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Impact of Interference Avoidance Strategies on CBRS Offload Networks

General Thoughts

- Much of the spectrum sharing work has focused on assuring no interference, similar to the manual, static model's objectives
- This is an extreme end of the performance curve, and is open to challenge as the appropriate objective for many networks
- Marshall previously challenged this assumption in: "*Interference Tolerance as an Alternative to Interference Avoidance*", *IEEE International Dynamic Spectrum Access Networks (DYSPAN)*, 2010, Singapore.

CBRS Co-Existence

- Significant effort by the CBRS community to find the “right” metric and method for determining the “best” co-existence solution
- This approach implicitly assumes that there is commonality in the business models for all of the participants in such a regime
- We will Investigate how the “best” co-ex solution varies as a function of a very simple business model

Network Design Objectives Considered

- Reliable:
    - Must assure assured level of service across the coverage area, with a single RAN
    - Inflexible on Interference criteria
- Offload
    - Assumes that it, or its customers, have recourse to a reliable network, although likely at higher cost
    - Might have multiple demands (such as neutral host), so can monetize excess capacity

Before Deciding that Interference Must be Avoided

- What is impact of interference?
    - Lost service?
    - Reduction in throughput at one service location?
- If reduction in throughput,
    - What is the total aggregate impact across the entire service area
- If loss of service
    - What are recourse options
        - Other bands of operation
        - Purchase more reliable service for specific cases of loss of service
- Approach -- determine what you lose achieving Interference avoidance, rather than just what you lose to interference itself

Analysis Approach

- Consider interference (and interference avoidance) impacts in terms of how the network satisfies various business needs and models
- Case study:
  - A network (MVNO like) that must provide a unit of capacity to its own users
  - Guaranteed bandwidth matches its own network in interference free capacity
  - Can buy service from a “reliable” network to provide coverage at a cost
  - Can sell excess bandwidth to other network providers at the same rate it sells to its customers
- The analysis will vary network separation through a range of highly interfering to interfering

Specific Modeling Assumptions

- Typical mixed environment propagation (r^3)
- "Acceptable" service is an LTE CQI of >5
- Co-channel (interfering) nodes are located above and below, and right and left of the serving node
- Worst case performance is assumed; no service is provided by the interfering nodes within the initial service area
- Focus is on shape of the relationships, not their specifics. This does not change (significantly) with power, propagation assumptions, or specific ranges
- Model kept "simple" to avoid specifics of costs, location, radios, etc.

The results are not very Influenced by these assumptions, and are consistent across a wide range of reasonable alternative assumptions

Even So, This is a Massively Pessimistic Model

- Assumes that any interfering node blocks ALL resource blocks at ALL times
- Does not consider the existence of high loss structures that massively increase path loss
- No consideration of AP duty cycle
- Impact:
  - Worst case required protection distance is unchanged
  - But; performance in shorter ranges should be much better than shown here

R^3 Propagation is very Conservative and is the Lower Bound of Measured Data!

- We have collected over 1,500,000 propagation points in dense/semi-dense environments
- Data shown is for benign environment with low buildings in MTV
- 30 dB in r^2 is 2^5 (32 times) in range, and 2^{10} (1,000 in density) impact
- R^3 is a reasonable lower bound for the measured path loss

