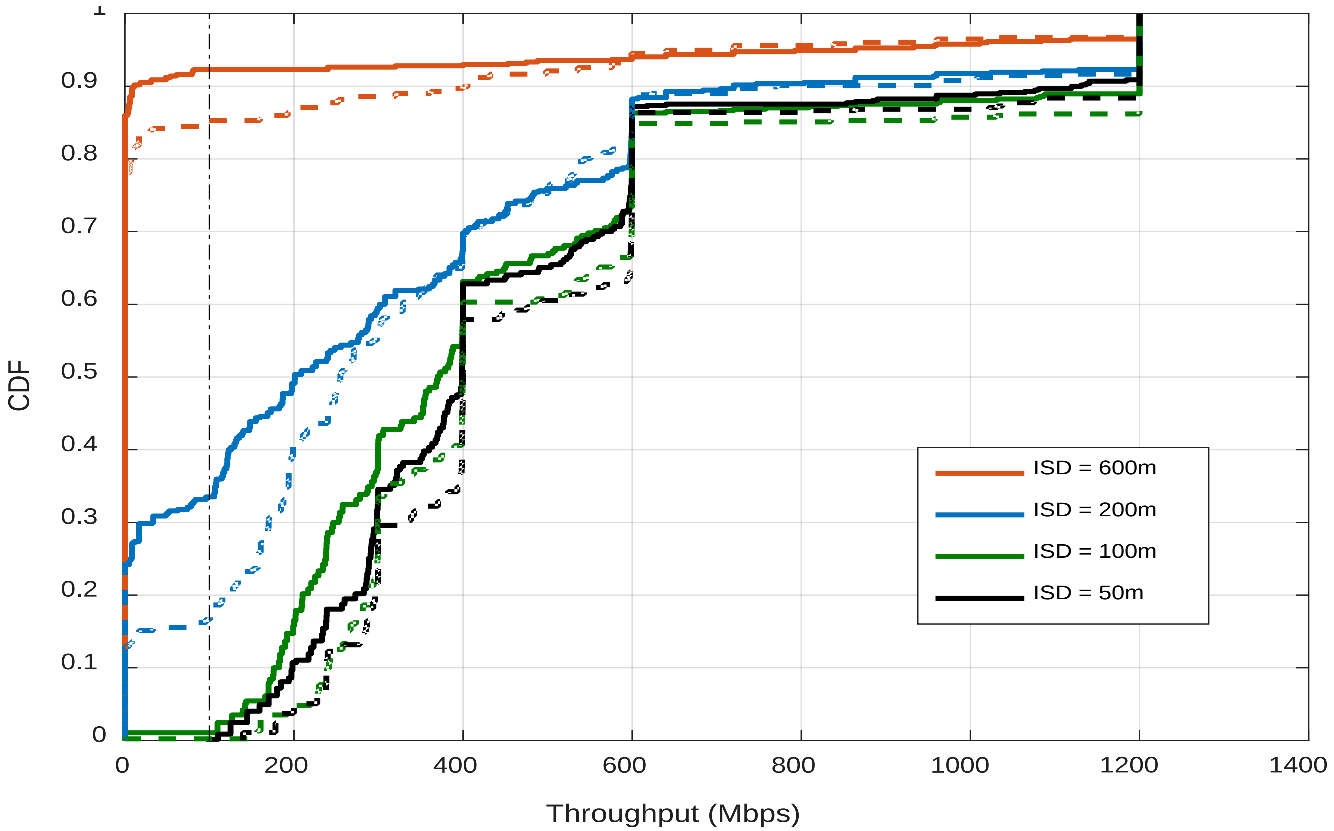
- Out-to-in penetration loss can be challenging
  - High efficiency windows tend to reflect rather than allow signal to pass through
  - Insulation wrapped in metal foil can also cause reflections and reduce penetrability
  - Commercial construction more challenging than typical residential
  - Suburban areas impacted heavily by foliage
- Penetration loss may be greater at lower frequency than at higher, depending on structure of material

