Theoretical bi-directional direct microwave radio link budget connecting 2A Hillside Crescent to the Auckland Sky Tower

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High Level Approach

We establish two locations, the Auckland Sky Tower ($\boldsymbol{S}$) and 2A Hillside Crescent, Mt Eden ($\boldsymbol{H}$). We consider both pathways by scrutinising the power of the signal received (P_r) by the corresponding receiver by investigating the size of the allowable fade margin relative to thermal noise floor of the receiver, other ambient noise if any and the required signal to noise ratio needed for the desired bit rate. Per perspective, consider the link budget expression built from the following predominate components (reserving notation for a transmitter, t and receiver, r.

- Transmitter Power P_t (note: we're working with Transceivers)
- Transmitter to Antenna feedline loss L_t
- Transmitter Antenna Gain G_t
- Free-Space Path Loss L_{FSPL} (using Friis Formula)
- Receiver Antenna Gain G_r
- Antenna to Receiver feedline loss L_r

$$P_r = (P_t - L_t + G_t) - L_{FSPL} + (G_r - L_r)$$

With the range of components provided, we will take an approach of using a combination of the cheapest components provided and iteratively swapping out different components and re-assessing the link budget. This problem actually represents a tree search problem where each node in the tree represents a configuration of components, neighbours of these nodes representing a new configuration with one component swapped out. The depth of search tree would inherently have favourable properties of being bounded to the number of interchangeable components. This tree complexity would be sufficiently small to accommodate a feasible BFS that exhaustively considers each configuration.

Bulleted Relevant Link Assumptions/Requirements

We can only ever attempt to converge to realistic estimations. One must additionally range through potential reasons of attenuation in exhaustion, e.g., atmospheric conditions, geographic obstructions, forms of interference, multipath, future climate projections and take them into account. Here we begin with a succinct and clean set of assumptions/requirements that built the foundation of these additional considerations.

- Available Bandwidth (both ways): 7.14MHz.
- Link Frequency: 3GHz.

  Hence $\lambda \approx 0.1m$ ($\lambda = \frac{c}{f} \approx \frac{3x10^8 m/s}{3x10^9 Hz}$)
- Point-to-point distance: 2.9km, r.

  Hence $L_{FSPL}(dB) \approx 111$dB ($10\log_{10}(\frac{(4\pi r)^2}{\lambda^2}) = 10\log_{10}(\frac{(4\pi 2900)^2}{0.1^2})$)
- Desired data rate: 50Mbit/s.
- Minimum fade margin: 6dB.
- Maximum operating temperature matching hottest temperature recorded in Auckland[1]: 34.0 ℃.

  Thermal noise of the receivers at both $\boldsymbol{H}$ and $\boldsymbol{S}$ is $\approx -105dBm$

  $$= 10\log_{10}(\frac{P_n}{1mW})$$

  P_n (Johnson–Nyquist noise formula)

  $k =$ Boltzmann's constant, $T = 273.15 + 34, B = 7.14 \times 10^6 Hz$
- Ambient noise at $\boldsymbol{H}$: thermal noise floor.
- Ambient noise at $\boldsymbol{S}$: 20dB above thermal noise floor.
- Ignoring geographic obstructions between $\boldsymbol{H}$ and $\boldsymbol{S}$.

[1] As per NIWA's climate publication

Minimum required SNR

Using the Shannon-Hartley theorem[2]. Given $C = 50Mbit/s$ and $B = 7.14MHz$:

$$
\begin{aligned}
SNR &= 2^{C/B} - 1 \\
&= 2^{\frac{50\times10^6}{7.14\times10^6}} - 1 \\
&\approx 2^7 - 1 \\
&= 127 \\
SNR_{dB} &= 10\log_{10}(127) \\
SNR_{dB} &\approx 21\text{dB}
\end{aligned}
$$

Organised list of Components

Below we normalise the components provided to a clearer table. E.g; converting transmitter power wattage (P_t) to more useful dBm unit (via $10\log_{10}(P_t/1\text{mW})$) and evaluating associated loss feedline proportionally considering lengths.