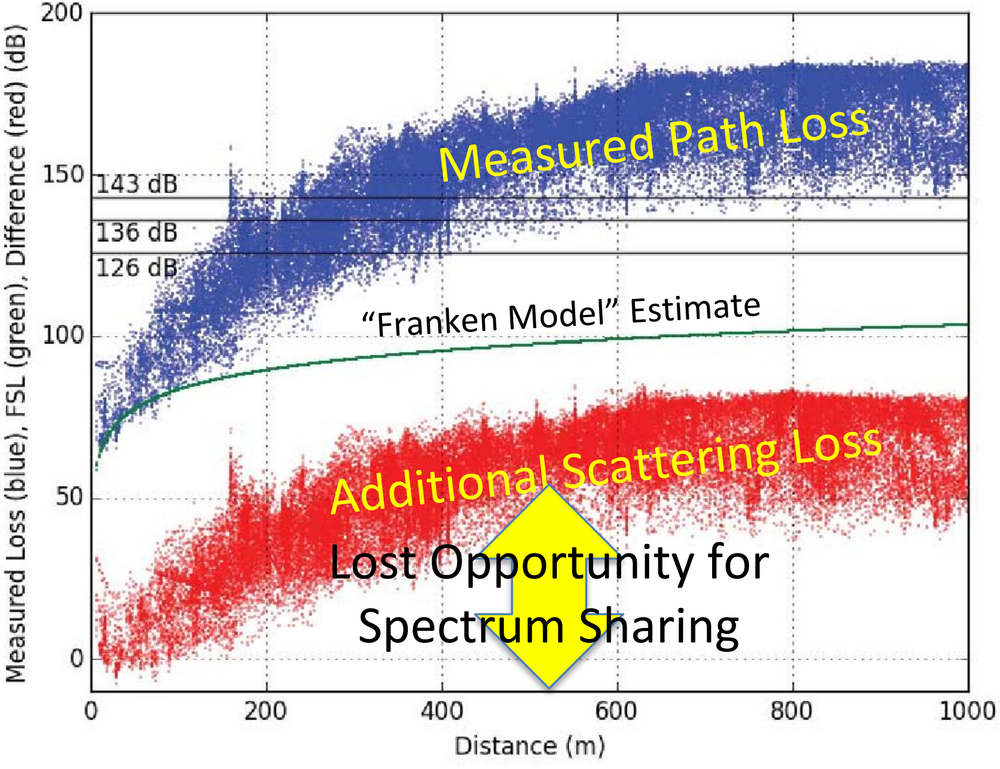
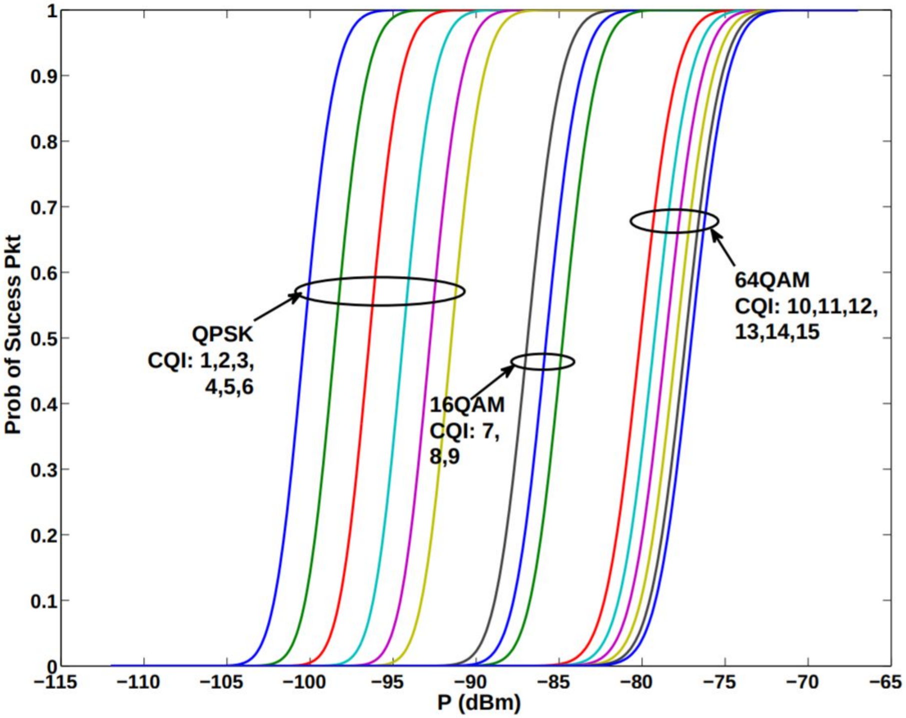