# Section 1.4.1: Home Exterior Lap Siding Penetration Loss Variation over Frequency

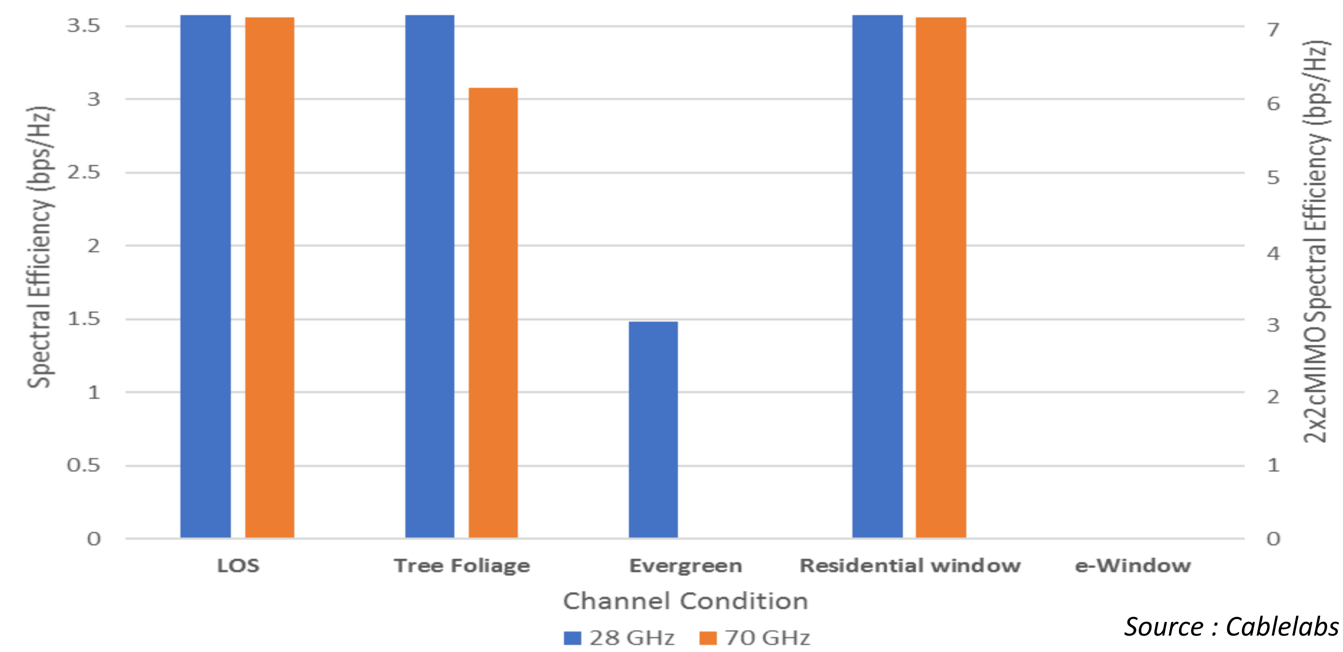



Note: Values indicate the low 50th percentile penetration loss for the bands

# Section 1.4.1: Probability of Service Outage on Inside CPE @ 28 GHz versus Bitrate Demand and BS Distance



# Section 1.4.3.1: Relative Path Impairment Performance