Predictive resource allocation based on real channel measurements

Understand the wireless channel variations and implement algorithm in MATLAB for predictive resource allocation

Master's thesis in Communication Engineering

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Department of Signals and Systems
CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2016:SSYX04

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Cover: Resource allocation base station antenna

Gothenburg, Sweden 2016

Abstract

Mobile traffic has seen a quite dramatic increase in recent times. Services, especially video streaming has seen a rapid increase and commands a large share of this mobile traffic. This increasing mobile data traffic brings in the problem of providing good quality services like smooth video playback at all times. The wireless channel that a mobile user sees is subject to many degrading effects e.g. path loss, shadowing, and multipath.

These phenomena become more pronounced reaching bad coverage regions such as tunnels. This calls for smarter bandwidth allocations by base stations. A new concept tackling this is predictive resource allocation (PRA). PRA seeks to exploit the location information of the user to understand the channel variations associated with it and provide sufficient bandwidth based on this information so that the end users have a quality experience. The scheme is prediction based and so is robust for all non-real time data that can be cached by the end user.

This thesis investigates PRA by conducting an empirical study of the signal strength variation i.e. the channel radio maps, experienced by a phone. An algorithm based on PRA is developed. The radio map data collected is utilised to evaluate the performance of this PRA algorithm. Conceptually, PRA employs an approach that makes efficient use of the airtime while increasing the throughput rates. This means it gives better rates at lower power consumption. In order to understand the working of PRA , a video degradation example is taken; basically it tests how much lower video degradation users suffer along with the network wide base station power consumption compared to equal share, a traditional resource allocation scheme. The results obtained are promising for multiple users served, for both video degradation and overall power consumption. This thesis shows that in terms of overall performance PRA performs better than the traditional resource allocation schemes.

Keywords: Predictive Resource Allocation, Channel, Video, throughput, power consumption.

Acknowledgements

I would like express my sincere gratitude to my supervisors, Srikar Muppirisetty and Dr. Henk Wymeersch for their continuous support of my thesis work, their patience, motivation and immense knowledge. I would also like to thank Dr. Mouhamed Abdulla for his valuable insights. I would also like to thank Rikard Reinhagen and Martin Dahlgren who worked with me throughout the thesis to realise the goal we set at the starting of thesis.

Suhail Ahmad, Gothenburg, August 2016

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Introduction

Mobile traffic has grown multiple times over the last few years. Technological advancements in the smart phone development have made mobile devices easy to use and a commodity that is not just restricted to communication. This has led to rapid growth in mobile data traffic growth. In addition, cheaper smartphones and budget data plans have further facilitated this dynamic growth reaching population high regions like India and China. A closer look at statistical figures of mobile data usage, it is evident that engaging activities like video streaming and photo sharing form the bulk of this traffic. This trend is only expected to grow given the rise of video sharing/ video content generating platforms like YouTube, HBO, Netflix and many more. Web platforms such as these have been able to gain much traction with the high speeds provided by latest network enhancements. As a result such services have grown in popularity and usage at a staggering rate. The Cisco Visual Networking index 2016 and Ericsson Mobility Report 2016 clearly show the rising popularity of video among mobile users.[1][2]

In order to serve such data heavy applications, video in particular, requires much bandwidth and a robust network to provide seamless video playback at all times. This presents to us a novel problem, providing the best quality of service to a mobile user watching a video on the go. Currently, as many of us may have noticed that while watching a video on mobile from one of these video sharing web platforms, say YouTube, we see much variation in its video quality and at many a times even have the video stalled. This is due to the fact that in the present scenario a mobile user experiences the QoS based on the coverage of the location the user traverses, if the location has good coverage the video playback is at the best quality but if he/she were to move to a bad coverage area the video playback experienced is of inferior quality. QoS is also dependent on the number of users being served by the base station at that instance. Again, if the number of users served is large, the bandwidth allocated to a user is much lower than when there are less users as expected this will result in a degraded video experience. This presents an immense scope of improvement. This is also what forms the problem statement of this thesis.

The majority of the works in research tackling this problem is being done on network layer and on video compression fronts to give users best quality video experience. The existing works on utilisation of channel information is very limited. Thus to further the research in this realm an objective is set to understand the variations of signal strength that a mobile user experiences and formulate a solution that overcomes this typical QoS problem.

The thesis involves extensive measurement campaigns, set for different scenarios to understand the signal strength variations in different physical settings. These measurements will also help establish a correlation between the scenarios, if any. The final set up is an algorithm to work like a prediction based resource allocator (PRA).