Chart 1: Propagation Loss Measured in Mountain View, California

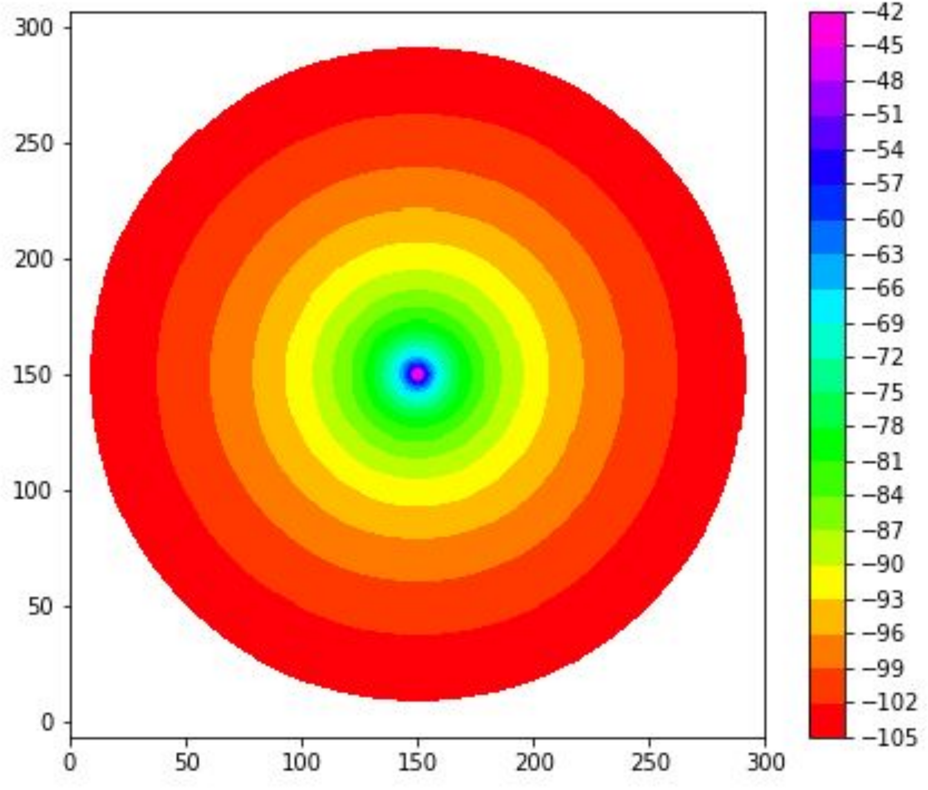
LTE Throughput Degradation is Gradual - Over a Wide Range

CQI Index	Modulation	Code Rate X 1024	Efficiency
0	No transmission		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3880
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	722	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547



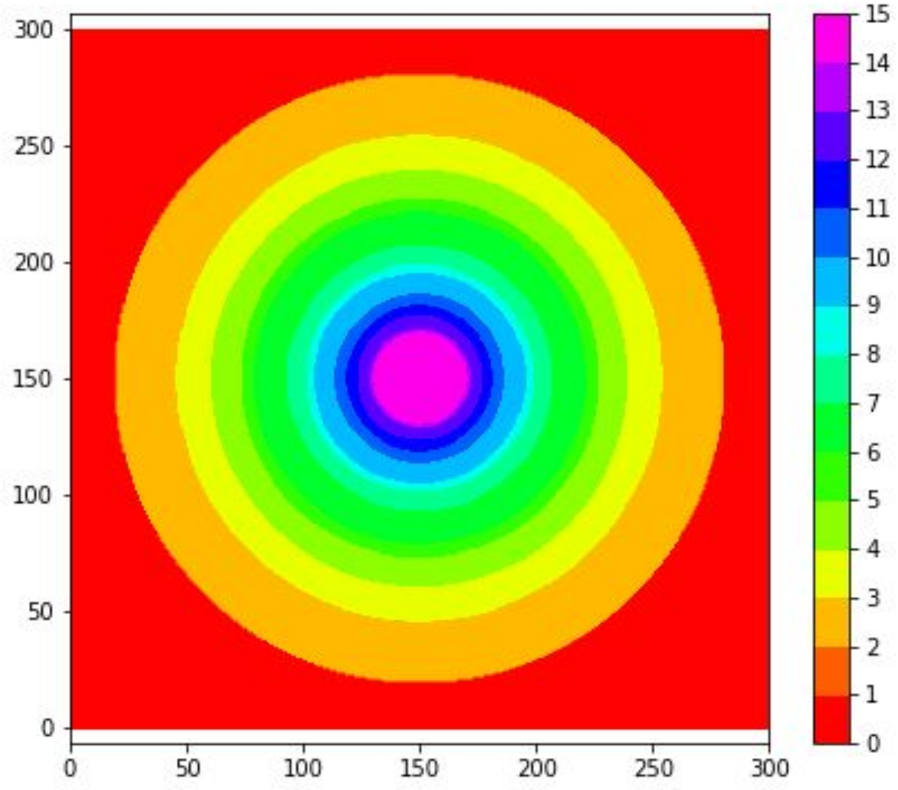
Example -- CQI 9 and 10 are approximately 5 dB apart, but efficiency loss is approximately 20%