Differential, 28 GHz to 70 GHz



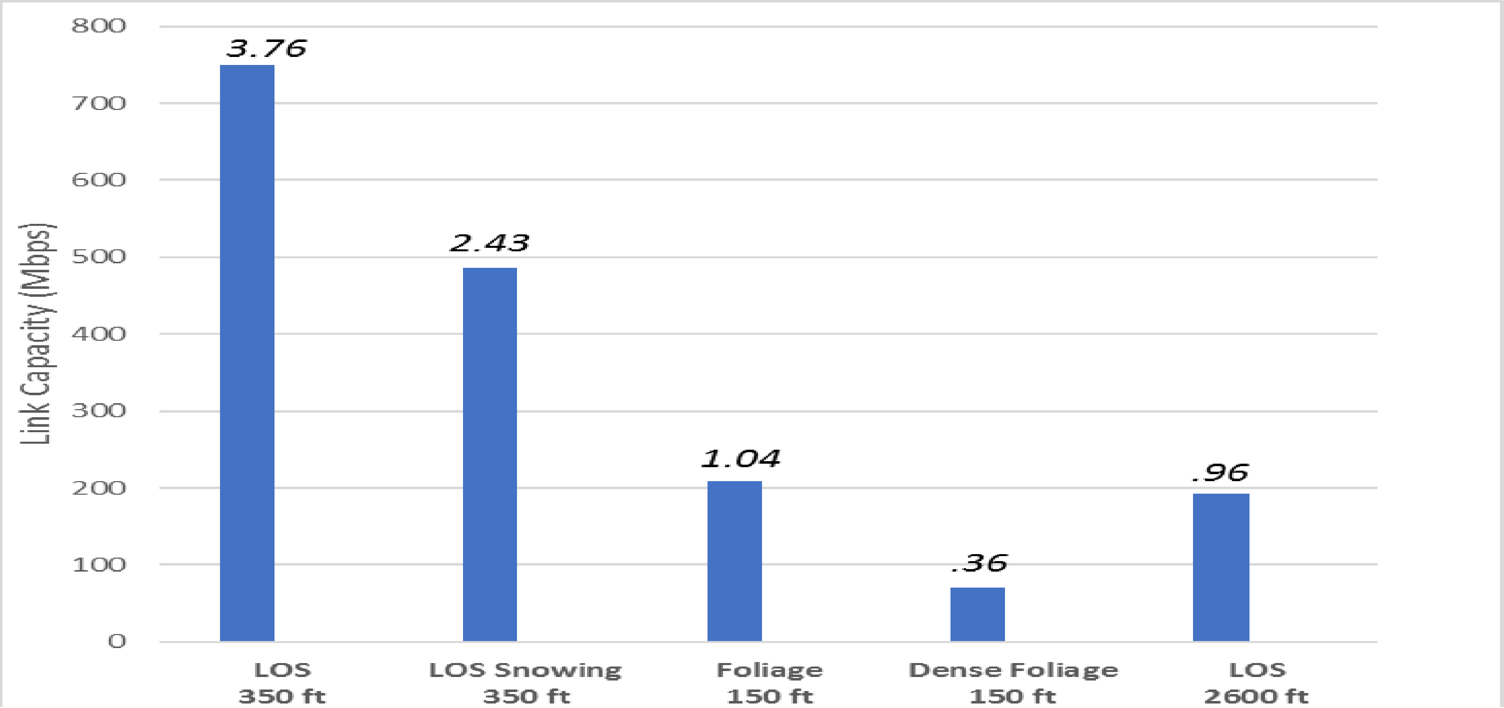

*Source : Cablelabs*

**Cablelabs testing of 28GHz and 70GHz**

**Evergreen trees had lowest spectral efficiency – Higher frequency at 70GHz struggled**

**Energy Efficient windows also struggled**

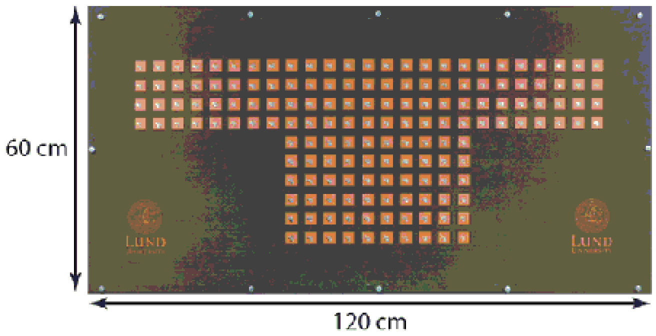
# Section 1.4.2: 37 GHz Link Path Impairment Performance



