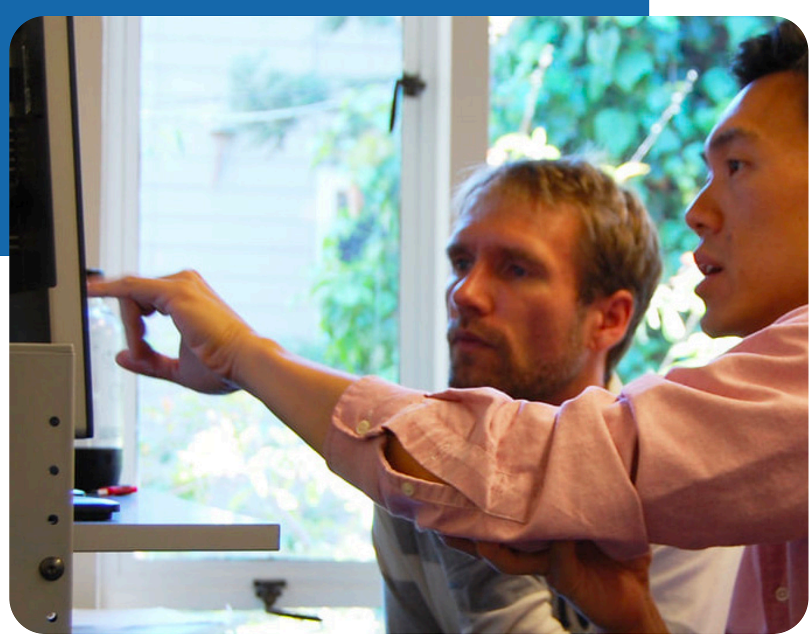
USER GUIDE

# G1 NETWORK PLANNING AND DEPLOYMENT GUIDE

General best practice guidelines for designing and deploying Tarana G1 networks.



# Contents

## Intended Audience

This document is intended for use by RF engineers interested in the design and validation of a Tarana G1 network including base nodes, remote nodes, and the Tarana Cloud Suite (TCS).

It is assumed that the reader has a good working knowledge of RF, wireless systems, and networking concepts.

### How to Use This Document

This document offers both general concept explanations as well as more detailed recommendations. Experienced engineers already familiar with the concepts can simply refer to the summary section of each chapter for specific guidelines.

# Network Planning and Design Overview

Thoughtful network design is crucial for the success of any network. Network design, especially wireless network design, is a complex subject with many dimensions to consider. A detailed analysis of every factor of network design is beyond the scope of this document, however, general best practice guidelines are offered here with respect to a Tarana G1 network.

## Network Planning Process

The following steps are strongly recommended for G1 network design:

- RF coverage and propagation modeling
- Cell design
- Sector capacity optimization
- Frequency selection
- Validation

## Key Terms and Concepts

The following concepts and terms are used throughout this document:

- Beamforming and RF nulls
- Spatial multiplexing and spatial resolution
- Interference cancellation

### Beamforming and RF Nulls

The ability to direct radio waves in specific directions is a fundamental tool for radio design and serves as the basis for everything from higher signal gain, to increased capacity, non-line-of-sight (NLoS) performance, and interference cancellation. A flexible and effective approach is to use multiple independent radio chains to create beams and nulls that are continually adjusted to maximize throughput and minimize interference. As shown in Figure 1, this involves adjusting the phases of independent radio chains so their signals combine constructively (increasing power) in directions where it will increase the system's overall efficiency. This type of constructive gain is known as beamforming. At the same time, signals can combine destructively (canceling each other out and reducing power) in directions where the signal is undesired, called RF nulls or RF nulling.

Greater overall performance gains can be achieved by applying these techniques on both transmit and receive to increase signal power while reducing interference and yielding a higher signal-to-interference-and-noise (SINR). Shannon's Limit, the theoretical maximum bandwidth of a wireless channel, is a function of SINR.

Optimizing SINR is therefore crucial to increase capacity, peak rates, and spectral efficiency.

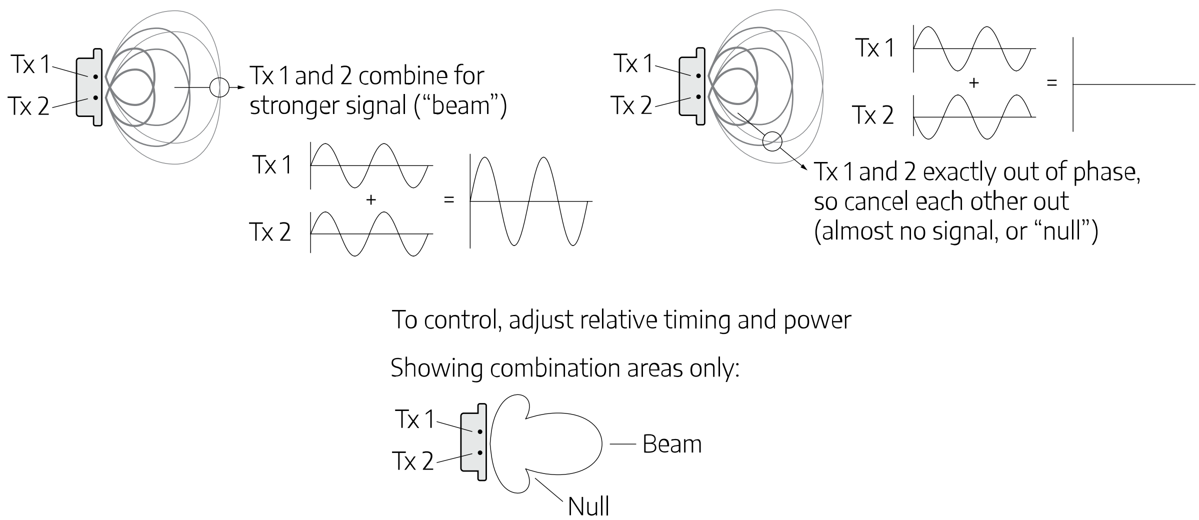



Figure 1: Algorithms applied to radios can control the direction and power of the signal through beams and nulls

One important aspect of beams and nulls: they can be performed at both ends of the link. The high precision of G1's multidimensional mapping of the channel, in turn, enables much higher precision in beam directionality and deeper nulls. The more directional the beam, the higher the gain and stronger the signal. The deeper the null, the more unwanted interference can be canceled. All of this, as noted above, will yield a higher SINR which directly affects overall radio (sector) capacity and link performance.

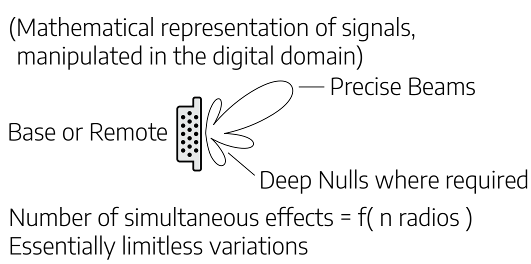



Figure 2: G1's precise digital beams and nulls enable greater signal strength and less interference

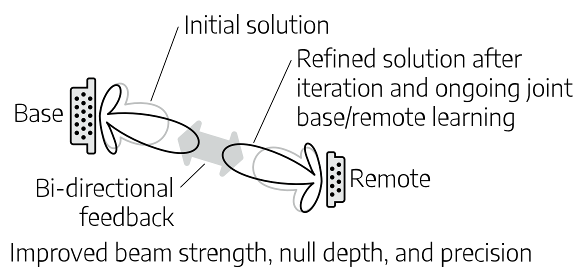



Figure 3: G1 nodes collaboratively find an optimal solution

## Spatial Multiplexing and Spatial Resolution

Where beamforming offers a mechanism for higher gain and RF nulls to remove interference, spatial multiplexing is a tool to deliver capacity. In this technique, different paths in the radio channel between base and remote are used to send more than one stream of information through the channel at the same time, thereby multiplying the channel's capacity. It does this by using coding of the streams on transmit (Tx) that allows them to be decoded separately on receive (Rx). This is also referred to as MIMO (multiple-in, multiple-out) and is reliant on the ability of the radios to create multiple streams or layers within the same frequency that can be distinguished from each other (spatially resolved).

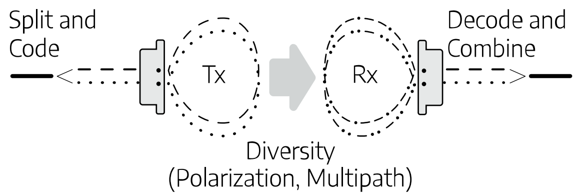



Figure 4: MIMO/spatial multiplexing uses multipath to create multiple unique streams of data

Spatial multiplexing commonly doubles channel capacity by taking advantage of vertical and horizontal antenna polarization to achieve sufficient channel diversity for at least two streams. Higher multiples (three or even four) can be achieved in channels with rich multipath diversity, which allows streams to arrive at different times and paths. Outside of dense urban areas with many reflection sources, outdoor systems are typically limited to two streams which is why Figure 4 shows the more common scenario of two Tx and Rx radio chains on each side of the link. Figure 5 shows how multipath in the environment creates unique spatial streams using multipath elements. Without this uniqueness, only one spatial stream will be possible, impacting overall link and sector capacity.

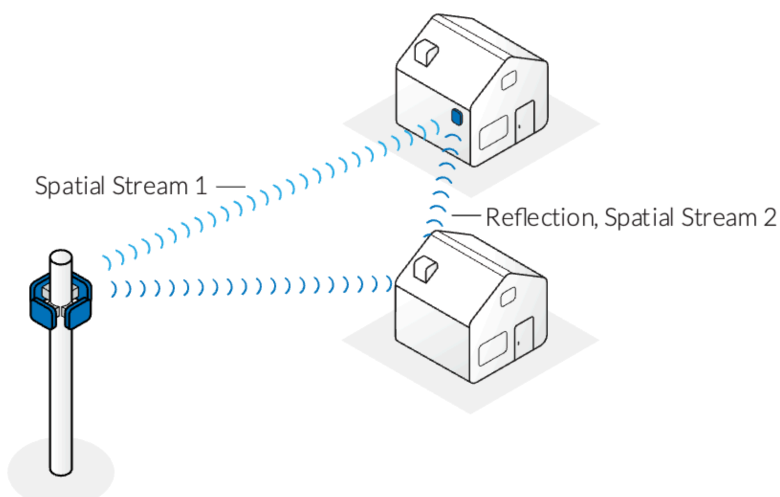



Figure 5: Multiple unique paths create two spatial streams

Spatial resolution is the term used to describe the ability of a radio to differentiate multiple spatial streams.

### Multi-User Distributed Massive MIMO (MU-DMM)

Until now, we have used MIMO in the context of one or more streams of data to a single user (node) scheduled over time, frequency, and space. This is referred to, more explicitly, as SU-MIMO. Multi-user MIMO (MU-MIMO) also supports multiple spatial streams and does so for multiple remote nodes simultaneously. The G1 approach takes these even further by applying MU-MIMO in a distributed massive MIMO implementation that takes advantage of many radio resources at both ends of the link across multiple users.

