Comparison of methods for estimating distance of nearest transmitter in a cellular radio network

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Introduction

Distributed optimisation of 4G communication systems.

- Collaborative project between BT and the University of Bath.
- Current 3G technology, familiar from mobile phones, is being replaced by LTE (4G) technology.
- Aim to explore the potential performance of such systems
- Algorithms and procedures need to work at local level within large network.
- Self-optimising network behaviour.

The model

- Transmitters, transmit a signal on a power P, distributed according to a Poisson point process.
- Receivers, pair to a transmitter, receive signal S from paired transmitter, signal from unpaired transmitters will count as interference I.
- Aim to maximise the signal to interference ratio, $\frac{S}{I+N}$.
- Signal S received at distance R from a transmitter is $S = \frac{PZ}{R^{\gamma}}$
- Z $=$ propagation effects such as fading.
- P $=$ power transmitted on.
- $\gamma =$ path-loss exponent, we have used $\gamma = 4$.

Why estimate distance?

- With the new technology, transmitters will be placed in unknown locations
- How to maximise $\frac{S}{I+N}$?
- Want to maximise coverage and minimise overlap
- Need to determine what power setting to choose to best do this
- Want to determine distance to nearest transmitter

Methods

- Method 1: proposed in Sian Webster's MSc Thesis, Distributed heuristic for optimising femtocell performance, University of Bath, 2015.
  - It attributes total signal received at the origin S_T to the nearest neighbour transmitter, $S_T \approx R_1^{-4}$ therefore $R_1 \approx S_T^{-1/4}$.
- Method 2: Improves on Method 1.
  - Estimate the error of Method 1 for a given value of S and adjust accordingly. Find that $R_1 \approx S_T^{-1/4} + 0.9 S_T^{-3/4}$.
- Conditional distribution of distance to nearest transmitter.
  - Makes distinction between signal contribution from transmitters within a chosen radius of the origin and those from outside.

Results

- Find that Method 1 gives a good approximation, particularly for large signal.
- Method 2 makes a significant improvement on Method 1, remains simple and quick to calculate.
- Method 3, the conditional distribution gives most accurate approximation to nearest neighbour.
    - However, due to limitations, such as working well with fading and computation time, it is not as practical as Method 2.
- Conclude that for future work Method 2 will be used, most likely in conjunction with another technique.
    - Will come back to this later in the talk.

Simulation

An overview of the techniques used for simulation.

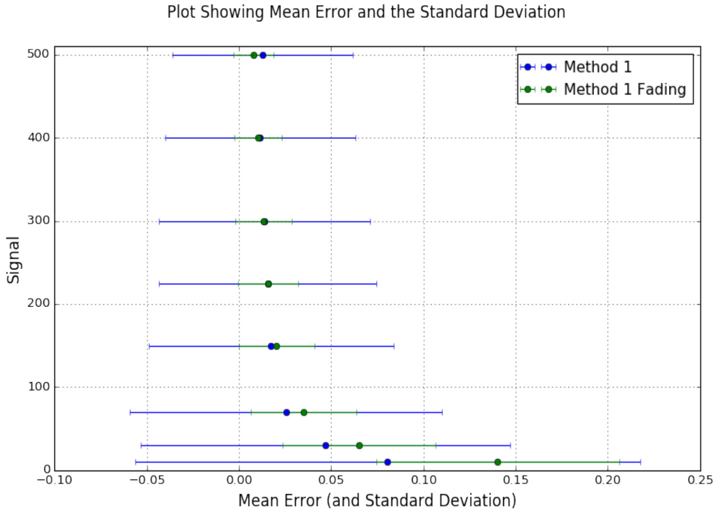
- Transmitters distributed according to a Poisson point process.
- As distance, not location, was important we used the faster method of generating exponentially distributed random variables. Then found the cumulative sum of these before taking the square root. This gave transmitter distances with the correct distribution.
- For a chosen signal value, we stored a simulation result within 0.98 or 1.02 of this value. Took at least 60,000 samples for each signal value.
- Used 100 transmitters for each sample. Experimented with using larger numbers but it was slower and did not impact results.
- From each sample stored total signal received at origin, distance to nearest transmitter, signal from nearest transmitter.