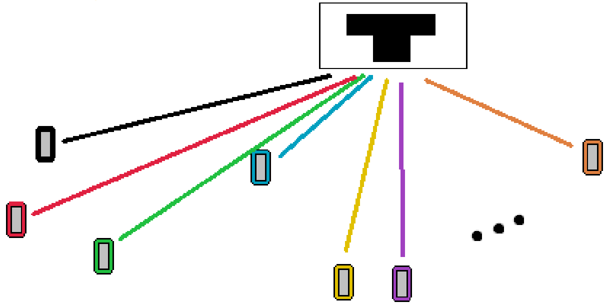

**From CableLabs data: the numerical column headers (spectral efficiency as bps/Hz) reflect the comparative difficulty in maintaining high MCS in the face of particulate or foliage scattering – and also images the effects of SINR collapse at long service radius due to simple propagation loss.**

# Massive MIMO POC

160 element planar array @ 3.7 GHz




*But:*
Arrays can be 3D (stacked layers), cylindrical with backside ground, etc. What matters is that the link DSP can precode the array to orthogonally pattern each of the receivers in its intended radiation footprint based upon sounding pilots dispatched by the clients to the array -- and how reciprocally "static" the virtual channel is between BS and client.



Lund University 2016 demonstration:

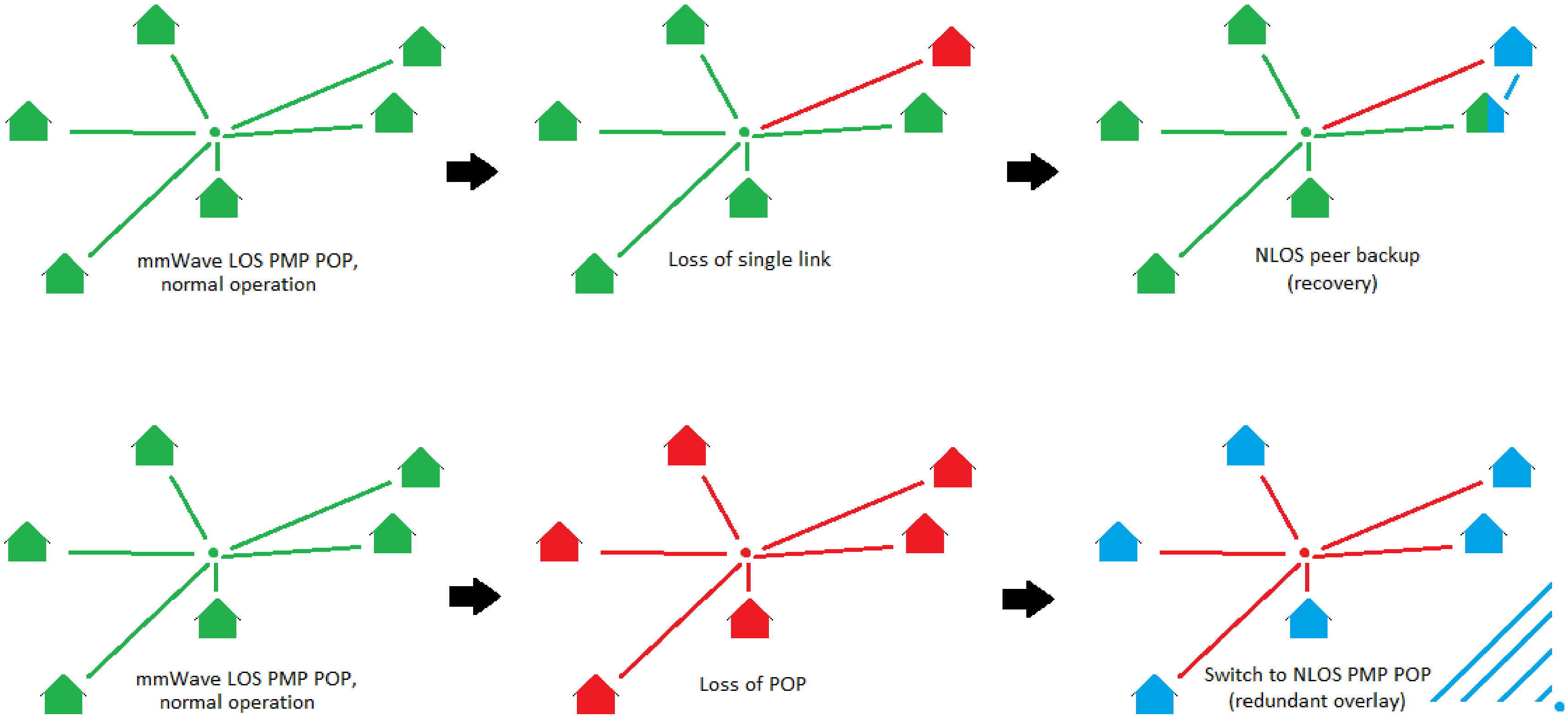
256-QAM over 20 MHz channel @ 3.7 GHz
24 1x1 or 2x2 clients
Ensemble spectral efficiency using array above:

**~ 150 bps/Hz**

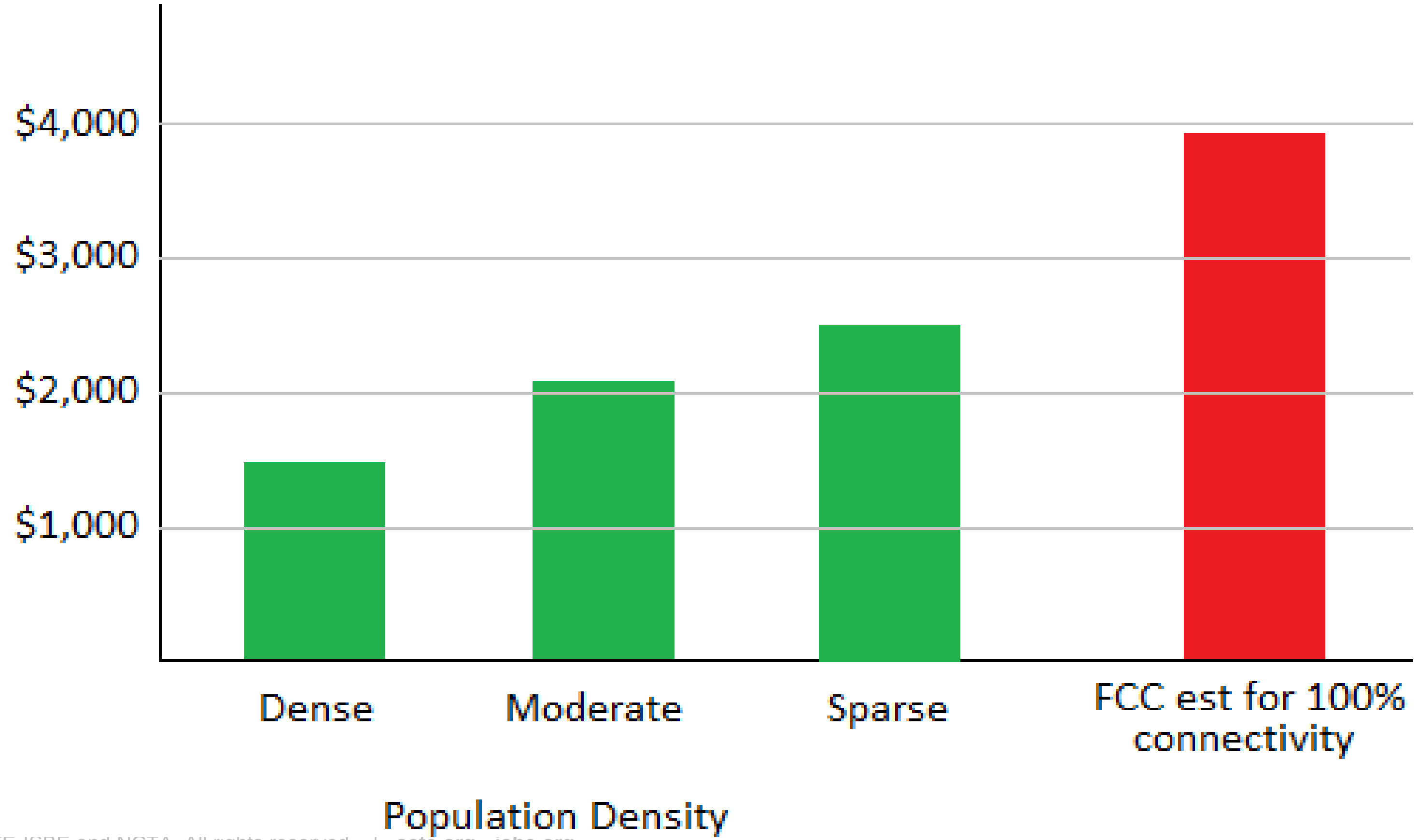
**Innovation in Element Arrays**

**Potential future architecture to use large Element arrays for base station and pair to CPE devices. Can generate 150bps/Hz at a price of size, cost, and range that could be applied to sub 6GHz and CBRS**

# Section 1.8: Hardening the Delivery (NLOS as Redundant