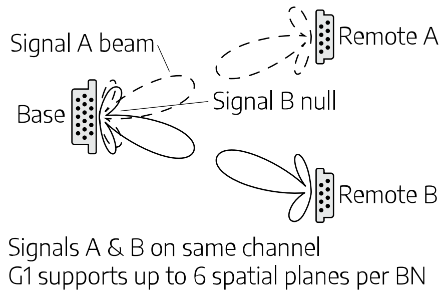



Figure 6: MU-MIMO (also known as spatial planes) allows multiple devices to use the same channel

G1 supports up to six independent spatial planes per base node, operating in combination with spatial multiplexing. Spatial planes can be allocated, as needed, amongst multiple remote nodes. These resources are allocated as determined by G1's 4D scheduler.

The 4D scheduler operates in the four dimensions of time, frequency, space, and MIMO rank with up to 128 sub-bands (625 kHz wide) that can be allocated per remote node across two 40 MHz carriers. When taken in conjunction with six spatial planes, the scheduler has 768 allocation units it can assign for any given frame of transmission.

Because the characteristics of the channel — such as interference sources and multipath effects — vary by frequency, precision is further enhanced by calculating Tx and Rx beamforming solutions independently for each of the 128 sub-bands.

This level of granularity is only possible with the very precise digital beamforming that is a hallmark of G1. Based on the accuracy of the channel information, beams can be created with greater gain and deeper RF nulls. All of this positively impacts SINR, spectral efficiency, peak rate, and capacity.

Figure 7 shows an example of how the 4D scheduler allocates resources on a per-base node basis.

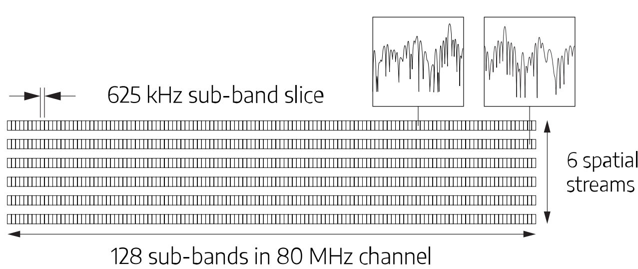



Figure 7: G1's 4D scheduler can allocate up to 768 unique solutions per BN (6 spatial streams x 128 sub-bands)

## Interference Cancellation

Interference is an expected part of wireless communications. A well-designed next-generation wireless network can significantly reduce high levels of interference that would otherwise impair link. This is as contrasted with legacy FWA equipment that, due to the many compromises it must make with repurposed technology, has far few tools with which to address this pervasive problem.

There are two types of interference that can be service-impacting: co-channel interference, also called self-interference, and external, or out of cell, interference.

## Co-Channel Interference

Co-channel interference is when an operator's network interferes with itself. This is typically due to situations that arise when multiple sectors operate on the same channel or frequency either on the same tower, a nearby tower, or both.

G1 uses a combination of the techniques described previously to create deep RF nulls in the direction of other equipment. Figure 8 shows an example of two base nodes on the same channel communicating with multiple remote nodes. By aligning the nulls in the direction of the unwanted signal, self-interference can by reduced by up to 45 dB.

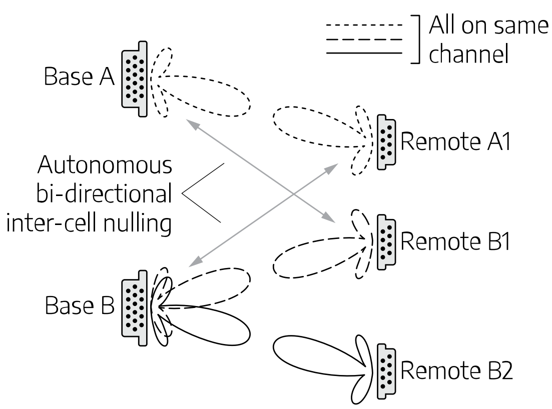



Figure 8: G1 cancels both intra- and inter- cell interference

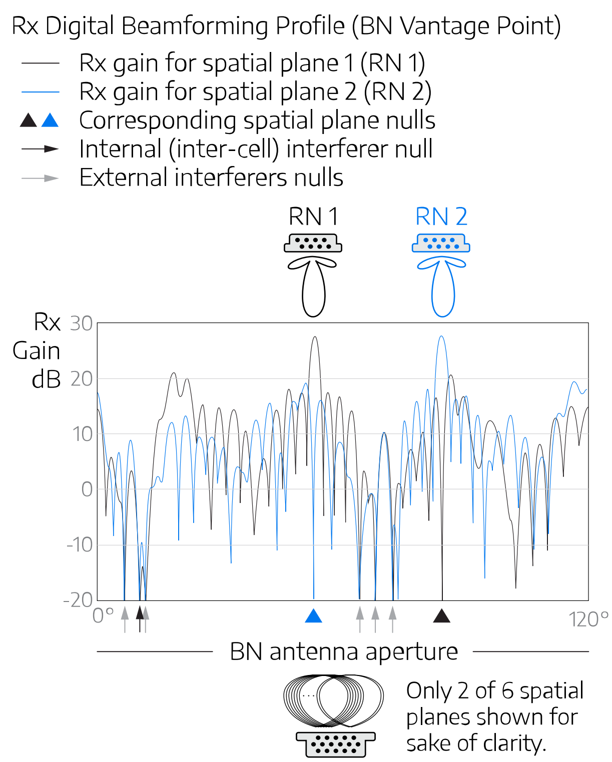



Figure 9: Deep nulling of unwanted signals (internal and external)

Because of these innovations, G1 can dramatically reduce the impact of interference that might otherwise render a system unusable.

**Frequency Reuse**

G1 can operate with a universal frequency reuse across the network, wherein all base nodes and cells operate at the same frequency pairs (one per each carrier used by G1, i.e., carrier 0 and carrier 1). The frequency reuse pattern is typically referred to as K. K=1 means the entire network is operating on the same spectrum. K=2 means there are two unique spectrum allocations (double the spectrum use of K=1) deployed in an alternating pattern within the network, and so on.

# RF Coverage and Propagation Modeling

One of the most important aspects of designing a wireless network is planning for RF coverage. This is typically done through the use of a propagation modeling tool. An accurate coverage model can be used to determine the type of coverage available at a particular location. Good modeling software takes into consideration information such as topology, buildings, foliage, etc.

A detailed description of the many commercial tools available is beyond the scope of this document. We use Google's Network Planner as an example here.

## Key Components for RF Propagation Modeling with Google Network Planner

The following resources are available for planning use and should always be used:

- Tarana for Google Network Planner Guide
- Tarana for Google Network Planner Resources Pack (antenna files, RSSI values, etc.)

## Configuring the Project Settings

A key part of working with an RF coverage tool is inputting the correct, vendor-supplied performance information. In Google Network Planner, this is part of the project settings. This typically includes antenna information, maximum antenna gain, and RSSI values. The Tarana for Google Network Planner resources pack includes antenna files for Tarana products and tables with suggested RSSI values based on deployment topology (rural, suburban, urban).

### CBRS

For CBRS operation, the network type should be set to mobility macro and maximum gain set to 18.5 dB.

### 5 GHz

For 5 GHz operation, the network type should be set to fixed wireless and the maximum gain set to 21.9 dB.

### Heatmap RSSI Values

In order to ensure the final coverage heatmap is accurate, use the values as defined in the Google Network Planner resources pack to ensure RSSI values match with Tarana performance.

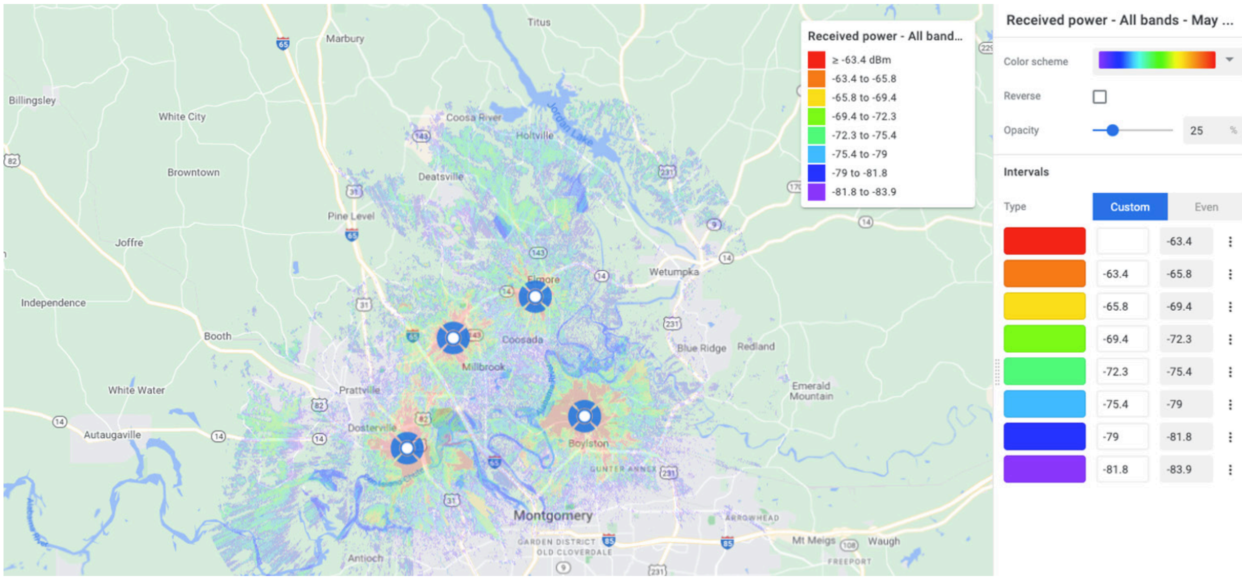



Figure 10: Final heatmap with adjusted values in Google Network Planner

## Throughput Estimation

The resources pack includes a spreadsheet that provides estimated capacity based on RSSI and pathloss for a link. This should be used as a guide when determining expected link capacity.

| | | | |
|---|---|---|---|
| **RN Ant Gain** | 18.5 | dBi | |
| **Fade Margin** | 3 | dB | |
| **Interference Margin** | 2 | dB | |
| **BN Transmit Power** | 36 | dBm/MHz | 49.7 dBm EIRP |
| **Network Profile 1** | 4.5:1 | DL/UL Ratio | Up to 15 Km Radius |

* **Blue** Font User Input Required

| MCS Index | RN Input RSSI (dBm) | Aggregate Capacity Per RN 2x40 MHz (Mbps) | Capacity 40MHz | | Capacity 2x40MHz | | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| | | | DL (Mbps) | UL (Mbps) | DL (Mbps) | UL (Mbps) | |
| 15 | -62.5 | 784 | 321 | 71 | 641 | 143 | 130.7 |
| 14 | -63.4 | 770 | 315 | 70 | 630 | 140 | 131.6 |
| 13 | -64.2 | 743 | 304 | 68 | 608 | 135 | 132.4 |
| 12 | -65.8 | 689 | 282 | 63 | 564 | 125 | 134.0 |
| 11 | -67.3 | 635 | 260 | 58 | 520 | 116 | 135.5 |
| 10 | -69.4 | 581 | 238 | 53 | 476 | 106 | 137.6 |
| 9 | -70.8 | 527 | 216 | 48 | 431 | 96 | 139.0 |
| 8 | -72.3 | 473 | 194 | 43 | 387 | 86 | 140.5 |
| 7 | -73.9 | 419 | 171 | 38 | 343 | 76 | 142.1 |
| 6 | -75.4 | 365 | 149 | 33 | 299 | 66 | 143.6 |
| 5 | -76.8 | 311 | 127 | 28 | 254 | 57 | 145.0 |
| 4 | -79.0 | 257 | 105 | 23 | 210 | 47 | 147.2 |
| 3 | -80.7 | 203 | 83 | 18 | 166 | 37 | 148.9 |
| 2 | -81.8 | 176 | 72 | 16 | 144 | 32 | 150.0 |
| 1 | -82.8 | 149 | 61 | 14 | 122 | 27 | 151.0 |
| 0 | -83.9 | 95 | 39 | 9 | 77 | 17 | 152.1 |

Figure 11: Google Network Planner RSSI to Layer 2 Throughput Table

For the latest version of this information, always refer to the guide and resources files on the Tarana learning portal at learn.taranawireless.com.