Method 1: Simple estimate

- Transmitters are on a uniform power $P = 1$ and there are no other propagation effects.
- Due to the path-loss, this method will be most true for large signal values.
- The estimation gives a lower bound of the distance to the nearest transmitter.
- Found the mean error and standard deviation of this method for different signal values.
- Recorded total signal at the origin S_T and distance to nearest transmitter R_1
- Error of estimation given by, Error $= R_1 - S_T$.
- Found this method works well also when the propagation effect of fading is applied.

Method 1: Fading

The below graph shows that Method 1 continues to work well in the case of Nakagami-1 fading, also known as Rayleigh fading.



Method 2: An improvement on Method 1

- Aim to improve the accuracy of Method 1.
- Estimate error of Method 1 for a given signal.
- Antal Jarai paper 'Conditional Distribution' finds an approximation of the error for an infinite number of transmitters as $S \to \infty$.
- Theorem 2 of this paper finds:

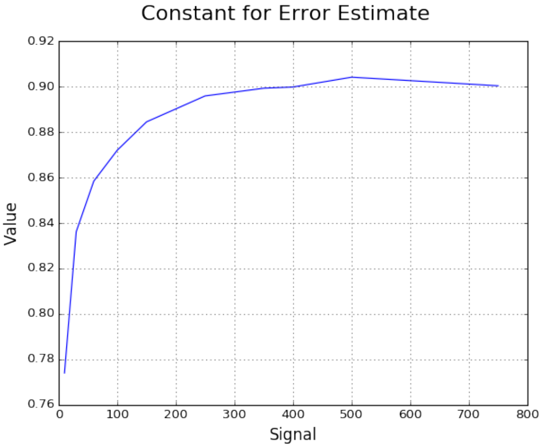
$$R_1 = S^{-1/4} + \frac{1}{4} S^{-5/4} S'(1 + o(1)) \text{ in probability as } S \to \infty$$

- For finite signal S it is found that the mean of S' is of order $S^{1/2}$ and therefore the error can be approximated by $cS^{-3/4}$ where c is a constant.
- The graph on the following slide shows the approximated constant. We found it to be approximated by 0.9
- Currently working on finding an expression to determine the constant.