The thesis report starts with a review of the concepts, studies and research work conducted on similar approaches. This is followed by the methodology adopted to carry out the work and the resulting PRA algorithm. This section is followed by a results section, here results from the measurement campaigns of the different scenarios are presented. This section also includes results from algorithm implementation culminating with an overall discussion. The final section provides a conclusion derived from the thesis and a discussion on possible future work in the area.

2

Theory

The study area of this thesis is new in its own right and has recently become part of much active research. The emphasis being 5G research for optimised implementation for cellular network. Wireless networks that are not only optimised in their networks but also optimised in the way they utilise the available spectrum.

As mentioned above, the research topic PRA is new however, other works with similar approaches but that realise other objectives have been done. So along with the limited theory available the other similar works are also mentioned in this section. The thesis paper on which much of the solution is derived from is discussed in detail.

Before delving into the literature that concerns the thesis work, a short emphasis is made on the concepts that this study involves. Channel capacity and path loss being the main concepts of interest. According to Shannon-Hartley theorem, the upper bound of the channel capacity is subject to the bandwidth available and the signal to noise ratio of the link in question.[3] This can be mathematically expressed as

$$C = B \log_2 (1 + \frac{S}{N})$$

where,

- C is the channel capacity (bits per second/bps);
- B is the bandwidth of the channel (hertz/Hz);
- **S/N** is the signal-to-noise ratio (**SNR**)
- **S** is the average received signal power for the bandwidth (watt/W);
- **N** is the average power of the Gaussian noise over the bandwidth (watt/W),
- **SNR** is measured in decibels/dB.

Path loss is defined as the degradation in power that a signal experiences as it propagates through an environment. It is important to note that this path loss thus differs for different environment it traverses. There are multiple reasons why a signal may experience such a degradation, the major reasons are listed here:

- **Free Space path loss**: This type of loss occurs when the signal moves through a space void of any obstructions where attenuation due to obstructing objects is negligible. However, as the signal traverses through this space the conversation of energy comes into play, as the area covered increases, the signal energy decreases.

- **Absorption**: As the signal passes through space it is prone to absorption, a rainy environment is a good example as rain attenuates the signal to a large extent. Different materials thus have different range of absorption, for example a window can have an absorption rate of 3dB. [6]

- **Multipath**: This is the most pronounced phenomena. The signals get reflected in a different way and thus reach the receiver observing´different paths as seen in Figure 2.1 and so signals add/subtract depending on the phase of the signal received. Any movement on the party of the receiver results in receiver seeing entirely different phases of the signals.

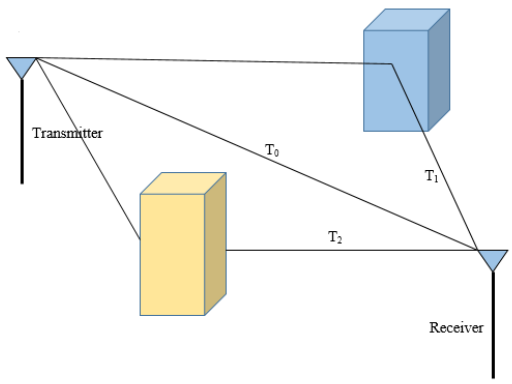


Figure 2.1: Multiple paths to the receiver

- **Losses due to Diffraction**: When an object with high density and rounded shape obstructs a signal diffraction takes place. Losses are high in this case compared to the case when the object has sharp edges.

The power utilised by smartphones is heavily dependent on how much path loss the received signal suffers. This basically affects the parameters mainly dealing with handovers in cellular communications. In LTE, it affects received signal strength indicator (RSSI), reference signal received power (RSRP), reference signal received quality (Reference Signal Received Quality). These parameters are important for the base station (BS) to determine its handover priorities.[4]

RSSI provides all information regarding the total received power which includes thermal noise and all interferences. It can be computed as $RSSI = widebandpower = N + I + SC$, where N is the noise, I is the interference power, and SC is the serving cell power. It is interesting to note that this parameter is not reported to e-NodeB by the UE. e-NodeB refers to base state stations in long term evolution (LTE).[4] RSRP on the other hand is the linear mean of the power contributions of the resource elements (REs), in a specific bandwidth, that carry cell-specific reference signals. A RE is defined as one 15 kHz subcarrier by one symbol. RSRQ is the ratio between RSRP and the RSSI and as such depends on the power of the serving cell.[4]

Another aspect that makes this research area all the more interesting is the involvement of user movement or more specifically the predictability of it. According to [7] there is a 93% predictability in user movement. This study was carried out for 3-month-long record, collecting the patterns of mobility for 50,000 individual. This is quite an astonishing discovery as this implies that movements of most individuals is very finitely localised. The paper also suggests that the majority of the population can be predicted based on this but for the few and the very few that cover large distances the predictability decreases. Having said that the predictability was not found to be lower than 80% for any given user. This makes case for predictive resource allocation even stronger. Now that the user movements become so predictable, it is easy to understand the channel variations of those frequented areas through the minimum drive test alternative. This will help help make the spectrum allocation in a more efficient manner both from the operator perspective and QoS perspective to the end user.