If in doubt about which values to use for your particular modeling software, please contact Tarana support.

## Summary

Tarana offers a detailed guide for Google Network Planner deployments, as well as valuable resources and tools that can be found at learn.taranawireless.com:

- Tarana for Google Network Planner Guide
- Tarana for Atoll Network Planner Guide
- Tarana Radio Resources Pack (antenna files, RSSI values, etc.)

When a tool requires maximum antenna gain, use the value of 18.5 dB for CBRS radios and 21.9 for 5 GHz radios.

# Cell Design

A cell is defined as a set of base nodes and their associated remote nodes. A typical cell deployment consists of three or four sectors (base nodes) per cell for 360° coverage. Good cell design will minimize interference with other radios, select the best operating frequencies and network profile, and ensure remote nodes connect to the optimal base node.

## Network Profiles

Cell ranges are based on the network profile used. G1 supports four different network profiles. A network profile determines the ratio between downlink (DL) and uplink (UL) and the maximum RF range between the base node and remote node. All G1 base nodes within close proximity must use the same network profile and frequency.

Optimal performance is dependent on selecting the best network profile based on required throughput and subscriber (remote node) location.

| Network Profile | DL:UL Ratio | Maximum DL/UL L2 Rate (Mbps) | Maximum Range (km) |
|---|---|---|---|
| 1 | 4.5:1 | 640/140 | 15 |
| 2 | 4:1 | 570/140 | 30 |
| 5 | 2.67:1 | 569/210 | 15 |
| 6 | 1.75:1 | 498/280 | 15 |

While overall performance such as throughput rate and link distance are important, selection of a network profile that is compatible with other co-located same-band radio equipment is equally important.

In general, and to avoid inter-sector and inter-remote node interference, the network profile should be the same among:

- All base nodes that belong to the same cell (on the same tower) and operate in the same band. For example, if two base nodes on the same network operate in UNII-3, even in different frequencies, they need to use the same network profile. Otherwise, a transmitting sector might interfere with another that is receiving, causing uncancellable interference in the same channel or even potentially in adjacent channel receivers.
- All base nodes in the same geographical area (i.e., base nodes that are close enough to hear each other's transmission) and operate in the same channel or overlapping channels.

## Overlapping Cells

Cells with overlapping coverage will always occur and are expected parts of a typical radio deployment. However, the overlap across cells should be minimized as much as possible by creating a cell boundary beyond which the remote nodes are associated with a particular cell or sector. This reduces interference, improves link performance, and creates a network that is easier to troubleshoot.

The picture below shows an example of two fully overlapping base nodes belonging to two different cells. The base nodes of these sectors are facing one another and operating at the same frequencies. The yellow remote nodes are connected to the yellow base node sector and the purple remote nodes are connected to the purple base node sector. A frequency reuse of K=1 is used, where K represents the operating frequency and 1 indicates all sectors in the cell are using the same frequency. K=2 indicates two sets of operating frequencies are used in the cell and so on.

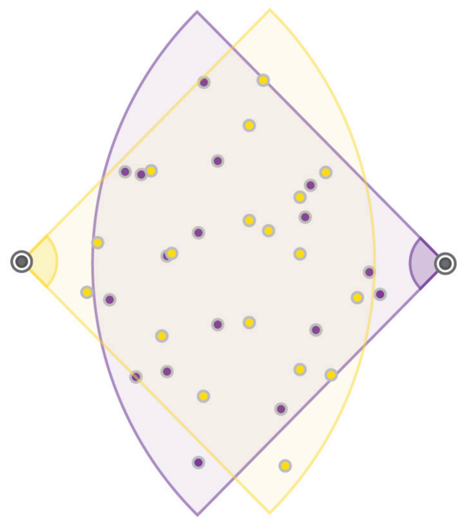


Figure 12: Remote nodes in overlapping cells are not connected to the closest base node

In the deployment shown above, a number of remote nodes are connected to a base node that is not the closest available. In general, a remote node should be connected to the best serving base node which is typically the one with the lowest pathloss assuming all base nodes are configured to operate at the same output power. There is also no clear boundary defining the area covered by the two cells. In both cases, the primary BN feature can be used to ensure remote nodes are always connected to their best-serving base node.

## Nested Cells

Nested cells are defined as cells where one cell is almost completely covered by a different cell. Nested cells and sectors are generally problematic and are not recommended. If nested cell operation is absolutely required, it is strongly recommended to use different frequencies.

The example below shows two nested cells in the same frequency. There are several important implications to how well interference cancellation will work in this type of deployment.

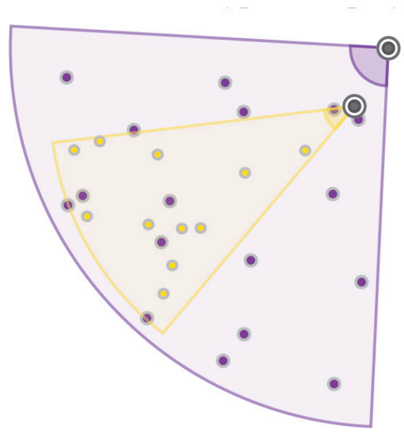


Figure 13: A nested cell one sector lies entirely within another sector

From the perspective of the remote node, shown in Figure 11, the base node of interest and the interfering base node are not spatially differentiated (resolvable) to the remote node. This causes uplink beam squinting in which the main part of the beam is slightly offset from the optimal direction to reduce interference. Beam squinting will cause some degradation in uplink and downlink performance.

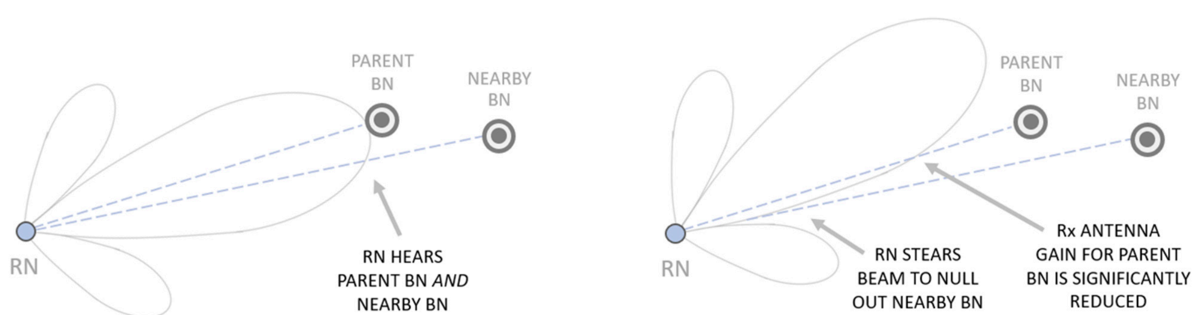



Figure 14: A nested cell one sector lies entirely within another sector

In the downlink, Figure 12, the remote nodes are not differentiated (resolvable) from each other to the base node. This causes the base node to squint its beam away from the desired remote node, causing a downlink performance degradation.

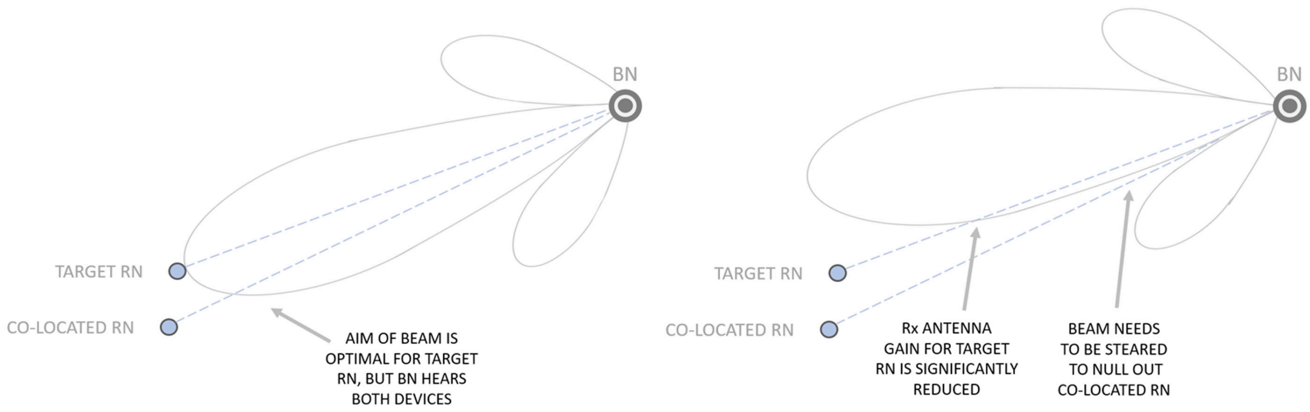



Figure 15: Remote node squints beam to null out co-located base node

Deploying remote nodes that are close together and connected to different base nodes in the same orientation is not recommended, as it will result in beam squinting. Figure 14 highlights two groups of remote nodes that are very close to each other and connected to different base nodes. The farther a remote node is from the base node, the less angular separation, making it more difficult for accurate spatial resolution to occur. In this example, the highlighted remote nodes will experience beam squinting due to their close proximity and the co-linearity of their respective base nodes. However, all remote nodes may experience some performance degradation due to the nested cell architecture. The best solution for these types of nested deployments is a K=2 frequency reuse or to use completely different bands such as 5 GHz and CBRS.

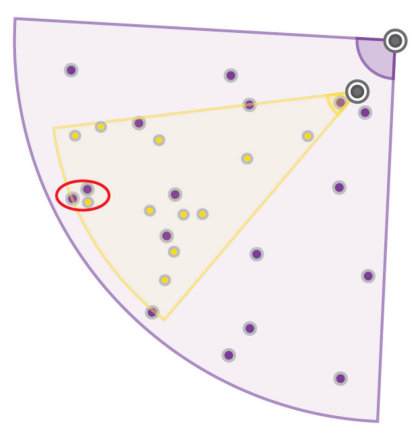


Figure 16: The remote nodes (circled in red) cannot adequately spatially resolve their respective base nodes

## Network Planning IDs

Network planning, in this aspect, refers to which base nodes a remote node should use to establish a link. G1 network planning is performed in TCS using the planning ID parameters. A planning ID is defined as a sequence consisting of a set ID, cell ID, and sector ID. The planning ID is defined in TCS as part of the configuration of a cell. Set and cell ID values are manually set by Tarana; they will be automatically assigned by TCS in a future release.