Network for LOS)



# Section 2.1: FTTH (P) Costs to Pass and Connect HH



# Section 2.1: FTTH Attachment Cost

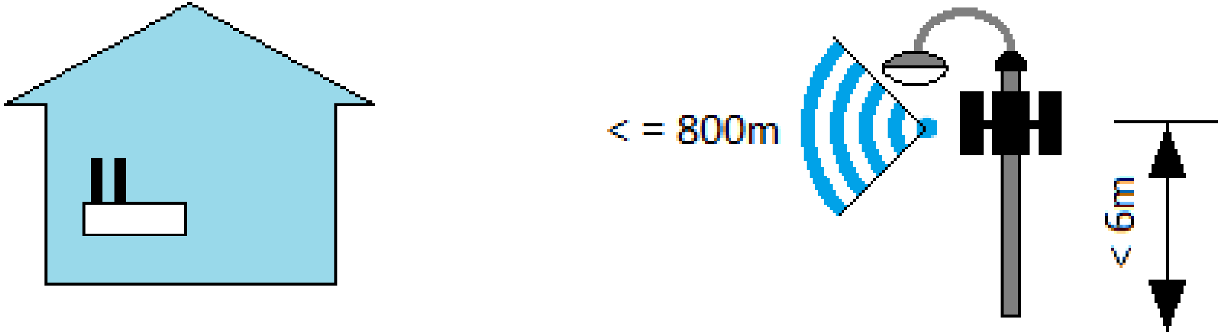
Home CPE

| | | | |
|---|---|---|---|
| $ 350* | Capex | $500 to > $5,000 | |
| $0 | Opex | $0 | |

This variable cost -- and the fact that it is 1:1 per HH -- creates the aperture for wireless delivery