Reference Node Signal Strength



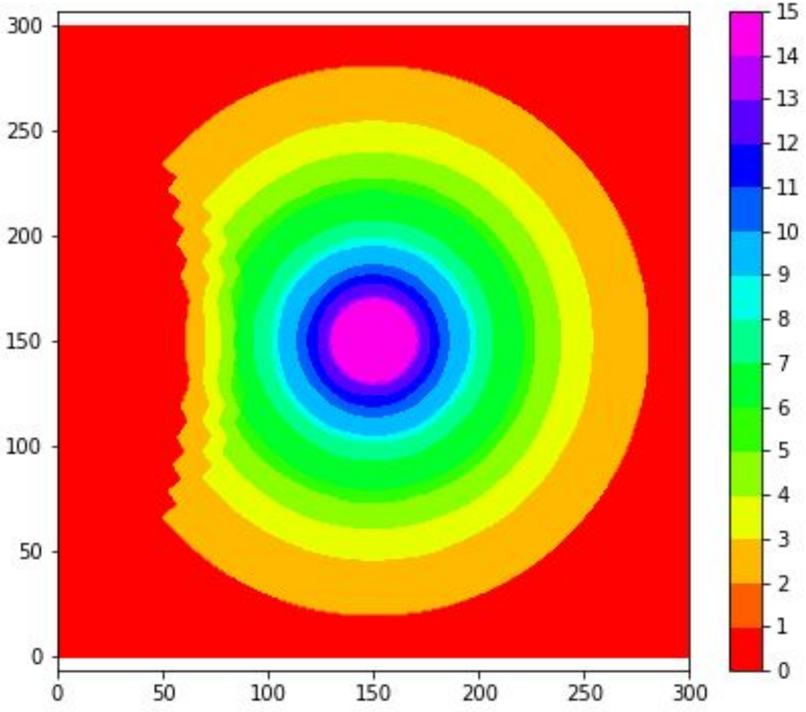
Each Distance
Unit Represents
10 Meters

Reference Node LTE CQI Values



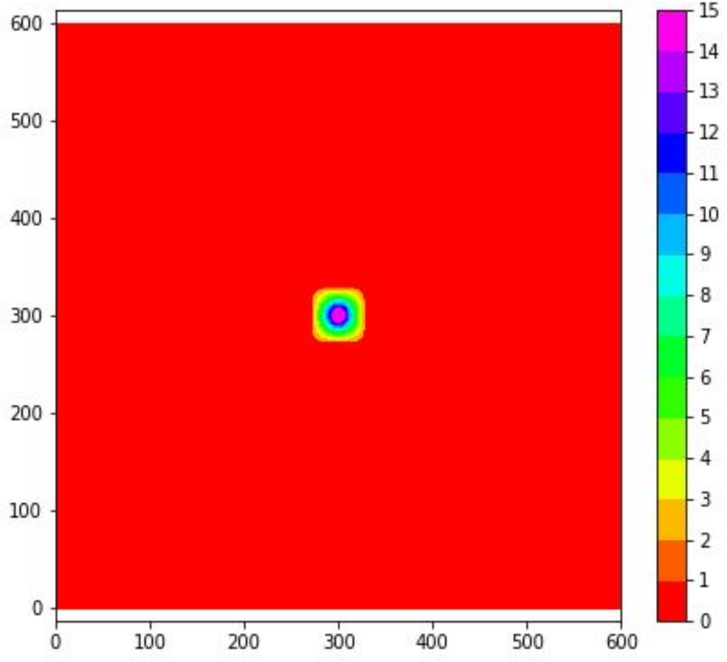
Each Distance Unit Represents 10 Meters

Example - CQI Impact of a Single Node at a distance of 800 Meters (9 O'Clock)