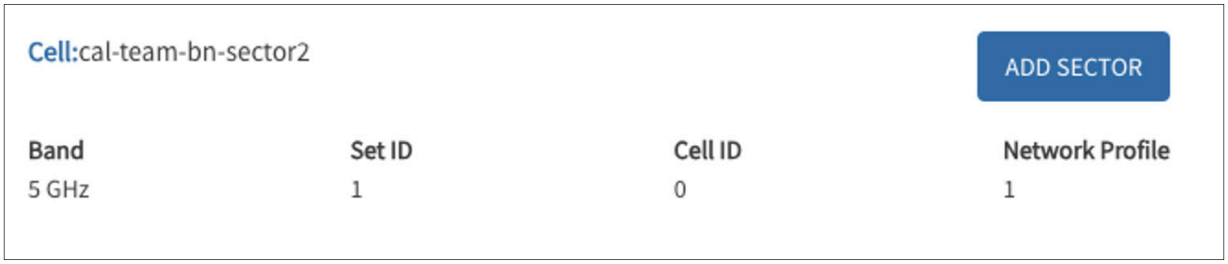



Figure 17: Cell definition within TCS allows the operator to configure set and cell IDs

A set is a collection of up to 24 cells within a single operator's network. The set ID must be a value between 0-5.

A cell is a collection of up to four sectors at the same site that share the same frequency bands. Values for the cell ID must be in the range of 0-23. In general, two cells with the same cell ID should not be within range of each other, i.e., close enough for the radios to hear each other's transmissions.

A sector is a base node and its associated remote nodes. The range for a sector ID is between 0 and 3 and is assigned automatically and in order when a base node is added to a sector. Taken together, a planning ID consisting of a set, cell, and sector ID uniquely identifies a base node (sector) within the operator's network.

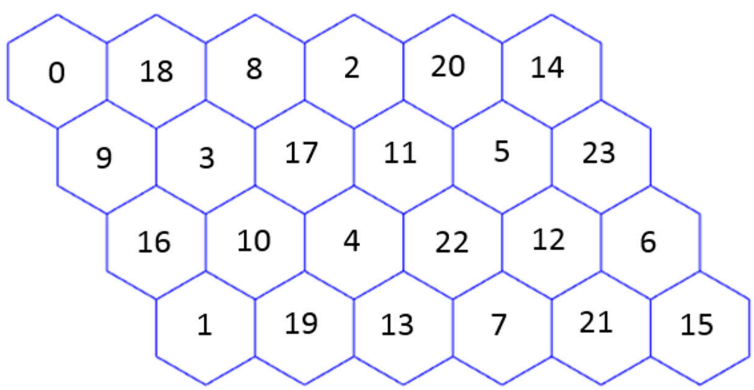



Figure 18: A set is a collection of 24 cells, each consisting of one to four sectors—each cell represents a geographic area of 9 km$^2$ (3 km by 3 km).

## Summary

Cell design and network planning are important tools that allow for optimal distributed loading of remote nodes across the entire network. The general guidelines below are recommended:

- The general recommendation for macro- and micro-type cell design is to avoid nested cells. In cases illustrated in this section, sectors may be limited by interference and will not be able to operate at maximum capacity. When additional cells are needed to increase capacity, cell location and the sector coverage area should be carefully considered to avoid nested cells. Re-aiming of remote nodes on the edge of the original cell may be beneficial.
- Planning IDs are a valuable tool for determining which base node a remote node should use to establish a link. Tarana will automate the planning ID process for clarity and simplicity.
- The primary BN feature can be used to help ensure remote nodes are always connected to the best-serving base node. The best serving base node is determined through a combination of lowest pathloss, load balancing, etc.
    - Remote nodes can connect to alternate base nodes if the primary base node goes down.
    - Operator can configure the remote node to instantly reconnect to the primary base node when it is available.

Selection of a network profile determines cell range and is driven by a number of factors:

- Desired throughput and maximum link distance.
- Compatibility with co-located same-band radios.
- Base nodes operating in the same band that are close enough to hear each other should use the same network profile to avoid unnecessary interference.

# Frequency Planning

## Bandwidth

G1 utilizes two 40 MHz carriers for radio transmission. Therefore, in general, G1 operation will use a total of 80 MHz bandwidth for K=1 frequency reuse, 160 MHz for K=2, and so on. Determining which frequency reuse scheme to use is a vital part of the network design. Unlike other systems, G1 enables K=1 frequency reuse which eliminates the need for complex RF planning or cases where sufficient clean spectrum is not available. However, while K=1 reuse is a valuable tool for operators, some impact on performance is always possible.

In general, the less overlap there is between radios, the less interference and the greater performance. Thus, a three-sector deployment (azimuthal separation of 120°) will incur less performance degradation than a four-sector deployment (azimuthal separation of 90°). This is recommended in cases where the higher subscriber capacity available with four sectors is not required.

With respect to spectrum, if sufficient clean spectrum is available, all of the spectrum should be used (i.e., K=2), especially across adjacent base nodes located at the same tower to achieve maximum performance. While not required, K=2 will allow for the fullest efficiency and provide additional resources headroom for the base node to handle other interference outside the operator's control. Selection of K can depend on the number of sectors at a site, i.e., for K=1 a three-sector cell is preferred while for K=2 a four-sector cell is recommended.

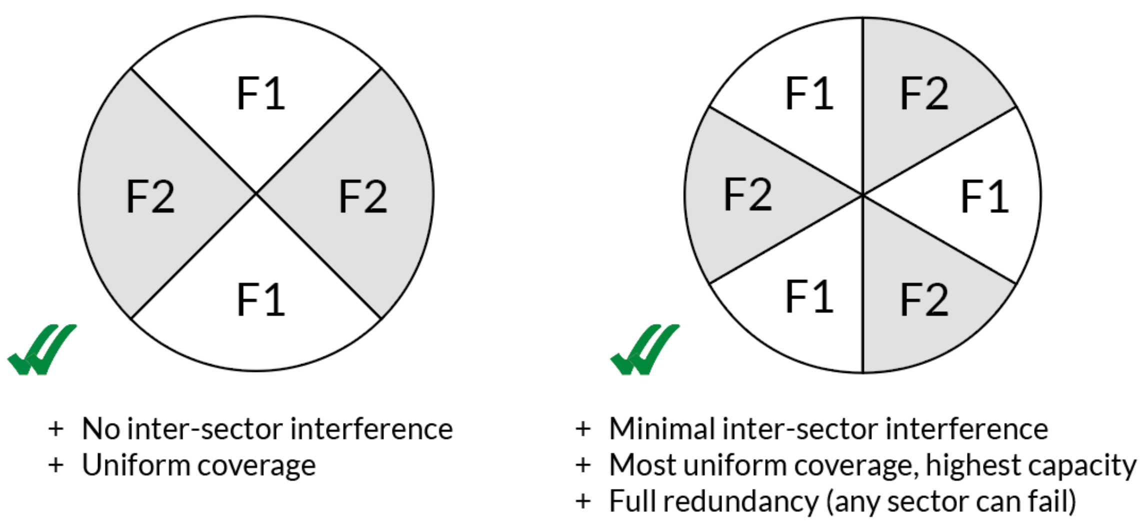



Figure 21: Multiple frequency reuse minimizes self-interference

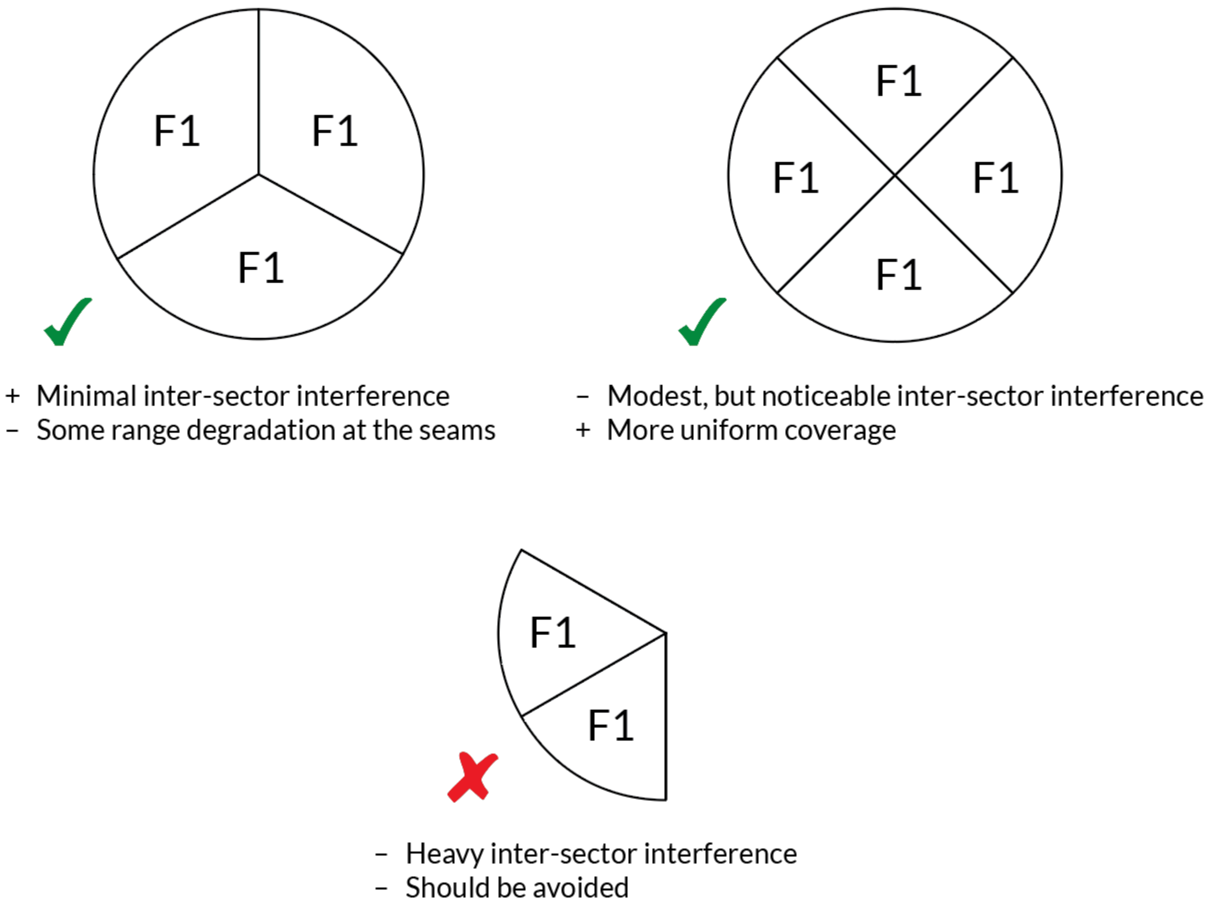



Figure 22: Three-sector deployment versus four-sector

## Base Node Frequency Selection

### Co-Existence with Other Co-Channel Radios

Deploying G1 base nodes in the same or overlapping frequencies as non-Tarana G1 equipment on the same tower is not recommended. This will likely result in performance degradation, which could be severe. The level of severity will depend on the power of the interfering radio, location, and azimuthal direction. In general, the further apart two co-channel radios are, the better the performance.