Majority of the physical work involves gathering real data of the channel that will be used as input to algorithms developed to assess the applicability of predictive resource allocation in commercial ventures. The idea of going around collecting data through multiple campaigns is technically known as minimum drive test (MDT). The aim of such a test is to network performance after implementation so that it can be optimised if the arises need. This entails collecting measurement, location and other relevant data by going around in a car/vehicle. The collected data is then analysed by offline tools. All the parameters that are affected are analysed and tweaked to get the optimum functioning. This drive test is carried out again to confirm that all the changes made have had the desired effect.
It must be noted that this is done throughout the day at different timings so that all constraints are given their due considerations to get a better picture of all the parameters. However, such a venture comes with costs, which increases as the area of deployment increases. For this purposes the 3GPP has included involving the UEs to reduce the operator costs for network optimisation. It has been shown that using UEs makes it feasible for the operators to gather more information and along with information available at the radio access network (RAN) BSs, this can help operators develop an exceedingly optimised coverage solution. To that effect 3GPP made features that overcome the need of MDT, part of its release 10 standardisation. The salient points pertaining to MDT are listed here:

- Automatic UE measurements collection and data logging used to replace the manual drive testing that the operators have to perform in their networks.

- Evaluation of network performance per physical location For both HSPA and

LTE.

The data collection for this thesis is a combination of MDT and the steps laid down by 3GPP. In order to collect data an MDT approach was taken using a smartphone. This smartphone does data logging on its own memory, which is then transferred to MATLAB for further processing.

An overview of some of the related or similar works done on predictive resource allocation. Efficient video delivery is the need that drives this development and the papers discussed henceforth take streamline video playback as the benchmark for all their studies.

It is seen that in [8] the experiments involve stored radio maps where they make use of these maps to give the predicted transmission rates. A similar approach is seen in [9] where a user prebuffers low quality segments before entering a bad coverage area. These solutions take into account the transmission rates and none of them work towards resource allocations based on the maps.

The above studies mention the need for best QoS video delivery, a look at the studies on power consumption are also presented here to understand the efficiency in power usage that can be derived. The paper [10] talks about predictive resource allocation between the BS power consumption and the network streaming quality.

The paper [11] presents a look ahead resource allocation (LRA) that improves rate predictions for enhanced and efficient delivery of stored videos. A multi-objective linear program (LP) provides the benchmark solution. It captures the trade off between network wide base station power consumption and minimising total video degradation. The LRA Algorithm is a heuristic approach to implement the benchmark. Another approach is also shown, which is called the distributed scenario, where each BS performs its own look ahead resource allocation. The results from the study show that PRA has 40% lower degradation as compared to the worst performing traditional resource allocation scheme, equal share. The BS power consumption at the base station was also lower before getting capped off. A clear advantage of LRA algorithm as compared to its traditional counterparts. This thesis work is heavily inspired from this approach, much of the implementation is modified to mimic this approach. The equations utilised for the MATLAB implementation of the algorithm have also been used from this paper. The measurement campaign data is utilised to further understand PRA and its viability as a scheme in real world scenario.

3

Methodology

This section describes the complete methodology of the thesis. The section starts by explaining about the equipments utilised. This is followed by the choice of scenarios, the routes undertaken to collect the signal strength logs, and an explanation of how the data was collected. Finally, the algorithm implementation is discussed and explained in detail.

3.1 Equipment

The first section deals with the procurement of the apparatus for the measurement campaigns. The study is an empirical study of signal strengths tied with the locations they correspond. Therefore, an extensive search was made to find the right apparatus that best fits the requirements and provides relevant additional information.