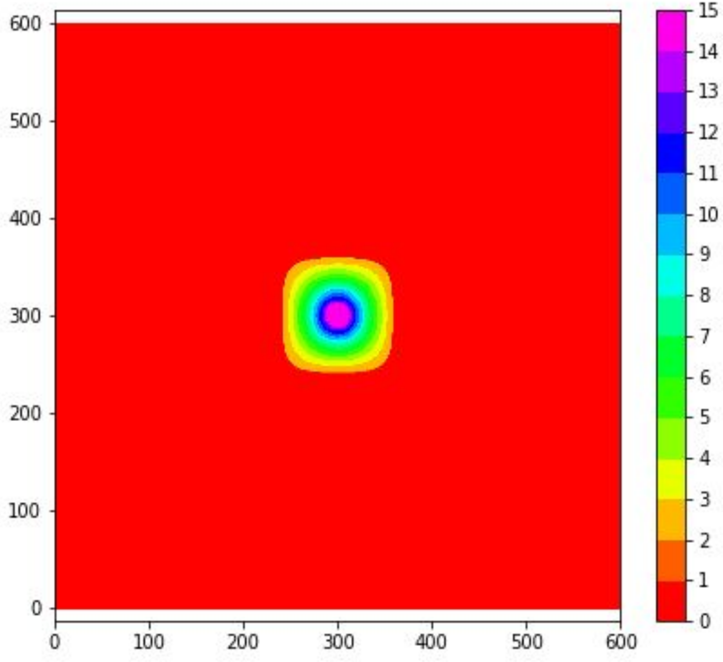


Each Distance Unit Represents 10 Meters

Example - CQI of Node With Four Interferers (3, 6, 9 & 12 O'Clock)



