# Modelling signal propagation for village radio networks

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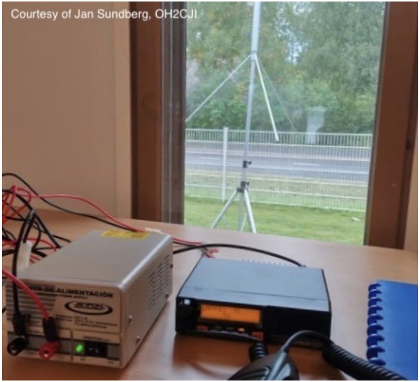
# What and why?

*Village radio networks* are a Finnish grassroot-level solution for wireless communication when mobile networks and the internet are unavailable.


At the moment, there is much village radio activity, e.g., in Lappland and Eastern Finland. The activity is spreading quickly.

# How?

These networks operate on the license free Finnish RHA68 VHF band near $70\mathrm{MHz}$ (wavelength $\approx 4\mathrm{m}$) using FM transmissions for speech.




Both hand-held radiophones (TX power $\leq 5\mathrm{W}$) and tabletop base stations (TX power $\approx 25\mathrm{W}$ as in picture) are used.

# Radio and antenna equipment

The network simulations are based on transceivers and antennas with the following characteristics:

- TX power $5\mathrm{W}$, i.e., 37 $\mathrm{dBm}$ to 50 $\Omega$ load.
- RX sensitivity $1\mu\mathrm{V}$, i.e., $-107\,\mathrm{dBm}$ from 50 $\Omega$ source at 20 $\mathrm{dB}$ SINAD.
- Total feedline losses 4 $\mathrm{dB}$.
- Vertically polarised, centre-fed half-wave dipoles with perfect matching at both ends, with total gain 3.2 $\mathrm{dBi}$.

Primary mode of propagation is *line-of-sight* with a secondary *ground wave* contribution. Reflections from structures, the sky wave, or more exotic forms of propagation are entirely neglected.

# Modelling approach and goal

The goal is to choose realistic locations for stations and connection intervals without too much footwork or poor investment.

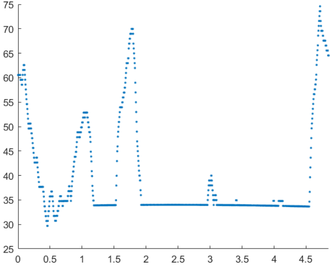
- Terrain elevation data only between the nodes (e.g., villages).
- Soil conductivity and vegetation types unavailable.
- Modelling tolerances include variations in weather and seasons.
- Optimised minimal network connections for the backbone network...
- ...to minimise cost for, e.g., antenna structures.

The model must be computationally light which excludes the direct EM approach.

Hence, geometric "ray optical" approach is taken with terrain elevation constraints, augmented with crude loss modelling.

# Terrain elevation data

The pilot terrain elevation data for Lohja region is obtained from the public sources of National Land Survey of Finland. Each contact interval is divided into 1000 subintervals of equal length.[1]

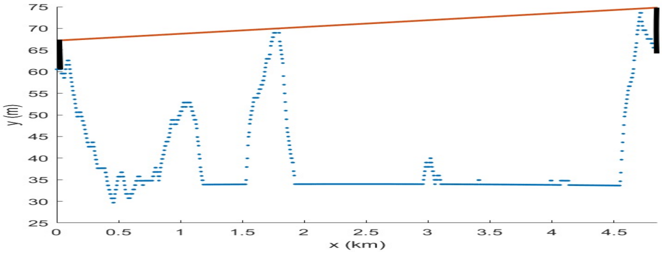




Different terrain and vegetation types not taken into account.

[1] Elevation data acquisition carried out by Ari Hiltunen, OH2CUC.

# Mast model

The mast model defines the penalisation factor called *mast number* $\mu$ which is large for connections that would not succeed without expensive mast structures.