The smartphones today provide decent positioning for a mobile user. The smartphones have downloadable apps that that help get the signal strengths. In Android phones, the Google Play Store provides umpty number of apps to do the aforementioned task. Alternatives to the smart phone were also looked at mainly in the form of software defined radios (SDR). The idea to employ SDR unit for the measurements was derived from the seminar held in October of 2015. The seminar informed about the use of NooElec USB dongle. NooElec is connected to a Laptop computer. This can then be used to analyse spectrum of choice. The seminar informed on how the dongle may be utilised to capture relevant bandwidth to analyse LTE communications. The features that made this an interesting choice were:

- USB dongle
- Compatibility with MATLAB
- Providing real time analsyis of the spectrum, RSSI variations
- Affordability

However, this came with drawbacks:

- Limitation of the bands that it analysed
- Requires laptop everywhere as the USB needs to be plugged in all the time

Figure 3.1: GNET Track Pro app from Google Play Store was used

(a) Google Nexus 5X

(b) App parameters

Figure 3.2: Nexus 5X and an in-app page

The clumsy nature of using Laptop to take data logs meant that using a smartphone was the only viable option. So a smartphone, Google Nexus 5P as seen in Figure 3.2a was ordered. The Google Play Store has many apps that give the signal strength along with additional cell related information. On making a thorough search for the right app that had a ll the satisfactory features was selected. That being the GNET Track Pro by Gyokov solutions. The Figure 3.2b shows some of the logged parameters.

The app stored RSRP, RSRQ, LTERSSI (long term evolution RSSI) along with the GPS based location, the Cell ID, the serving base station and a colour coded map to show the variation of signal strength while traversing any given route. This made the app an excellent choice to do the readings. This can be seen in the screen shot of the log page taken from the phone during one of the measurement campaigns in Figure 3.3.

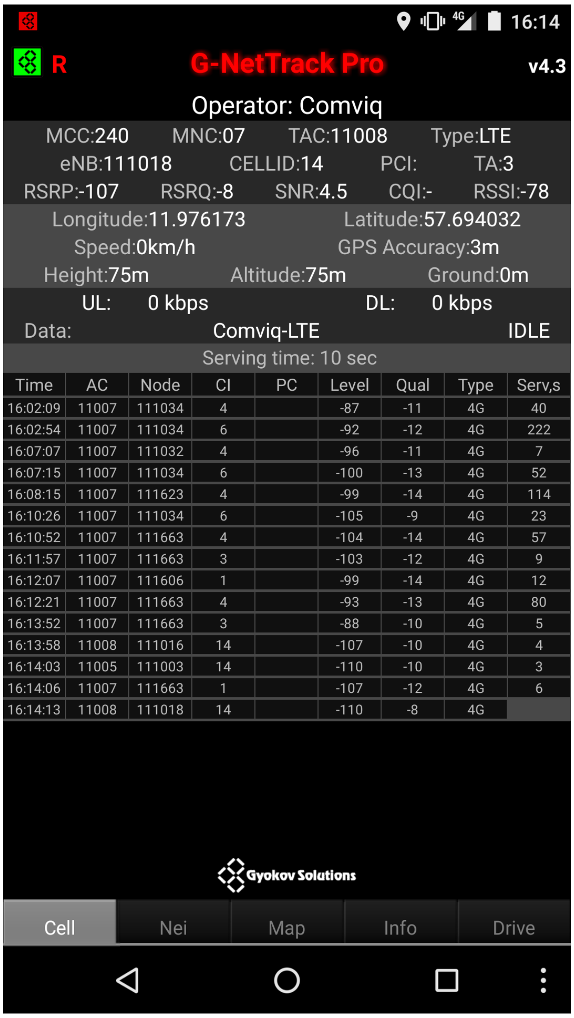


Figure 3.3: In-app logging screen shot

3.2 The Route

The three different scenarios were taken into consideration.

- Korsvägen to Wavrinskys Plats
- Gibraltargatan
- Chalmers Johanneberg campus to Chalmers Lindholomen campus

3.2.1 Korsvägen to Wavrinskys Plats

The first and the main scenario is the tunnel scenario. Stretching from Korsvägen to Wavrinskys Plats. This route was chosen mainly because of the tunnel to understand the channel variations through it. Another reason being that both the tram stops are more or less at similar distance away from their respective tunnel openings. This gives us a good understanding on as to how the channel behaves on the lead up to entering and then leaving the tunnel from both directions. Figure 3.4 shows the complete route.