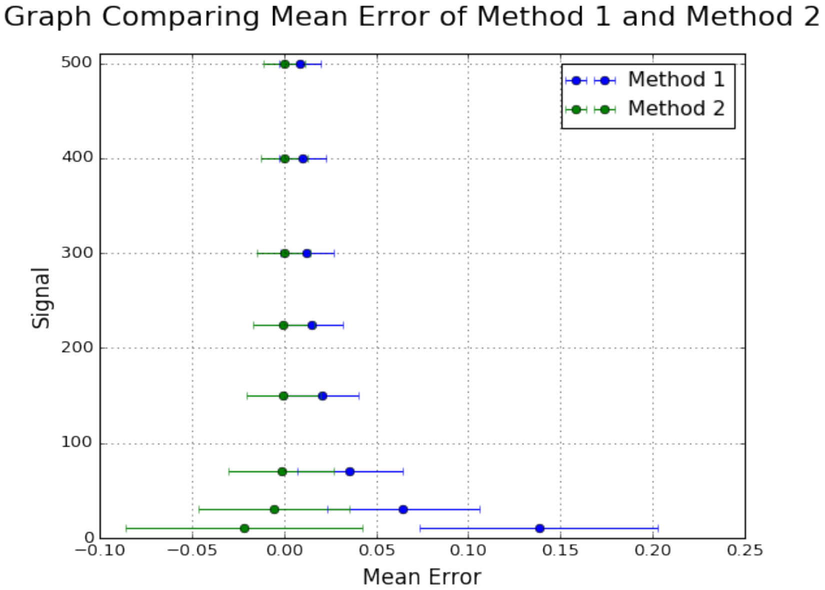
Graph finding constant

To find the constant c,

$$c = (R_1 - S^{-1/4}) \times S^{3/4}$$



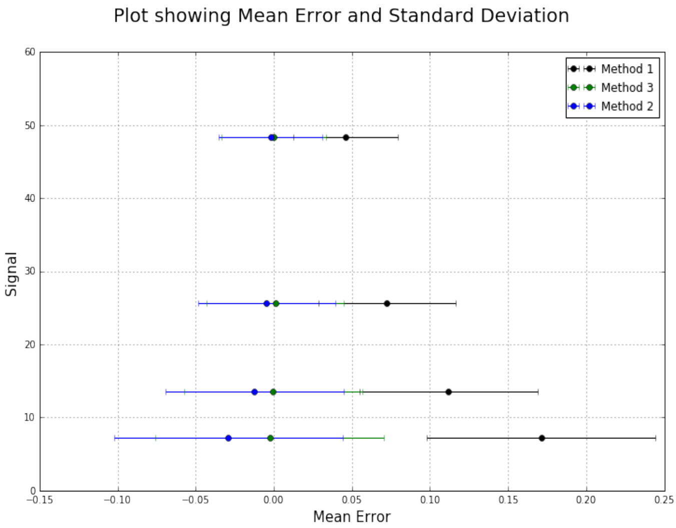
Graph comparing Method 1 and Method 2



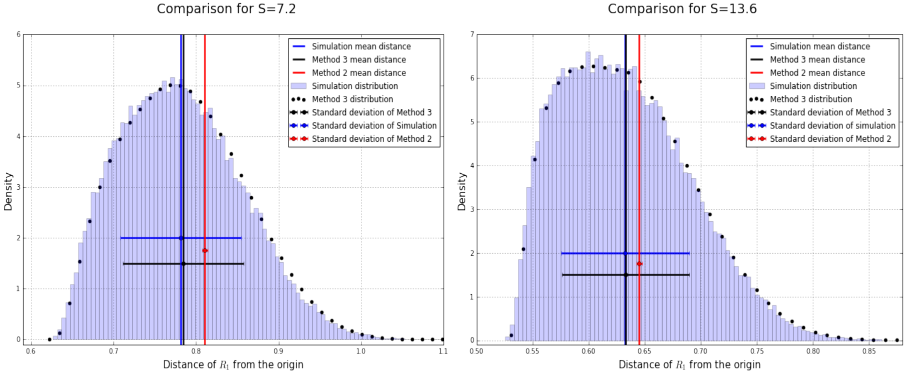
Method 3: Conditional Distribution

- The third method is a conditional distribution of the distance to the nearest transmitter. Antal Jarai is currently producing a paper on this.
- This method makes a distinction between transmitters within a given radius of the origin and those outside of it. It approximates the signal contribution from transmitters outside of this radius by a Gaussian distribution.
- This method proved to work very accurately.
- The following graphs compare the methods