***Uplink Interference***

Radios with co-channel interference on the same tower will interfere with each other unless they use the same frame profile. While this is often possible with licensed spectrum such as CBRS it is not always possible in unlicensed bands such as 5 GHz and 6 GHz.

Significant horizontal and vertical separation between the G1 base node and the co-channel interfering radios can be helpful to mitigate mutual interference. Separation should always be as far as is practical to minimize interference. In general, horizontal separation will have a greater impact than vertical, but both will materially benefit performance.

Tarana's unique Asynchronous Burst Interference Cancellation (ABIC) at the base node will further protect each base node from co-channel interference on the tower. Although performance degradation is reduced beyond what is typically possible for other wireless systems, some degradation is still to be expected when all radios are operating on the same frequencies.

The Gigabit (G1) family eliminates interference by pointing a spatial null at the interference source. In the case where a base node sees an interference source in the same line as a connected remote node, it cannot point a beam in this direction and a spatial null in the same direction to cancel interference. This can hinder upload performance.

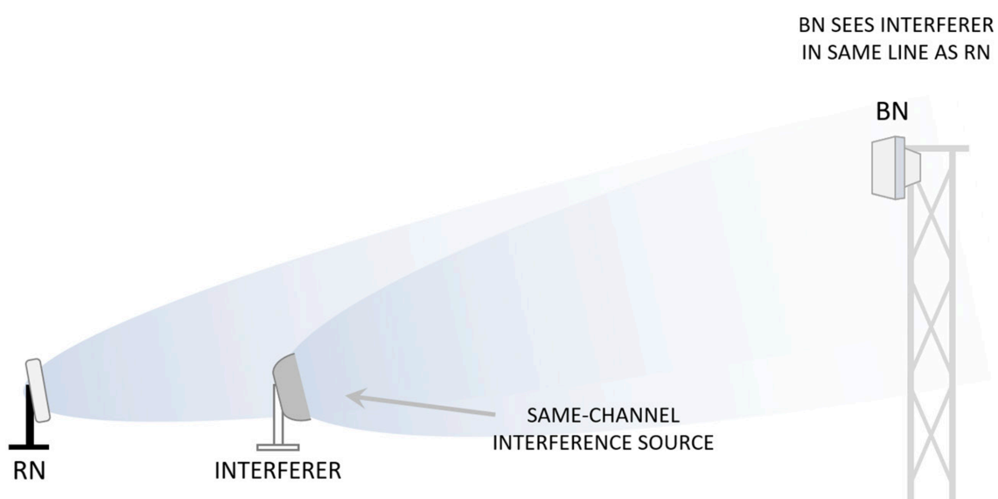



Figure 23: Co-linear interference between remote node and base node impacts uplink performance

***Downlink Interference***

Remote nodes are typically deployed kilometers from the base node on the tower. At that distance, the angular separation between the base node and the interfering co-channel radio on the same tower is minimal. A remote node cannot point a beam towards the tower while also pointing a spatial null in the same direction to cancel interference. Because of this, downlink performance can be affected, especially if the interfering radio on the same tower points towards the remote node.

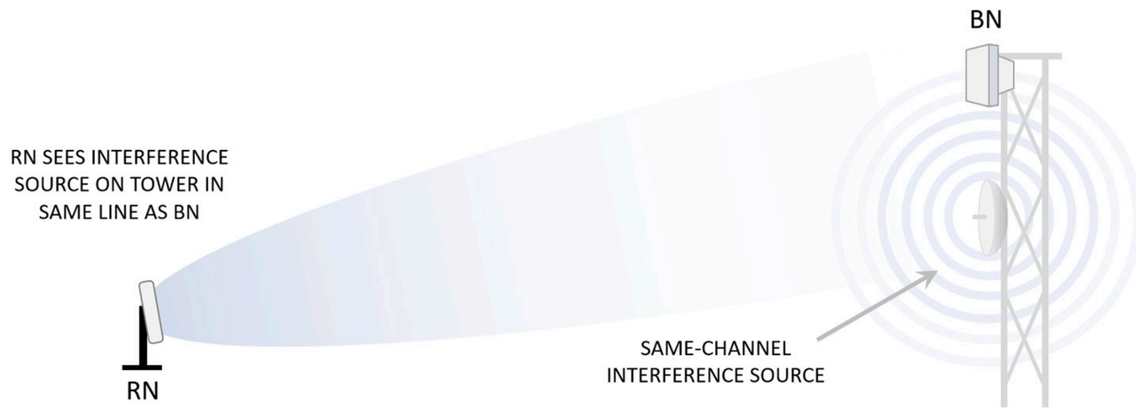



Figure 24: Co-linear interference at the tower impacts downlink performance

### Co-Existence with Adjacent Channel Radios

Operating in a different channel as other equipment on the same tower does not necessarily mean no interference will occur. Good planning best practices will take into consideration power, frequencies, and timing between G1 and the interfering equipment.

#### *CBRS*

G1 CBRS equipment is designed with effective filtering to eliminate transmission outside the range of 3550–3700 MHz. However, co-located CBRS base stations operating in adjacent channels can cause brute force overloading of the base node if the frame timing is not synchronized. This is especially true for very high-power C-band base stations where the equipment is permitted to output at much higher power levels than G1. In this case, timing synchronization is critical to ensure acceptable performance. Timing synchronization will ensure the two devices either transmit or receive simultaneously and therefore do not interfere with each other. In general, CBRS 3GPP base stations (LTE or 5G-NR) will comply with the co-existence guidelines of the OnGo Alliance, which specifies the following compatible TDD frame type:

- LTE frame structure type 2, SSF 7 (compatible with G1 network profiles 1 and 2)

All devices configure their frame timing relative to 1 pulse per second (PPS) that is coordinated by GPS. However, the 3GPP standard does not specify the offset between the PPS and 3GPP slots within the 10 ms frame. If there is a mismatch between equipment, the frame offset configuration setting in TCS should be used to ensure base nodes are using the same offset as co-located 3GPP equipment.

A spectrum scan can be helpful to determine the optimal frame alignment when other equipment is on the same tower as the base node. For best results, operators are encouraged to coordinate radio operation with other operators on the same tower.

***Unlicensed Bands***
In UNII-1 and UNII-3, the allowed EIRPs are lower when compared to CBRS and licensed bands. This reduces the potential for interference to occur when using non-overlapping channels in close proximity, but it does not eliminate interference when G1 and other vendor equipment are using the adjacent frequencies. Because there is no uniform synchronization timing in these bands, the possibility of interference exists. To minimize the impact of other equipment on G1, both horizontal and vertical separation is highly recommended.

### Frequency Selection

A spectrum analysis-based audit of nearby transmitting devices in the area where a base node will deploy is highly recommended. This allows operators to monitor the interference landscape. The interference landscape should ideally show all sources of nearby transmitters on candidate frequencies. It is important to understand that a channel with a worse interference landscape does not necessarily correlate with worse performance. This is because the directionality and co-linearity of the interference across links is more important than simple interference strength.

Operators are encouraged to regularly monitor interference levels at the base node and reevaluate frequency selection. This information can be fed into a co-existence analysis tool that determines how far the base node can be located to avoid saturating the radio receiver. This is especially important in unlicensed frequencies where many devices are not time synchronized. This tool would take into account the antenna pattern of the interfering gear, power levels, operating frequencies, and azimuth and elevation positioning relative to the base node as well as the base node's own adjacent channel interference cancellation capabilities.

## Summary

In general, the following is highly recommended to ensure optimal G1 performance:

### CBRS

Determine whether other CBRS (or adjacent high-power C-band) base stations are co-located on the same tower. If that is the case, ensure the base node does not operate in the same frequency and coordinate with other operators to ensure the same frame timing and offset is used. Coordination will benefit both operators by improving network performance for each system. Make use of horizontal and vertical separation to further reduce potential interference for maximum efficiency.

### Unlicensed Bands

Determine whether other equipment is present (UNII-1 and UNII-3) on the same tower. Avoid using the same frequencies as these radios, if possible, to ensure maximum efficiency. If this is not possible, ensure the antenna of the interfering radio does not point within the azimuthal coverage angle of the base node.

Regardless of whether other same-band radios are using the same frequency or adjacent frequencies, increase separation between the base node and other radios as much as possible. Both horizontal and vertical separation are recommended.

## Sector Capacity Optimization

Sector (base node) capacity is an important metric that ultimately affects how many subscribers a given base node can support. Key factors include azimuthal diversity of remote nodes, height and elevation orientation of the base node, and link quality.

### Azimuthal Diversity

To achieve maximum potential capacity, the remote nodes should be spread uniformly across the base node's azimuthal field of view (90°+). Doing so improves the ability of the base node and remote node to use spatial multiplexing to achieve the highest possible rate. If all remote nodes cannot be spatially resolved, capacity and performance will drop, e.g., fewer spatial streams may be possible between the base node and remote nodes.

For example, if all remote nodes are clustered within a 15° angle or less from the base node, this does not allow as much chance for spatial resolution, degrading performance and, ultimately, sector capacity. A G1 base node supports up to six spatial streams. With all remote nodes closely co-located, sector capacity is reduced by one third (for a total two spatial streams). At a 30° angle, roughly four spatial streams are possible. To ensure full spatial streams and capacity, an angle of 45° or better is recommended for azimuthal diversity.

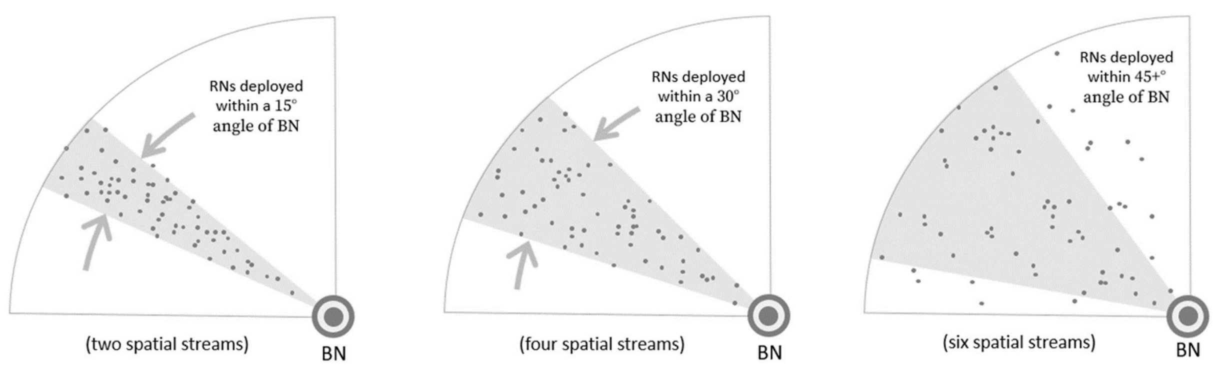



Figure 25: Greater azimuthal diversity allows more spatial streams and capacity

Another example of how this might work, is tower placement. An operator may choose to place a base node at a very high elevation (such as a mountain top) where it can easily connect to a cluster of remote nodes. However, this might not be the best solution from a spatial perspective. Instead, planning could allow for a closer-in tower where the azimuthal field of view of the base node yields better spatial multiplexing.