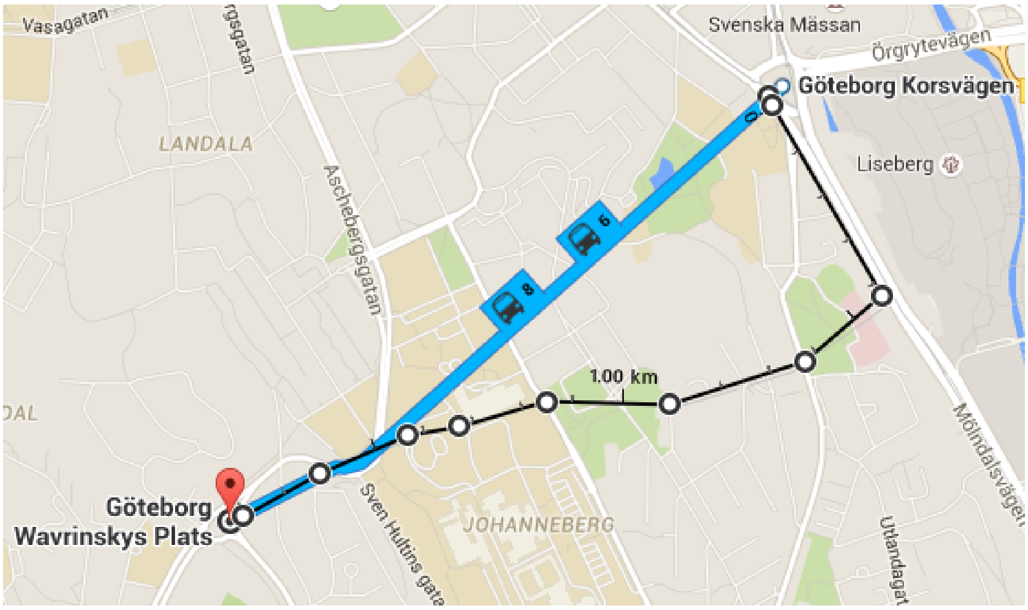


Figure 3.4: Map - Korsvägen to Wavrinskys Plats

3.2.2 Gibraltargatan

The second scenario involved taking the readings while walking along a street of choice. This was done in order to understand the the signal strength variations and their difference from the measurements versus the tunnel scenario. The street chosen was Gibraltargatan, which is the street that runs parallel to Chalmers Johanneberg Campus. This route was chosen because of its straight-ish nature and its proximity to the campus. The walk was close to 1.2 km from bus stop Pilbågsgatan to junction between Läraregatan and Gibraltargatan. The route is marked here in Figure 3.5.

3.2.3 Chalmers Johanneberg campus to Chalmers Lindholomen campus

A third scenario was later added to uderstand the channel variations for the route connecting the two Chalmers Campuses, one in Johanneberg and the other being in Lindholmen. The route starts from Sven Hultins gata at the Johanneberg campus and ends at Teknikgatan at the Lindholomen campus. The return route is much the same but upon reaching close to Chalmers the bus takes Gibraltargatan and does

Figure 3.5: Pilbågsgatan to Läraregatan

not retrace its route completely. The route, both to and from Johanneberg campus, are shown in the Figures 3.6 and 3.7.

3.3 Measurement Campaign Methodology

The following part presents the particulars about the measurement campaign and how it was carried out. An emphasis was made to maintain the same conditions, as much as possible, through out all the campaigns. That is to say a standard orientation like the placement of the phone, position on tram and more particulars were set for a scenario and maintained throughout that scenario.

An empirical collection of data includes data collection at different times of the day. And so for all the cases the measurement campaigns were carried out during various times of the day to get a more ideal averaging of the readings. For each experiment campaign, there were subtle changes in the way readings were taken depending on the feasibility of the scenario and conditions.