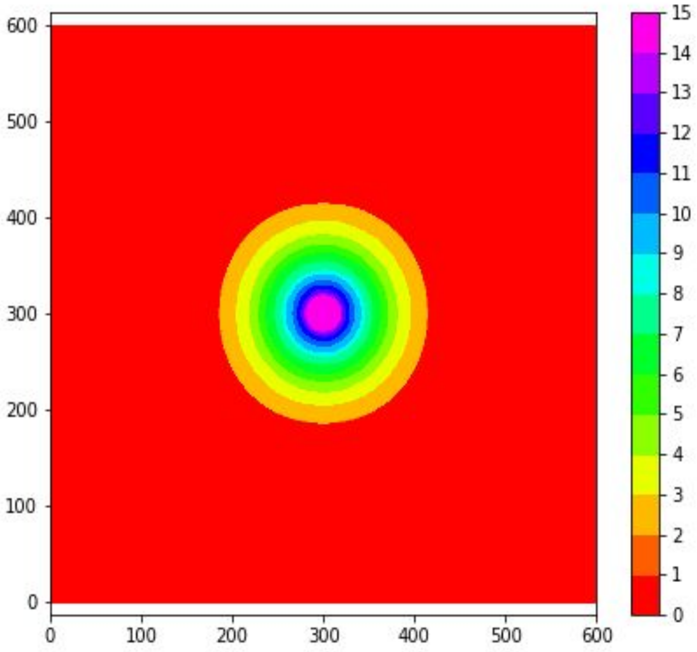
250 Meters



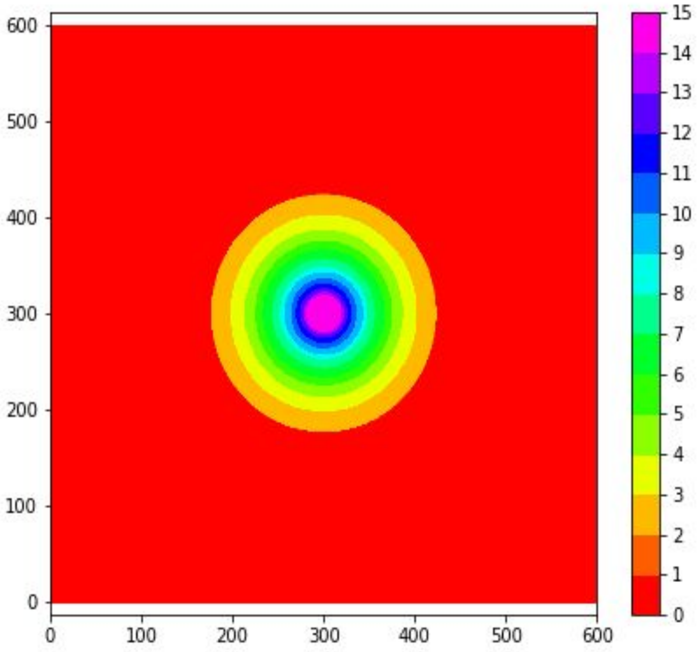
550 Meters

Each Distance Unit Represents 5 Meters

Example - CQI of Node With Four Interferers -- Same Locations



1250 Meters



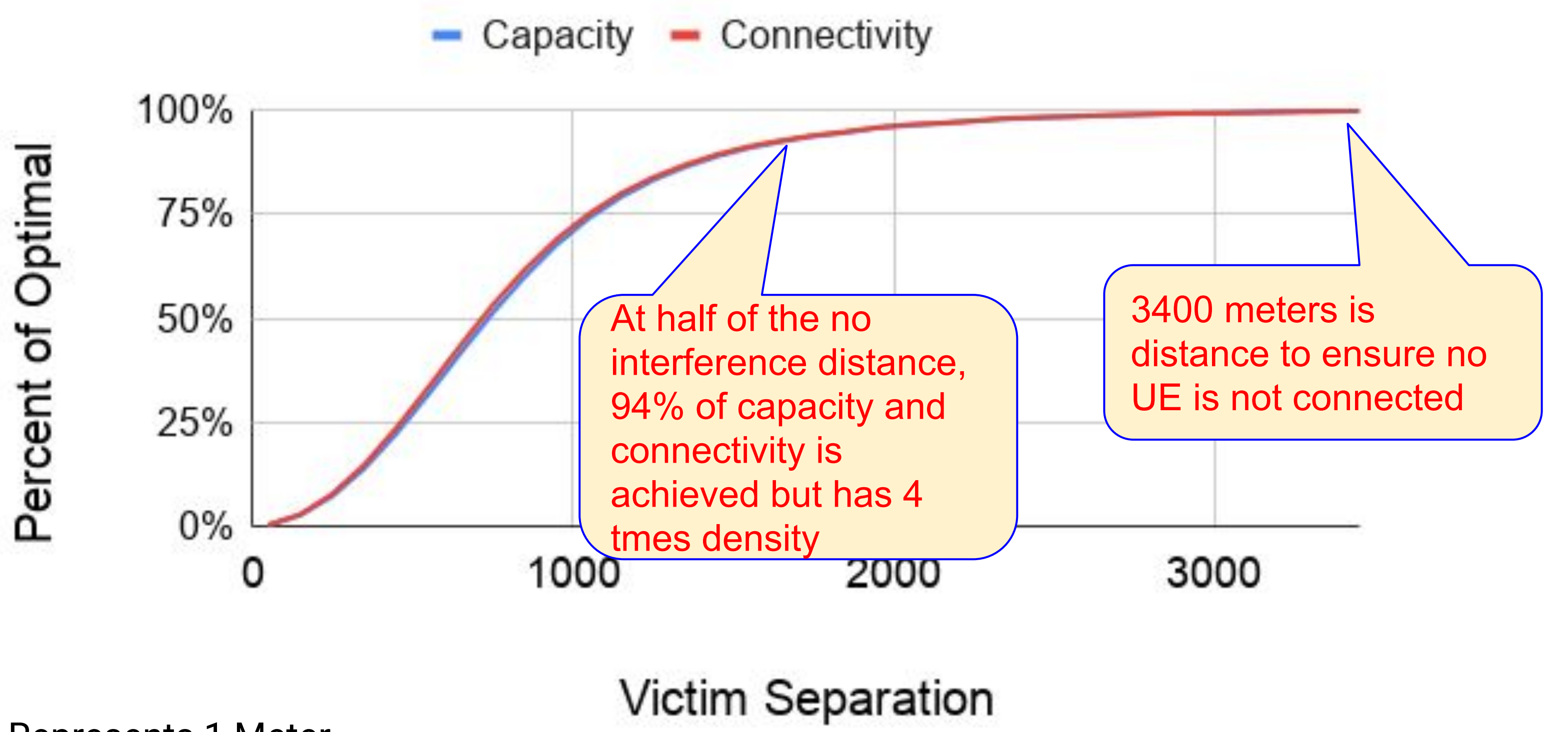
3050 Meters

Each Distance Unit Represents 5 Meters

Specific Modeling Analytics - Performance

- Connectivity
  - Considers the number of locations (viable) that have “reasonable service” (CQI>5)
  - Connectivity Index = Number Locations viable under Interference/ Number viable under no Interference
- Capacity
  - Capacity is the sum of the bits/hertz of All Nodes with “reasonable service”
  - Capacity Index is the ratio of the capacity with Interference/ capacity with no Interference