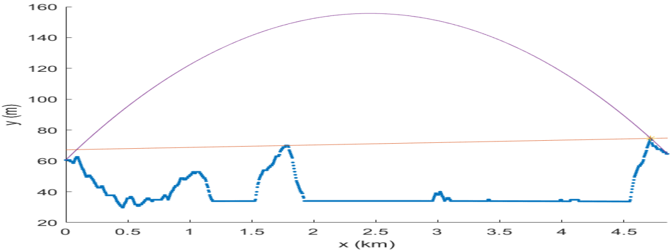



Mast number is the minimum total height of masts required for a line-of-sight connection between the endpoints.

Attainability and cost of the line-of-sight connection.

# Curvature model

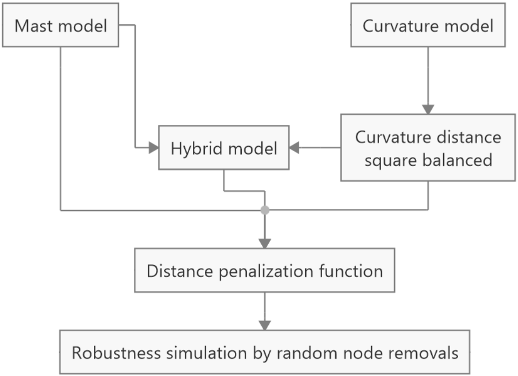
The curvature model defines the penalisation factor called *curvature number* $\kappa$ which is large for connections that would require a lot of bending of the wavefront.




The curvature number $\kappa$ is the angle of the circular arc per length $L$, where $L$ is the distance of endpoints.
Since roughly $\mu \sim \kappa L^2$, there has to be balancing of $\mu$ and $\kappa$ by the factor $L^\alpha$, $\alpha \approx 2$, to get comparable penalisations.

Attainability of a ground wave -type connection.

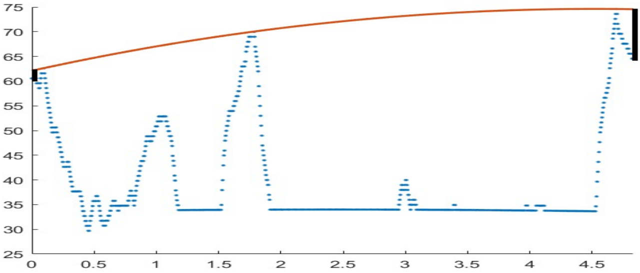
# Hybrid model (1)




A rule of thumb: In typical flat terrain, 80% of the connection distance is "explained" by the line-of-sight to the horizon and 20% by the ground wave at about 70 MHz.

# Hybrid model (2)

The hybrid model computes a *bent wavefront propagation path* above the terrain obstacles by a combination of mast height and curvature.




The balancing and scaling between mast height and curvature can be done in great many ways.

The hybrid model defines the pair $(\mu, \kappa)$ for the connection interval, depending on the way how balancing is carried out.

# Modelling of transmission losses

The starting point is the *free space path loss* formula

$$\mathrm{FSPL(dB)} = 20\log\left(d \cdot \frac{1}{\mathrm{m}}\right) + 20\log\left(f \cdot \mathrm{s}\right) + 20\log\left(\frac{4\pi}{c} \cdot \frac{\mathrm{m}}{\mathrm{s}}\right).$$

For $20\,\mathrm{km}$ connection at $70\,\mathrm{MHz}$ we have $\mathrm{FSPL(dB)} \approx 95\,\mathrm{dB}$. Without additional transmission losses, this would give $68\,\mathrm{dB}$ SINAD at the receiver which is an unreasonably high value.

However, there are significant other losses such as

- line-of-sight through forest and other vegetation, and
- losses due to weather conditions.

We use the value of $2.4\,\mathrm{dB/km}$ as the *rate of exponential loss* in the medium, corresponding to the maximum distance of $20\,\mathrm{km}$ of a reliable radio contact through vegetation and air.