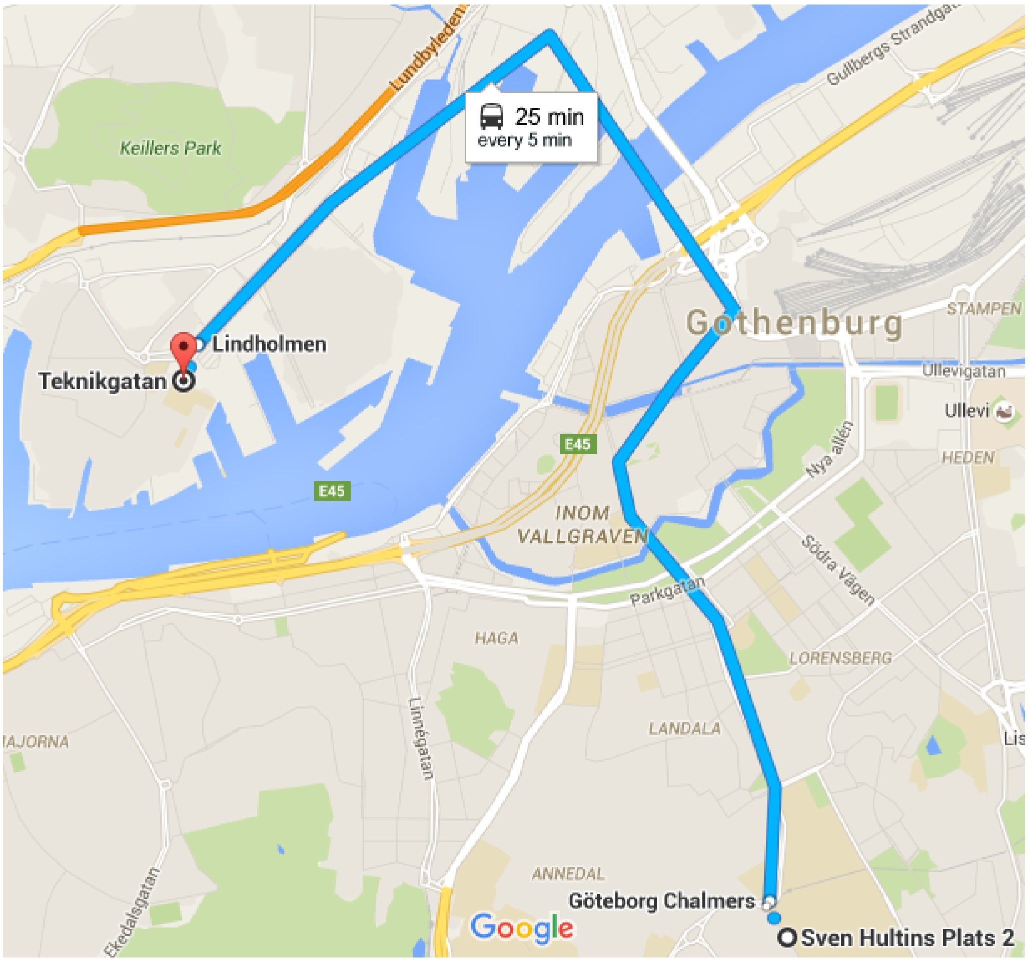


Figure 3.6: Chalmers to Lindholmen

3.3.1 Tram Measurement Campaign

In the case of tram measurement campaigns, the readings were taken standing in the last wagon of the tram with the phone held at a comfortable height. The starting log position were fixed on both the tram stops and the logs were made in a singular trip manner instead of a continuous running for the entire number of trips for a given day. Trams 6 and 8 were used in tandem going to and from the stations for any given measurement campaign. It is noteworthy that a few trips were made using tram 13 when the frequency of trams 6 and 8 dropped.

In the first week the app setting were made such that it took readings every second, with a distance interval of 1 m and GPS refresh time interval of 10 ms. The app logs all the readings in a text file which was extracted from the phone. MATLAB allows for text files to be easily imported into its environment along with all the variable names. The variables were then utilised to help plot the data. In the pilot study period, week long data produced showed some really interesting results with regards to the variations around the tunnel both on the Korsvägen side and Chalmers side.