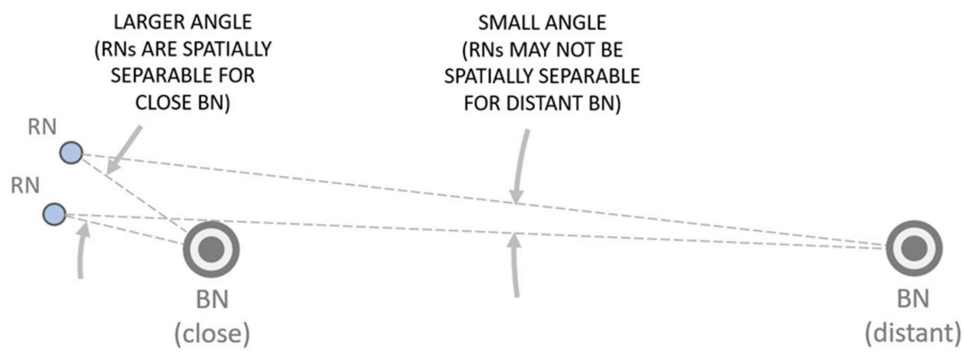



Figure 26: Closer towers allow for greater spatial separation

## Base Node Height and Elevation Orientation

In cellular networks there is always a trade off between height of the base station and exposure to interference. Typically, the higher a base node is mounted above ground level (AGL), the larger the area it can cover. This can be a good choice in a macro-cell environment where the number of towers is relatively sparse. The downside, however, is that the base node is exposed to a greater number of potential sources of interference that it may not be able to spatially resolve. The higher the elevation, the higher the probability the base node will encounter spatially unresolvable interference relative to the remote nodes, i.e., interference that it cannot point an RF null towards and effectively cancel. This can limit link performance. This guideline particularly applies to any unprotected (unlicensed) spectrum such as 5 GHz and 6 GHz bands.

In general, limiting the base node's exposure to interference will improve overall link performance and sector capacity. One exception to this is when extra height is required to get over an obstacle such as dense foliage. A higher elevation is helpful in this case to avoid unacceptable signal attenuation that would otherwise occur.

## Link Quality

Link quality is a key component of overall sector capacity. As a general rule, the higher quality the links, the greater the capacity. Overall link quality is primarily impacted by pathloss, interference, and radio location.

### Path Loss

The pathloss is one of the prime indicators of link quality. It relates to achievable MCS level and throughput capability as well as stability of the link. The reported pathloss for a link can be compared to the calculated pathloss (such as from a pathloss calculator) using the frequency and distance of the link. An RF propagation tool is extremely useful in this case to determine predicted pathloss and corresponding performance. If the pathloss is higher than the calculated pathloss, this indicates the link could be obstructed to some degree.

Using the reported pathloss, the theoretical maximum throughput of the link can be obtained from Appendix A: Maximum Allowed Pathloss Tables for the utilized frequency band. If the actual performance of the link as tested using the internal speed test is lower than what the MAPL table predicts, this could be the result of the following:

- High interference-to-noise ratio (INR)
- Low signal-to-interference-and-noise ratio (SINR)
- Sensitivity loss due to receiver overload
- Co-linear interference
- A combination of the above

**The Impact of Interference**

It should be noted that a high INR does not necessarily mean the link will be degraded. The Tarana Gigabit (G1) family includes RF innovations that greatly reduce the impact of interference. Degradation will depend on both the strength and the width of the interference. It is possible to have a high INR that only overlaps a small part of the carrier width (frequencies). Conversely, there could be a moderate INR that overlaps a majority of the carrier width. Determining this interference landscape is an important part of RF planning.

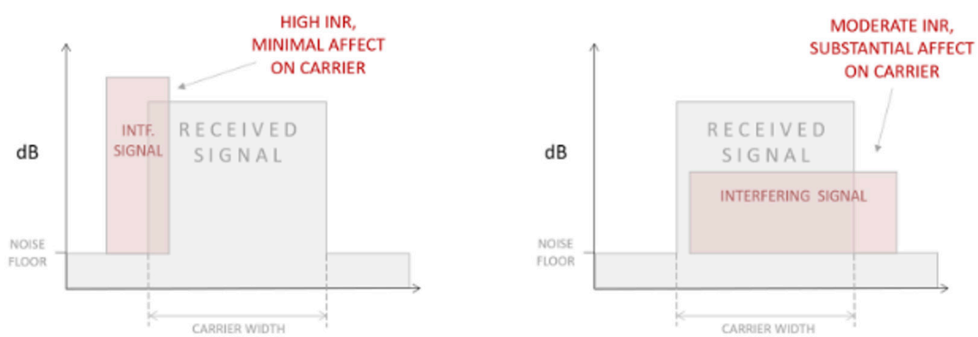



Figure 27: The impact of INR is a function of strength and width of interference

Assuming the interference is overlapping a large number of carrier frequencies, a high INR value (> 40 dB) can indicate that performance may start to suffer in the direction of the reporting device. For example, if a remote node has a high INR, it may have trouble receiving data from its base node. This could result in lower downlink performance.

If a base node has a high INR on a given carrier, it may have trouble receiving data on that carrier from the connected remote nodes in the sector, resulting in lower overall uplink performance. It is worth noting that this is not uncommon for base nodes mounted on towers. This is for two reasons:

- Towers may have several other same-band radio devices mounted in close proximity to the base node.
- There may be numerous same-band radio devices on the same frequency as the base node pointed directly at the tower.

Since this metric is carrier-dependent, it can help to change the base node carrier frequency to a cleaner part of the spectrum if a high INR is seen on the given carrier. It should be noted that, if a single remote node sees a high INR, it does not necessarily mean that the rest of the remote nodes in the sector also see a high INR. For this reason, changing the carrier frequency may not be beneficial as it may negatively affect other remote nodes that have a low INR.

### Base Node Location, Remote Node Location

When analyzing link performance, the locations of the base node and remote node should be considered separately. As Figure 14 illustrates, each location could have very different RF environments.

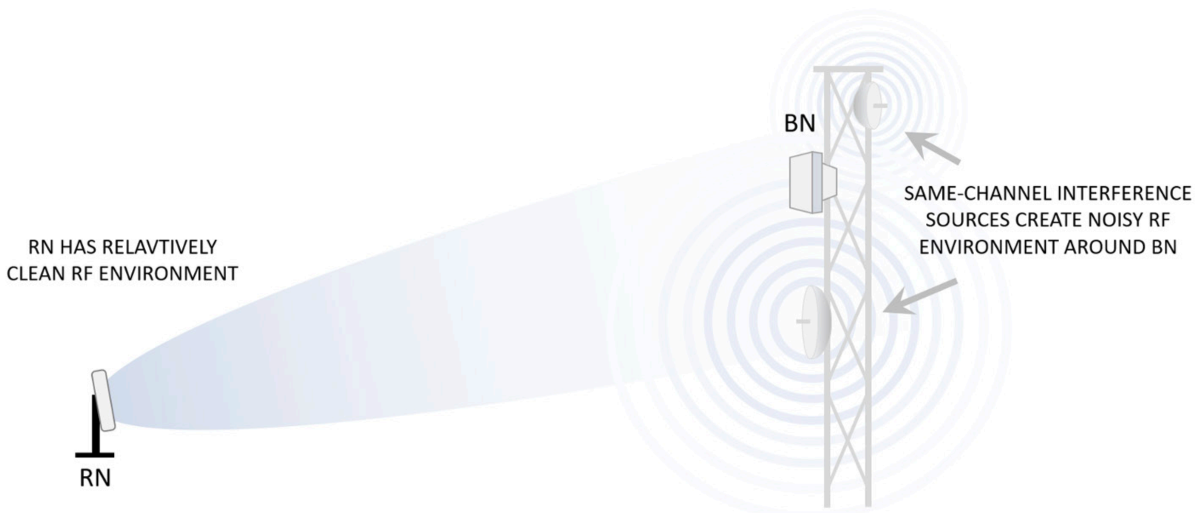



Figure 28: Base node and remote node may have different interference environments

Each respective environment will influence directional data flow. If the base node is in a noisy RF environment, it might have more trouble hearing the transmissions from its connected remote nodes. This can affect upload speeds for the entire sector. Performing an RF scan at the location of the base node and choosing the optimal carrier frequencies can help avoid such an issue. Sufficient separation between the base node and other mounted radio devices can also improve the situation.

If a remote node is experiencing local interference, it may have trouble hearing transmissions from the base node. This could result in lesser download speeds for the remote node. Unlike having interference at the base node location, local interference at the remote node may not affect the entire sector. For example, other remote nodes in the sector could be in a much cleaner RF environment giving them satisfactory download speeds. For this reason, changing carrier frequencies of the base node might not be the best way to remedy the situation.

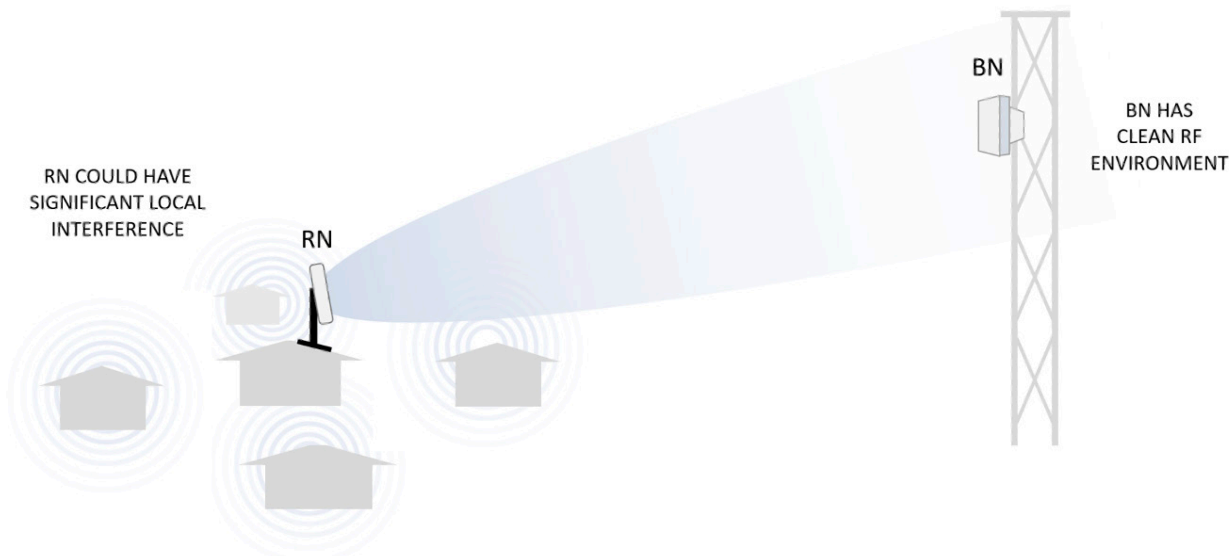



Figure 29: Remote node experiences significant local interference, impacting downlink performance

### Co-Linear Interference

Co-linear interference occurs when an interfering radio is on the same or overlapping azimuthal bearing as one of the radios in a link. This often occurs when multiple radios are installed on the same tower and at the same azimuth setting serving subscribers in the same area. This interference can occur outside the link distance as well as within, e.g., co-linear interference can occur up and down the tower in which radios from different operators create near field interference and receiver overload conditions.