Capacity and Connectivity as a Function of Separation Distance



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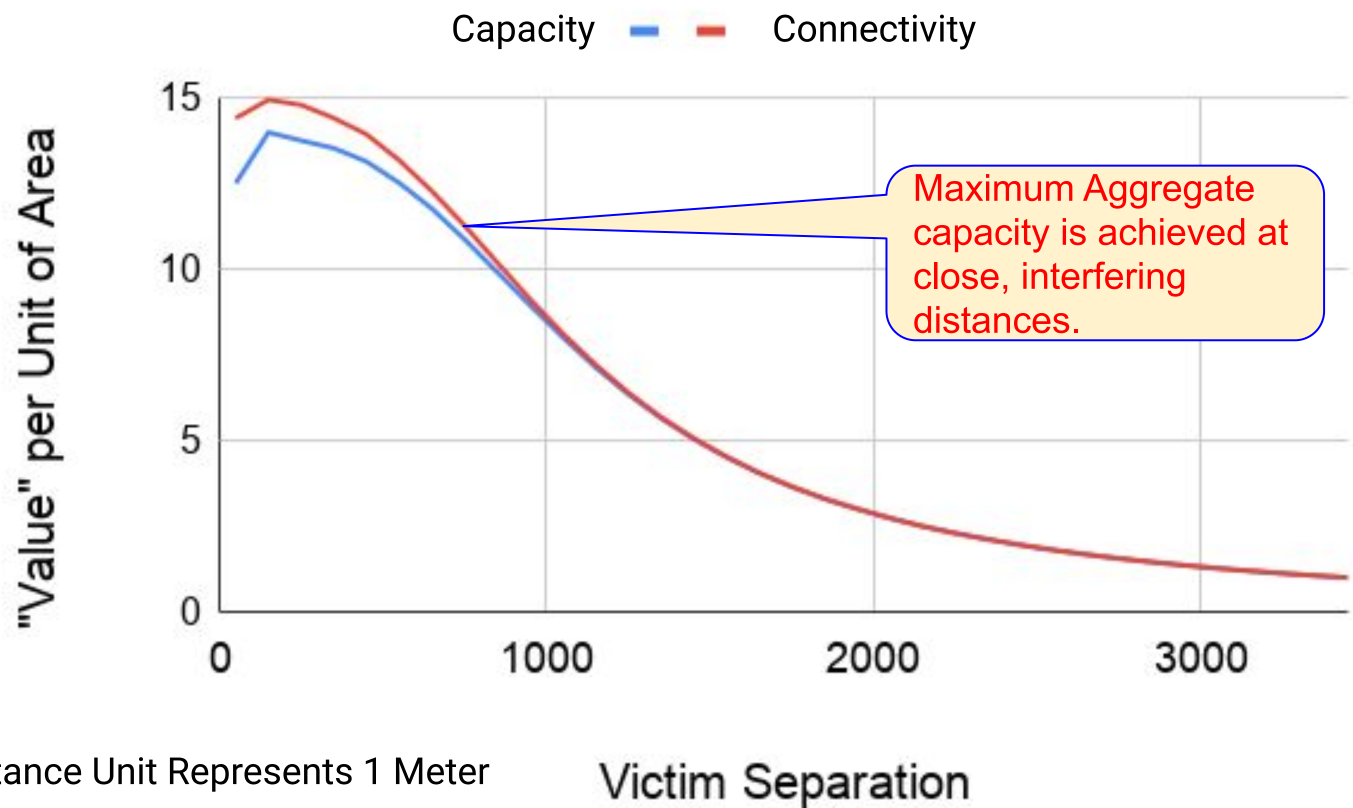
Each Distance Unit Represents 1 Meter

Specific Modeling Analytics - Aggregate Capacity

- Aggregate capacity is the sum of the achieved bandwidth times the density that can be achieved for the corresponding separation distance
- Normalized by the no-interference spacing and capacity value
- “Optimal” results need to be tempered by business realism and practicality