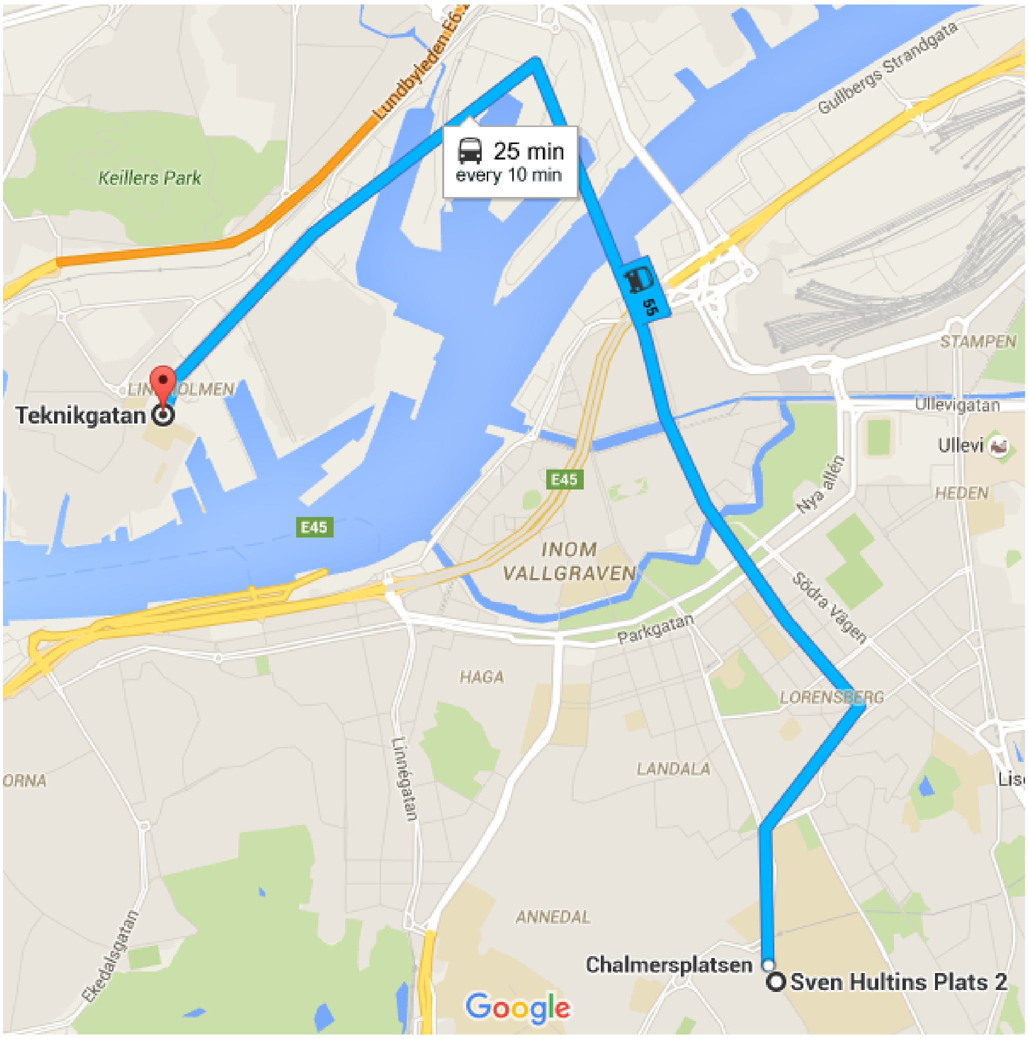


Figure 3.7: Lindholmen to Chalmers

The main interest for this study is the variation inside the tunnels but unfortunately these were not captured in the log. This was due to the fact that the app stopped logging when the GPS accuracy became bad. This was not apparent as in real time whilst using the app, the readings displayed in the app display were changing as the tram traversed the tunnel. In the second iteration, the settings of the app were updated to allow for indoor logging as well. How this works is as the smartphone enters the tunnel and loses its GPS locater accuracy the indoor mode is turned on. Then for the period of time the phone traverses the tunnel, the app continues logging and when the phone re-emerges on the other end and the GPS accuracy is restored to acceptable levels, the app maps the signal strengths to the line joining the two ends of the tunnel in a progressive manner imitating the trams path through the tunnel.

3.3.2 Walk Measurement Campaign

In the walk scenario, it was not feasible to carry the phone in hand the way it was kept in the tram scenario. So a different orientation was adopted. The phone was kept heads up on the right hand front facing pocket of the jacket for all the reading campaigns taken on the walking route. The starting points on both ends of the walking route were fixed and a brisk walking style was adopted with a look to maintain the time taken for each trip.

3.3.3 Bus 55 Measurement Campaign

A partnership with Keolis, the company that employs the drivers for the Electricity buses, was struck. A completely electric bus was chosen for this purpose. This particular bus was chosen as it provided more room to the driver at the front, so keeping the phone there as it logged was ideal. This kept it under constant supervision of the driver and thus be kept without being disturbed for the entire ride. The measurements were taken over a period of two months starting from March to end of April 2016. A MATLAB script was made to visualise all the data collected, to get an understanding of the overall trend by mainly looking at the averaging of these runs.

The results from all these measurement campaign scenarios are presented and discussed in Chapter 4.

3.4 PRA Algorithm

The main purpose behind logging the data is to understand how a location and prediction based resource allocation algorithm would fair compared to a traditional resource allocation scheme. It is clear from the theory that the biggest difference was seen between the equal share scheme and the PRA. So for this thesis equal share was implemented along with the PRA algorithm to give a good comparison benchmark. The data collected was put as input for these algorithms. In Chapter 2 a discussion was made on how PRA method is utilised and the results that have been achieved. In this section a more detailed approach is made.

In the equal share algorithm the bandwidth being served by the Base Station (BS) was equally divided between the users. In the following we detail the methodology behind the PRA algorithm. The idea is to provide excellent streaming by minimising the BS power consumption for the network. In essence this allows for buffering at the user equipment (UE) so that the BS does not have to transmit as the UE consumes this buffer.

A closer look at the mathematics behind this problem and the resulting solution is now given.

A network with BS set K and user set M is considered with any user being denoted by i and and any BS being denoted by B. The video being served is assumed to be always present at the base station. Time slots are divided equally as τ and is denoted by $n \in N$, where the set of considered time slots is N = 1, 2, ...,N. In each slot, the wireless channel is shared between multiple users while keeping the achievable data rate constant for each user. The coherence time τ is set to 1 s, which means that for that duration the channel does not change to be of any significant importance. The achievable data rate is dependant on the path loss model $PL(d) = 128.1 + 37.6 \log_{10}(d)$ where user-BS distance (d) is in km.