Where possible, the G1 radios will make use of beam squinting to attempt to work around the interfering radio, however, some degradation is expected. To work around this, one or more of the following options are recommended:

- Choose a different, non-overlapping frequency
- Change the azimuth
- Change the tilt
- Increase separation between the two radios vertically and horizontally

### Azimuth versus Tilt

While adjusting azimuth is a standard part of any installation, tilt optimization can yield even greater improvements. Base node tilt should always be determined with the help of radio planning software for optimal results. This setting should then be confirmed with an accurate digital level at installation time.

Tilt is also important for remote nodes. This is because the remote node has a 55° field of view and beamforms on the horizontal axis rather than the vertical. Most installations will use a 2–5 degree uptilt — although this can change depending on the elevation difference between the remote node and base node. Adjusting tilt can not only improve alignment and overall performance, it can also help mitigate interference from nearby sources such as Wi-Fi within a residence.

## Summary

Sector capacity affects how many subscribers a given base node can support. Key factors include azimuthal diversity of remote nodes, height and elevation orientation of the base node, and link quality. To achieve maximum capacity, the following are recommended:

- An angle of 45° or better is recommended for azimuthal diversity of remote node locations from base node.
- Adjusting tilt can yield greater link performance than only adjusting azimuth.
- Use closer towers where possible, to increase spatial separation.
- Use lower towers where possible to reduce the impact of outside interference.
- Plan for the highest quality link possible by reducing INR and sensitivity loss while increasing SINR.
- Avoid co-linear interference.

## Deployment Validation

Once a network is deployed, there are a number of key performance indicators (KPIs) that can be used to validate expected performance with achieved performance as deployed. The metrics referred to here are available through TCS with the exception of the alignment metric which is available via the remote node web UI during installation.

Many metrics are available for both carrier frequencies (carrier 0 and carrier 1) and should be viewed individually and not as a single 80-MHz channel, but rather as two 40 MHz carriers. This is especially important to consider since each carrier could be in a different band of the 5 GHz spectrum (for example, U-NII 1 and U-NII 3). Each carrier could have drastically different RF factors and propagation effects for the given path of the link (reflection, diffraction, multipath, penetration).

### Link Quality

There are a number of metrics that can be used to determine deployed link quality. These include:

- Alignment metric
- Pathloss and excess pathloss
- Interference
- Signal-to-interference-and-noise-ratio (SINR)
- Sensitivity loss
- Receive signal

#### Alignment Metric

The alignment metric is a unitless value between 0 and 30 that is available during remote node installation. As the name implies, this metric is used during the aiming portion of installation to ensure the best possible alignment between the base node and the remote node. As a general practice, a remote node should not be moved until it has completed calibration. Once calibration is complete, the remote node may be slowly turned and, using the alignment metric as a guide, aligned to the best azimuthal bearing.

The alignment metric is used for aiming only and does not take into consideration other factors that could impact link performance such as interference, pathloss, etc. To determine link performance, the following metrics should be used as reported by TCS.

#### Pathloss

As mentioned previously, the pathloss metric is a key indicator of expected performance. Pathloss relates to achievable MCS level and throughput capability. The reported pathloss for a link can be correlated with the calculated pathloss (such as from a free space pathloss calculator) using the frequency and distance of the link. The amount of pathloss experienced by a link above that from free space pathloss is excess pathloss. The greater the excess pathloss the more attenuated or obstructed the link and the lower the link performance.

Using the reported pathloss, the theoretical maximum throughput of the link can be obtained from Appendix A: Maximum Allowed Pathloss Tables for the utilized frequency band. If the actual performance of the link as tested using the internal speed test is lower than what the table predicts, this could be the result of the following:

- High interference-to-noise ratio (INR)
- Low signal-to-interference-and-noise ratio (SINR)
- Sensitivity loss
- Co-linear interference
- A combination of the above

### Interference

The metric Intf. Noise Ratio Max Carrier “X” (where X refers to carrier 0 or carrier 1) indicates the INR experienced by a base node or remote node. In general, a value of 40 dB or less is preferred. For more information the impact of INR, see the section The Impact of Interference.

### SINR

In general, the higher the SINR metric the better a link will perform. A SINR should ideally be at or above 20 dB. A SINR that is close to 0 dB indicates a link where the interference and noise are nearly as strong as the signal of interest, degrading performance.

It is important to note that reported SINR is measured at the time of data transmission, therefore in order to get an accurate measurement some traffic should be traversing the link.

#### *Downlink SINR*

A low DL SINR metric implies the remote node is seeing strong interference, which could affect downlink speeds. If other remote nodes in the sector mostly have higher downlink SINRs, this typically means the interference is in the general area of the remote node in question, such as other point-to-point links, or Wi-Fi access points.

#### *Uplink SINR*

A low UL SINR metric implies the base node is seeing strong interference. This could mean that the interference is either in the general area of the base node, or that interference sources are pointed at the base node from a distance, or both.

If the base node is experiencing a low SINR, this may result in lower-than-expected uplink speeds for the remote nodes in the sector. In this case, it could be beneficial to change one or both of the carrier frequencies of the base node.

**Sensitivity Loss**

The Sensitivity Loss Max Carrier metric is used to indicate the peak received signal level in decibels on the carrier (0 or 1). Sensitivity loss can indicate strong interference. For example, a remote node that has a pathloss of 125 dB or more and a sensitivity loss is likely experiencing heavy interference. A non-zero sensitivity loss on a base node is also typically associated with high interference levels.

**Received Signal**

The Rx Signal Carrier metric indicates the strength of the received signal (in decibels) on a given carrier (0 or 1). A remote node's received signal value may be significantly lower when the link is not sending data. If the remote node is not seeing external interference, this value should be close to the noise floor. If the remote node is not sending data and the receive signal is elevated from the noise floor, this can be an indicator of interference in the view of the remote node.

**Link Quality Summary**

To summarize, the tables in the next section show the relationship between transmission direction and possible issues that might impact link performance.

## Conclusion

With Tarana G1, operators have more tools to improve performance than any other system or technology. Savvy operators can take advantage of simple design considerations to improve performance and overall efficiency even more, boosting sector capacity, link throughput, and reliability.

Considerations for getting maximum efficiency and performance include:

- Ensure remote nodes connect to their best-serving base node through the use of cell design, planning ID, and primary BN functionality.
- Reduce cell overlap and avoid nested cell designs.
- If subscriber capacity is not a consideration, a three-sector site configuration can be a better choice than four sectors.
- Use base node azimuthal diversity, height, and elevation orientation to maximize link performance and sector capacity.
- Use the maximum amount of unencumbered (clean) spectrum available. In severely congested environments, K=2 may be a better use of spectrum.
- Where possible, use maximum horizontal and vertical separation of G1 and other same-band radios.
- Use GPS and network profiles where possible to coordinate transmission and reception of same-band radios.

When these techniques are combined with RF propagation and planning tools and real-time assessment of RF conditions, operators can deliver high-performing, reliable next-generation fixed wireless access.

# Appendix A: Maximum Allowed Pathloss Tables

Pathloss, or path attenuation, is the reduction in power density of an electromagnetic wave as it propagates through space. It is a major component in the analysis and design of the link budget of a telecommunications system. This term is commonly used in wireless communications and signal propagation.

Shown below are tables that show the maximum allowable path loss for the Tarana G1 system in both 5 GHz and CBRS frequencies by network profile. This is used in the Google Planner Tool for Tarana partners.

## Network Profile 1

**5GHZ**

| | | | |
|---|---|---|---|
| RN Ant Gain | 21.9 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 2 | dB | |
| BN Transmit EIRP | 36 | dBm | |
| Network Profile 1 | 4.5:1 | DL/UL Ratio | Up to 15 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 784 | 321 | 71 | 641 | 143 | 123 |
| 15 | -66.5 | 770 | 315 | 70 | 630 | 140 | 124 |
| 14 | -67.4 | 743 | 304 | 68 | 608 | 135 | 125 |
| 13 | -68.7 | 689 | 282 | 63 | 564 | 125 | 127 |
| 12 | -70.4 | 635 | 260 | 58 | 520 | 116 | 128 |
| 11 | -72.2 | 581 | 238 | 53 | 476 | 106 | 130 |
| 10 | -73.9 | 527 | 216 | 48 | 431 | 96 | 132 |
| 9 | -75.4 | 473 | 194 | 43 | 387 | 86 | 133 |
| 8 | -76.9 | 419 | 171 | 38 | 343 | 76 | 135 |
| 7 | -78.3 | 365 | 149 | 33 | 299 | 66 | 136 |
| 6 | -79.7 | 311 | 127 | 28 | 254 | 57 | 138 |
| 5 | -82.2 | 257 | 105 | 23 | 210 | 47 | 140 |
| 4 | -83.8 | 203 | 83 | 18 | 166 | 37 | 142 |
| 3 | -84.9 | 176 | 72 | 16 | 144 | 32 | 143 |
| 2 | -85.8 | 149 | 61 | 14 | 122 | 27 | 144 |
| 1 | -86.9 | 95 | 39 | 9 | 77 | 17 | 145 |

**CBRS**

| | | | |
|---|---|---|---|
| RN Ant Gain | 18.5 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 0 | dB | |
| BN Transmit Power | 37 | dBm/MHz | 49.7 dBm EIRP |
| Network Profile 1 | 4.5:1 | DL/UL Ratio | Up to 15 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 784 | 321 | 71 | 641 | 143 | 133 |
| 15 | -66.1 | 770 | 315 | 70 | 630 | 140 | 134 |
| 14 | -67.1 | 743 | 304 | 68 | 608 | 135 | 135 |
| 13 | -69.1 | 689 | 282 | 63 | 564 | 125 | 137 |
| 12 | -70.1 | 635 | 260 | 58 | 520 | 116 | 138 |
| 11 | -72.1 | 581 | 238 | 53 | 476 | 106 | 140 |
| 10 | -74.1 | 527 | 216 | 48 | 431 | 96 | 142 |
| 9 | -75.1 | 473 | 194 | 43 | 387 | 86 | 143 |
| 8 | -77.1 | 419 | 171 | 38 | 343 | 76 | 145 |
| 7 | -78.1 | 365 | 149 | 33 | 299 | 66 | 146 |
| 6 | -81.1 | 311 | 127 | 28 | 254 | 57 | 149 |
| 5 | -82.1 | 257 | 105 | 23 | 210 | 47 | 150 |
| 4 | -84.1 | 203 | 83 | 18 | 166 | 37 | 152 |
| 3 | -85.1 | 176 | 72 | 16 | 144 | 32 | 153 |
| 2 | -86.1 | 149 | 61 | 14 | 122 | 27 | 154 |
| 1 | -89.1 | 95 | 39 | 9 | 77 | 17 | 157 |