Component	Option	Specification	Cost	Notes
Transceiver	Model 1	20dBm	600	-
	Model 2	33dBm	750	-
Antenna (***S***)	Yagi	7 dBi	120	No feedline needed
	Small Dish	12 dBd	150	No feedline needed
	Big Dish	20 dBi	250	Requires feedline
Feedline (***S***)	-	1.2dB loss	50	Required for Big Dish
Antenna (***H***)	Yagi	7 dBi	120	No feedline needed
	Small Dish	12 dBd	150	No feedline needed
	Big Dish	20 dBi	250	Requires feedline
Feedline (***H***)	-	0.6 dB loss	40	Required only for Big Dish

To be fair, we could clean this table up even more by coupling the ”Big Dish” with the associated required Feedlines and standardising antenna gains by moving dBd units to dBi. But this is more than sufficient to continue.

[2] $C = B\log_2(1 + SNR)$, C, capacity, B, bandwidth, SNR, signal-to-noise ratio.

Examining the cheapest configuration

As mentioned earlier, we'd ideally do these configuration comparisons programmatically, would provide opportunity to build a generalised link system builder. But we simply don't have time to go ahead with this approach. We shall instead just iterate through modifications of our cheapest network configuration by interchanging parts leaning on the fact there aren't too many components needed to grok.

$\boldsymbol{H} \to \boldsymbol{S}$

- Model 1 Transmitter (20dBm)
- No transmitter to antenna feedline (0 loss)
- Yagi Transmitting Antenna (7dBi gain)
- Yagi Receiving Antenna (7dBi gain)
- No antenna to receiver feedline (0 loss)

Component	Gain/Loss	Signal Level at this Stage
Transmitter output power	N/A	+20dBm
Transmitter feedline loss	0dB	+20dBm
Transmitting antenna gain	+7dBi	+27dBm
Path loss	-111dB	-84dBm
Receiving antenna gain	+7dBi	-77dBm
Receiving feedline loss	0dB	-77dBm
Minimum SNR required:	-21dB	-98dBm
Noise floor (+20dB for $\boldsymbol{S}$)	N/A	-85dBm
Fade Margin	up to -13dB	

Pretty far under our 6dB threshold hence we need to improve our configuration. In particular we need to somehow improve our link budget by at least 19 dB to maintain target fade margin. Note the similarity between this link budget and the converse. It'd be exactly the same except we'd remove 20dB from the budget due 20dB less additional ambient noise at $\boldsymbol{H}$.

Minimum Required Improvement

Notice how there is no single component change (coupling the "Big Dish" with the required feedline) that on it's own can introduce 19dB into the link budget relative to the part it is replacing. We break down our options and associate "upgrade costs" to surface minimum best options.

- 150: we can introduce 13dBm on the transmitter.
- Replace transmitting "Yagi Antenna" for one of;

  30: "Small Dish", note the dBd, hence adds 7.15dBi

  180: "Big Dish" and feedline, adds 11.8dBi
- Replace receiving "Yagi Antenna" for one of;

  30: "Small Dish", note the dBd, hence adds 7.15dBi

  170: "Big Dish" and feedline, adds 12.4dBi

There are two equivalent options, with associated improvement costs of 180 relative to previous componentry. That is swapping one of the transmitting/receiving antennas with the "Small Dish" and bumping our transmitter to "Model 2" for $\boldsymbol{S}$. Notice how the antenna swapping would add gain to both $\boldsymbol{H} \rightarrow \boldsymbol{S}$ and $\boldsymbol{H} \leftarrow \boldsymbol{S}$.

- Model 2 Transmitter (33dBm)
- No transmitter to antenna feedline (0 loss)
- "Small Dish" Transmitting Antenna (14.15dBi gain)
- Yagi Receiving Antenna (7dBi gain)
- No antenna to receiver feedline (0 loss)

Component	Gain/Loss	Signal Level at this Stage
Transmitter output power	N/A	+33dBm
Transmitter feedline loss	0dB	+33dBm
Transmitting antenna gain	+14.15dBi	+47.15dBm
Path loss	-111dB	-63.85dBm
Receiving antenna gain	+7dBi	-56.85dBm
Receiving feedline loss	0dB	-56.85dBm
Minimum SNR required:	-21dB	-77.85dBm
Noise floor (+20dB for $\boldsymbol{S}$)	N/A	-85dBm
Fade Margin	up to -13dB	