* Fiber Gateway Modem + Install

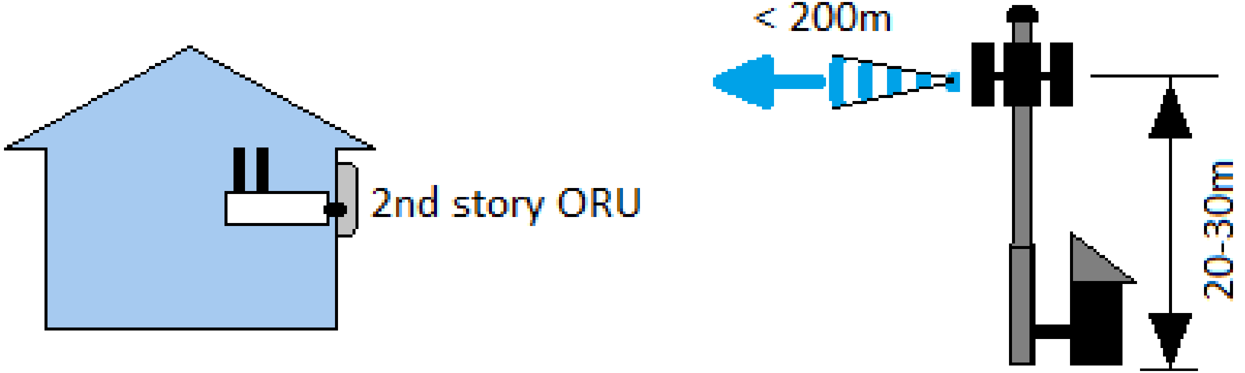
# Section 2.2: 3.5 GHz CBRS POP and HH Costs




| Home CPE | | PMP POP |
|---|---|---|
| $300 | Capex | $3,000 |
| $0 | Opex | $725* |

*Per annum. Assumes $25 power, $200 maintenance and $500 Spectrum Licensing (PAL)

# Section 2.3: mmWave (LOS) POP and HH Costs




| Home CPE | | PMP POP |
|---|---|---|
| $650 | Capex | $22,500 |
| $0 | Opex | $4,200* |

*Per annum. Presumes $3000 Power, $200 maintenance and $1000 Spectrum Licensing

## Section 2 (summary): Cost Inflection Points

- All of the FTTH cost is upfront and scales with the size of the SG.  In round terms, if you are reaching 100 new customers in a subdivision and the cost to pass and connect is $2,000 (+ $500 for CPE install), the investment is $250K.
- NLOS represents a middle ground; with 800m of service radius, it is possible that your 100 customers can all be reached with one POP ($3,000 to install and $725/year to run – but all of this can be amortized over the SG).  The investment in each HH then becomes $300 CPE (self-install), $30 allocation for the mast and $7.25 allocation for the OPEX.  The caveat here is that without massive MIMO, the QoE is not very future-proof – and even with massive MIMO, the service lifetime may be limited to << 10 years.
- LOS service is going to depend upon site survey dynamics – how many masts (with reduced service radius and the LOS aperture requirement) are needed to reach the 100 clients (in this case).  The analysis then follows the NLOS case – with higher allocations for both CAP- and OPEX.  Absent NLOS redundancy, QoE for reliability will be worse but the client bitrates – and solution longevity – much better than NLOS.

# Much Done – More To Do

- Opportunity for 5G Fixed Wireless Services for MSO not clear
- Economics to extend HFC or build Fiber Deeper are better – certainly for Gbps speeds
- 5G millimeter wave LOS opportunity is challenged by reliable performance at range – given terrain conditions and further challenged by economics of the CPE device
    - Does the CPE need Dual PHY – millimeter wave + sub 6GHz LTE or Wi-Fi
        - LOS and NLOS solutions required ?
    - Can it be placed inside Window and be user installed
    - If its placed outside window - will it be ergonomically and economically viable
- Is there better opportunity to map sub 6GHz frequencies to use Massive Element arrays and use paired elements to CPE devices increasing the bps/Hz but increasing the size of the Base Station cell
- Backhaul considerations
    - Opportunity to Backhaul 5G for future mobility solutions. (Near term for CBRS cells ?)
- Adding NLOS and LOS POP/Cells to HFC and Fiber Networks seems to be an investment more in future mobility vs FWA

# THANK YOU!

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JR Flesch & Bryan Pavlich - ARRIS

Special Thanks
CableLabs
Qualcomm

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