## Network Profile 2

**5GHZ**

| | | | |
|---|---|---|---|
| RN Ant Gain | 21.9 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 2 | dB | |
| BN Transmit EIRP | 36 | dBm | |
| Network Profile 2 | 4:1 | DL/UL Ratio | Up to 30 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity Per | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 713 | 285 | 71 | 570 | 143 | 123 |
| 15 | -66.5 | 700 | 280 | 70 | 560 | 140 | 124 |
| 14 | -67.4 | 676 | 270 | 68 | 541 | 135 | 125 |
| 13 | -68.7 | 627 | 251 | 63 | 501 | 125 | 127 |
| 12 | -70.4 | 578 | 231 | 58 | 462 | 116 | 128 |
| 11 | -72.2 | 528 | 211 | 53 | 423 | 106 | 130 |
| 10 | -73.9 | 479 | 192 | 48 | 383 | 96 | 132 |
| 9 | -75.4 | 430 | 172 | 43 | 344 | 86 | 133 |
| 8 | -76.9 | 381 | 152 | 38 | 305 | 76 | 135 |
| 7 | -78.3 | 332 | 133 | 33 | 265 | 66 | 136 |
| 6 | -79.7 | 283 | 113 | 28 | 226 | 57 | 138 |
| 5 | -82.2 | 233 | 93 | 23 | 187 | 47 | 140 |
| 4 | -83.8 | 184 | 74 | 18 | 147 | 37 | 142 |
| 3 | -84.9 | 160 | 64 | 16 | 128 | 32 | 143 |
| 2 | -85.8 | 135 | 54 | 14 | 108 | 27 | 144 |
| 1 | -86.9 | 86 | 34 | 9 | 69 | 17 | 145 |

**CBRS**

| | | | |
|---|---|---|---|
| RN Ant Gain | 18.5 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 0 | dB | |
| BN Transmit Power | 37 | dBm/MHz | 49.7 dBm EIRP |
| Network Profile 2 | 4:1 | DL/UL Ratio | Up to 30 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity Per | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 713 | 285 | 71 | 570 | 143 | 133 |
| 15 | -66.1 | 700 | 280 | 70 | 560 | 140 | 134 |
| 14 | -67.1 | 676 | 270 | 68 | 541 | 135 | 135 |
| 13 | -69.1 | 627 | 251 | 63 | 501 | 125 | 137 |
| 12 | -70.1 | 578 | 231 | 58 | 462 | 116 | 138 |
| 11 | -72.1 | 528 | 211 | 53 | 423 | 106 | 140 |
| 10 | -74.1 | 479 | 192 | 48 | 383 | 96 | 142 |
| 9 | -75.1 | 430 | 172 | 43 | 344 | 86 | 143 |
| 8 | -77.1 | 381 | 152 | 38 | 305 | 76 | 145 |
| 7 | -78.1 | 332 | 133 | 33 | 265 | 66 | 146 |
| 6 | -81.1 | 283 | 113 | 28 | 226 | 57 | 149 |
| 5 | -82.1 | 233 | 93 | 23 | 187 | 47 | 150 |
| 4 | -84.1 | 184 | 74 | 18 | 147 | 37 | 152 |
| 3 | -85.1 | 160 | 64 | 16 | 128 | 32 | 153 |
| 2 | -86.1 | 135 | 54 | 14 | 108 | 27 | 154 |
| 1 | -89.1 | 86 | 34 | 9 | 69 | 17 | 157 |

## Network Profile 5

**5GHZ**

| | | | |
|---|---|---|---|
| RN Ant Gain | 21.9 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 2 | dB | |
| BN Transmit EIRP | 36 | dBm | |
| Network Profile 5 | 2.67:1 | DL/UL Ratio | Up to 15 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity Per | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 784 | 285 | 107 | 570 | 214 | 123 |
| 15 | -66.5 | 770 | 280 | 105 | 560 | 210 | 124 |
| 14 | -67.4 | 743 | 270 | 101 | 541 | 203 | 125 |
| 13 | -68.7 | 689 | 251 | 94 | 501 | 188 | 127 |
| 12 | -70.4 | 635 | 231 | 87 | 462 | 173 | 128 |
| 11 | -72.2 | 581 | 211 | 79 | 423 | 159 | 130 |
| 10 | -73.9 | 527 | 192 | 72 | 383 | 144 | 132 |
| 9 | -75.4 | 473 | 172 | 65 | 344 | 129 | 133 |
| 8 | -76.9 | 419 | 152 | 57 | 305 | 114 | 135 |
| 7 | -78.3 | 365 | 133 | 50 | 265 | 100 | 136 |
| 6 | -79.7 | 311 | 113 | 42 | 226 | 85 | 138 |
| 5 | -82.2 | 257 | 93 | 35 | 187 | 70 | 140 |
| 4 | -83.8 | 203 | 74 | 28 | 147 | 55 | 142 |
| 3 | -84.9 | 176 | 64 | 24 | 128 | 48 | 143 |
| 2 | -85.8 | 149 | 54 | 20 | 108 | 41 | 144 |
| 1 | -86.9 | 95 | 34 | 13 | 69 | 26 | 145 |

**CBRS**

| | | | |
|---|---|---|---|
| RN Ant Gain | 18.5 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 0 | dB | |
| BN Transmit Power | 37 | dBm/MHz | 49.7 dBm EIRP |
| Network Profile 5 | 2.67:1 | DL/UL Ratio | Up to 15 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity Per | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 784 | 285 | 107 | 570 | 214 | 133 |
| 15 | -66.1 | 770 | 280 | 105 | 560 | 210 | 134 |
| 14 | -67.1 | 743 | 270 | 101 | 541 | 203 | 135 |
| 13 | -69.1 | 689 | 251 | 94 | 501 | 188 | 137 |
| 12 | -70.1 | 635 | 231 | 87 | 462 | 173 | 138 |
| 11 | -72.1 | 581 | 211 | 79 | 423 | 159 | 140 |
| 10 | -74.1 | 527 | 192 | 72 | 383 | 144 | 142 |
| 9 | -75.1 | 473 | 172 | 65 | 344 | 129 | 143 |
| 8 | -77.1 | 419 | 152 | 57 | 305 | 114 | 145 |
| 7 | -78.1 | 365 | 133 | 50 | 265 | 100 | 146 |
| 6 | -81.1 | 311 | 113 | 42 | 226 | 85 | 149 |
| 5 | -82.1 | 257 | 93 | 35 | 187 | 70 | 150 |
| 4 | -84.1 | 203 | 74 | 28 | 147 | 55 | 152 |
| 3 | -85.1 | 176 | 64 | 24 | 128 | 48 | 153 |
| 2 | -86.1 | 149 | 54 | 20 | 108 | 41 | 154 |
| 1 | -89.1 | 95 | 34 | 13 | 69 | 26 | 157 |

## Network Profile 6

**5GHZ**

| | | | |
|---|---|---|---|
| RN Ant Gain | 21.9 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 2 | dB | |
| BN Transmit EIRP | 36 | dBm | |
| Network Profile 6 | 1.75:1 | DL/UL Ratio | Up to 15 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 784 | 249 | 143 | 499 | 285 | 123 |
| 15 | -66.5 | 770 | 245 | 140 | 490 | 280 | 124 |
| 14 | -67.4 | 743 | 237 | 135 | 473 | 270 | 125 |
| 13 | -68.7 | 689 | 219 | 125 | 439 | 251 | 127 |
| 12 | -70.4 | 635 | 202 | 116 | 404 | 231 | 128 |
| 11 | -72.2 | 581 | 185 | 106 | 370 | 211 | 130 |
| 10 | -73.9 | 527 | 168 | 96 | 335 | 192 | 132 |
| 9 | -75.4 | 473 | 151 | 86 | 301 | 172 | 133 |
| 8 | -76.9 | 419 | 133 | 76 | 267 | 152 | 135 |
| 7 | -78.3 | 365 | 116 | 66 | 232 | 133 | 136 |
| 6 | -79.7 | 311 | 99 | 57 | 198 | 113 | 138 |
| 5 | -82.2 | 257 | 82 | 47 | 163 | 93 | 140 |
| 4 | -83.8 | 203 | 65 | 37 | 129 | 74 | 142 |
| 3 | -84.9 | 176 | 56 | 32 | 112 | 64 | 143 |
| 2 | -85.8 | 149 | 47 | 27 | 95 | 54 | 144 |
| 1 | -86.9 | 95 | 30 | 17 | 60 | 34 | 145 |

**CBRS**

| | | | |
|---|---|---|---|
| RN Ant Gain | 18.5 | dBi | |
| Fade Margin | 3 | dB | |
| Interference Margin | 0 | dB | |
| BN Transmit Power | 37 | dBm/MHz | 49.7 dBm EIRP |
| Network Profile 6 | 1.75:1 | DL/UL Ratio | Up to 15 Km Radius |

| MCS Index | RN Input RSSI | Aggregate Capacity Per | Capacity 40MHz DL | Capacity 40MHz UL | Capacity 2x40MHz DL | Capacity 2x40MHz UL | Pathloss (dB) |
|---|---|---|---|---|---|---|---|
| 16 | -65.1 | 784 | 249 | 143 | 499 | 285 | 133 |
| 15 | -66.1 | 770 | 245 | 140 | 490 | 280 | 134 |
| 14 | -67.1 | 743 | 237 | 135 | 473 | 270 | 135 |
| 13 | -69.1 | 689 | 219 | 125 | 439 | 251 | 137 |
| 12 | -70.1 | 635 | 202 | 116 | 404 | 231 | 138 |
| 11 | -72.1 | 581 | 185 | 106 | 370 | 211 | 140 |
| 10 | -74.1 | 527 | 168 | 96 | 335 | 192 | 142 |
| 9 | -75.1 | 473 | 151 | 86 | 301 | 172 | 143 |
| 8 | -77.1 | 419 | 133 | 76 | 267 | 152 | 145 |
| 7 | -78.1 | 365 | 116 | 66 | 232 | 133 | 146 |
| 6 | -81.1 | 311 | 99 | 57 | 198 | 113 | 149 |
| 5 | -82.1 | 257 | 82 | 47 | 163 | 93 | 150 |
| 4 | -84.1 | 203 | 65 | 37 | 129 | 74 | 152 |
| 3 | -85.1 | 176 | 56 | 32 | 112 | 64 | 153 |
| 2 | -86.1 | 149 | 47 | 27 | 95 | 54 | 154 |
| 1 | -89.1 | 95 | 30 | 17 | 60 | 34 | 157 |

Tarana's mission is to accelerate the deployment of fast, affordable internet access around the world. Through a decade of R&D and more than $400M of investment, the Tarana team has created a unique next-generation fixed wireless access (ngFWA) technology instantiated in its first commercial platform, Gigabit 1 (G1). It delivers a game-changing advance in broadband economics in both mainstream and underserved markets, using either licensed or unlicensed spectrum. G1 started production in mid-2021 and has been embraced by more than 250 operators in 19 countries and 41 states. Tarana is headquartered in Milpitas, California, with additional research and development in Pune, India.