Aggregate Capacity as a Function of Node Separation

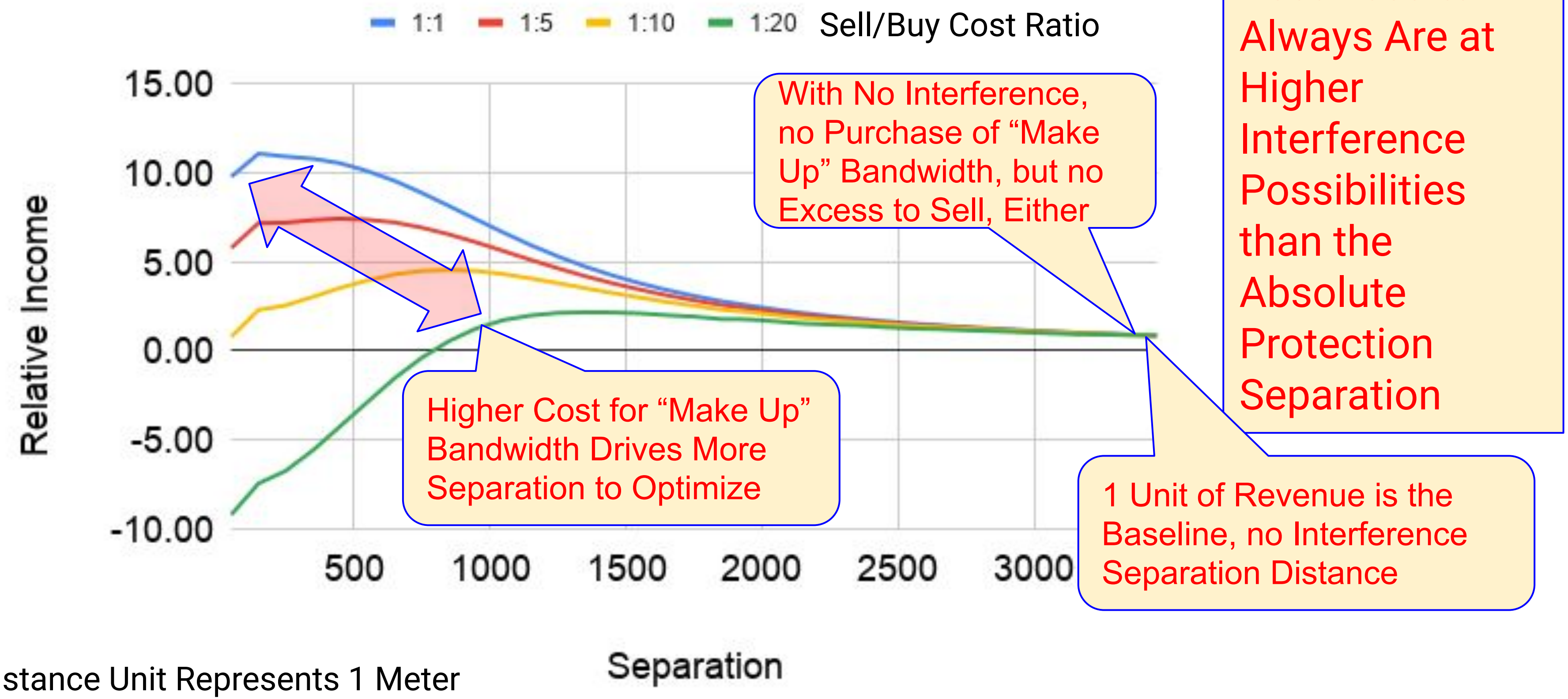


Each Distance Unit Represents 1 Meter

Specific Modeling Analytics -Revenue

- Model
  - A business with commitment to deliver one unit of bandwidth over a service area, It can supply this, or can purchase at some multiple of it's own revenue.
  - Excess bandwidth can be sold for the same income it makes on its committed service
  - Net Revenue is normalized against the no interference distance revenue (network capacity, with no purchased bandwidth)
- Impact
  - At large separation distance, little purchase is needed, but little excess is sold
    At short separation distances, excess bandwidth is sold, but a lot must also be purchased
- Cost is the purchase of "make up" capacity for each AP, which is some multiple of the revenue per unit of capacity. This cost could also reflect less tangible considerations, such as user feedback, reputation, , ...

Net Revenue as a Function of Sell/Buy Spread and Separation



Each Distance Unit Represents 1 Meter

Technical Conclusions

- There are fundamental differences between capacity offload networks and traditional highly reliable networks
- A focus on I/N is not relevant to short range, dense networks in clutter environments, were S/(I+N) is more instructive
- Need to examine impact across the coverage range, not just the worst case point within coverage.
- The “necessary” Interference avoidance point for a maximally reliable network is very different than the “optimal” point for an offload network with recourse to a reliable network

Policy Conclusions

- There is no “right” answer to the coex criteria
- It is driven by individual business cases/missions/recourse to other networks and customer expectations, not engineering
- Imposing a common criterion is tantamount to imposing a business model
- Interference can be addressed by other means than separation: Other bands, other providers, closer spacing (raise “S”), shared infrastructure, ...
- Clear that any single criterion’s impact will be highly asymmetric:
  - What is “beneficial” to one application is harmful/destructive to another
  - It is not really “co” beneficial.