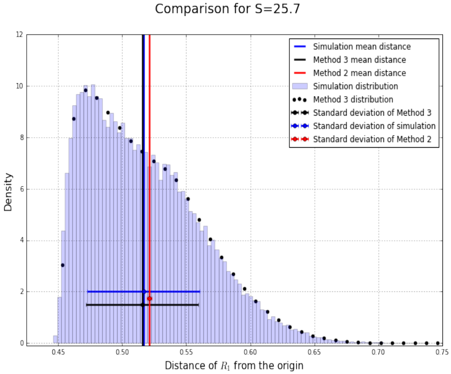
Comparison of Three Methods

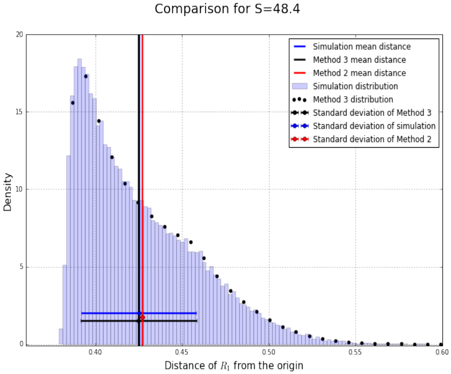


Comparing Method 2 and Method 3



Comapring Method 2 and Method 3





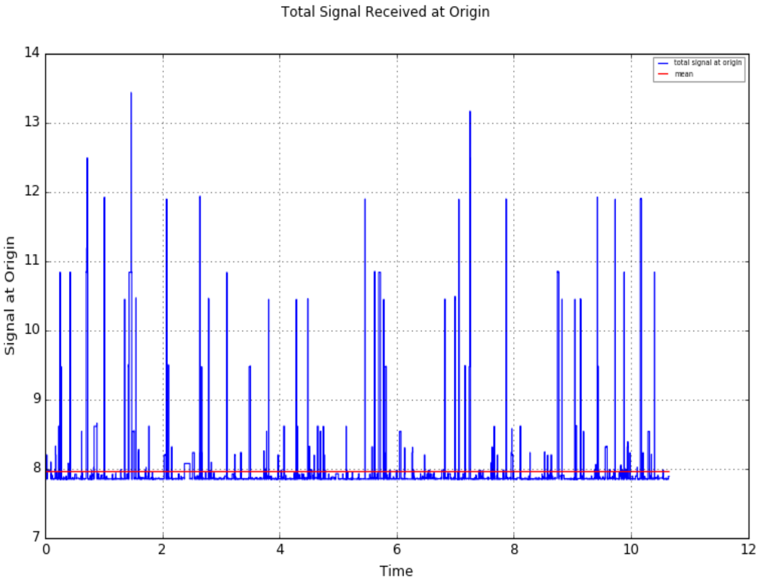
Summary

- Despite the improved accuracy of the conditional distribution, Method 2 is what will be used going forwards.
- For a real-world scenario where there are many other factors that affect signal recorded it will be accurate enough.
- Another benefit is it's simplicity
- This method of estimating distance to nearest neighbour will be used in future work.

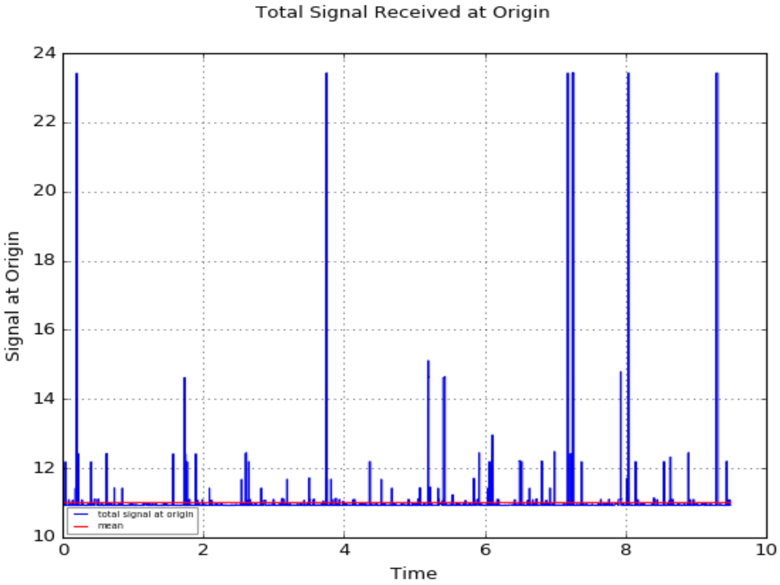
Further Work

- Find an expression for the constant in Method 2.
- Adapt for when transmitters are not on a uniform power, multi-level methods.
- Power Pulse Method. This is when a transmitter will increase its power to a maximum level for a short period of time before returning to previous power.
- Aim to use Method 2 in conjunction with Power Pulse Method to estimate distance in a multi-level scenario.
- Two graphs showing the Power Pulse Method.

Power Pulse Illustration



Power Pulse Illustration



Thank you