# Hybrid model with distance penalisation

The lossy hybrid model is a combination of $(\mu, \kappa)$ and distance penalisation accounting for propagation losses, following the provisional design principles:

1. The mast number $\mu$ gives the baseline for penalisation.
2. The baseline penalisation is adjusted by $\kappa$ so that, e.g., $\approx$ 20% – 50% lowered $\mu$ produces a propagation path by sufficient wavefront bending (or dispersion).
3. The additional loss penalisation is scaled so that connection distances over 20 $\mathrm{km}$ are strongly disfavoured.

Of course, all this is very inaccurate, mathematically non-rigorous, non-uniquely defined, heuristic, *ad hoc*, and what have you. But so is setting up radio networks in hilly forests anyway.

In this kind of "penalisation modelling" no one cares that your kettles are dirty if the soup is good.

# Network optimisation (1)

Let us denote by

$$\xi_j, \quad j = 1, 2, \ldots \frac{n(n-1)}{2}$$

the penalisation factor produced by the lossy hybrid model for all connection intervals in a network where $n$ is the number of node points, i.e., villages.

Using $\xi_j$'s as weights for a Minimum Spanning Tree (MST) algorithm (such as Kruskal's algorithm), a connected backbone network can be computed using only the highest quality connection intervals with lowest penalisation factors $\xi_j$.

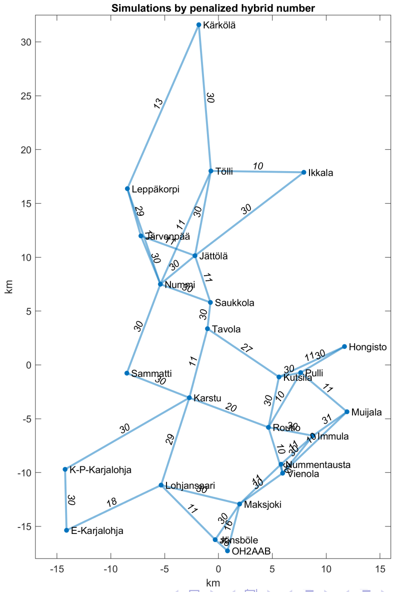
However, using MST directly as a radio network design would lead to some overly long relayed connections, which is particularly inconvenient in radio networks based on speech.

# Network optimisation (2)

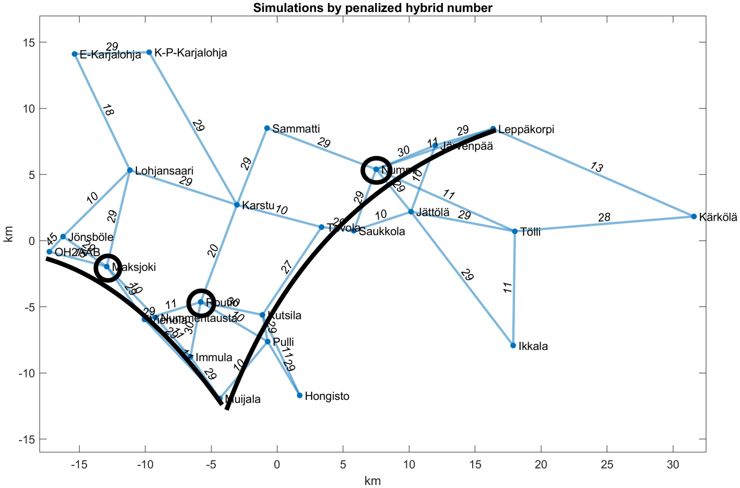
For robustness, the MST can be computed for 10000 subsets of nodes where 30 % of the nodes have been randomly excluded.

If a connection interval is part of relatively many such MST's on subsets, then it should be favoured in the radio network design.

This data comprises 25 village centra in Lohja area, Southern Finland.



# Network optimisation (3)




The proposed backbone radio network for Lohja area. Particularly important terrain corridors and the central points at Maksjoki, Routio and Nummi are shown by thick black line.

That's all, folks. Questions?