Lookahead (prediction) window is known as N, the upcoming time slots. A future link rates matrix is formed which is determined by calculating the expected received power with regards to the future user locations. This is given by

$$r_{i,n} = \tau B \log_2(1 + \frac{P_{rx}}{N_0 B})[bits] \tag{3.1}$$

where P_{rx}, N_0, B are the received power, noise power spectral density and bandwidth of transmission respectively. This is based on Shannon's equation. The rate equation (3.1) will generate a matrix for future link rates which can be shown by $\mathbf{r} = (r_{i,n} : i \in M, n \in N)$. The BS airtime is shared among different users. A resource allocation matrix is thus defined as $\mathbf{x} = (x_{i,n} \in [0,1] : i \in M, n \in N)$ which gives time fraction that a user is assigned bandwidth from a BS in each time slot n. The rate received by each user is then given as an element wise product $x \odot r$. The BS is always required for these allocations as the UE can move along multiple cells for any given N slots.

The BS power consumption is based on linear power model. This is given by the equation

$$p_{k,n} = P_0 + (P_m - P_0)(BS)^{load}_{k,n}, 0 < (BS)^{load}_{k,n} \leq 1 \tag{3.2}$$

Where BS_{load} is computed as $(BS)^{load}_{k,n} = \sum_{i \in U_{k,n}} x_{i,n}$. P_0 is power consumption at minimum non zero load and P_m is power consumption at the maximum load.

Now, a UE requesting a video at time $n = 1$ is considered, at streaming rate A (bps). Thus the minimum video content at each time slot n, required for smooth streaming is calculated to be $\tilde{D}_{i,n} = A\tau n$, where τ represents equal duration time slots.

The cumulative allocation made to the user is given by $\tilde{R}_{i,n} = \sum_{n'=1}^{n} x_{i,n'} r_{i,n'}$. If $\tilde{R}_{i,n} \geq \tilde{D}_{i,n}$ then user will experiece smooth video. This implies that a look-ahead scheme that is aware of the user channel conditions will make majority of its transmissions during good channel conditions and at other not so good channel conditions, it will try to maintain the $\tilde{R}_{i,n} \geq \tilde{D}_{i,n}$ condition. This robustness is non existent in traditional resource allocation schemes where the user is served even when it experiences poor channel conditions. This helps lookahead resource allocation (LRA) scheme more efficient use of the resources available, lowering airtime usage which results in lowering of power consumption.

LRA can be formulated as a linear program, where a BS airtime due to linear load dependent power model (3.2) is minimised,

$$\begin{aligned} \text{minimize} \quad & \sum_{j=1}^{m}\sum_{i=1}^{M} x_{i,n} \\ \text{subject to:} \quad & \text{C1:} \sum_{i\in U_{k,n}} x_{i,n} \le 1, && \forall k \in K, n \in N \\ & \text{C2:} \quad \tilde{D}_{i,n} - \tilde{R}_{i,n} \le 0, && \forall i \in M, n \in N \\ & \text{C3:} \quad 0 \le x_{i,n} \le 1, && \forall i \in M, n \in N \end{aligned} \tag{3.3}$$

constraint C1 ensures that air time of all users working with a BS is less than or equal to 1 at each time slot. Constraint C2 keeps the check for cumulative video content requirement. Constraint C3 provides bounds for the resource allocation factor.

At medium to high loads, satisfying constraint C2 becomes challenging leading to video experience degradation or even video stalling all together. So video degradation is defined as

$$VD_{i,n} = [\tilde{D}_{i,n'} - \sum_{n'=1}^{n} x_{i,n'} r_{i,n'}]^{+} \tag{3.4}$$

this implies that when $\sum_{n'=1}^{n} x_{i,n'} r_{i,n'} > \tilde{D}_{i,n'}$ future content has been buffered, and $VD = 0$ and in the converse scenario, the user experiences degradation meaning that VD is the unfulfilled video demand. Thus average VD can be calculate as $VD_{Net} = \frac{1}{NM} \sum_{n=1}^{N} \sum_{i=1}^{M} VD_{i,n}$.

Thus an optimal pre-buffering resource allocation that minimises both the VD and the BS airtime equation is required which will work with the trade-off between the two. In order to visualise this in a better way weights have been added in the form of ω_{VD} and ω_{Air} for VD and airtime variables respectively. MN are the normalisation factors.

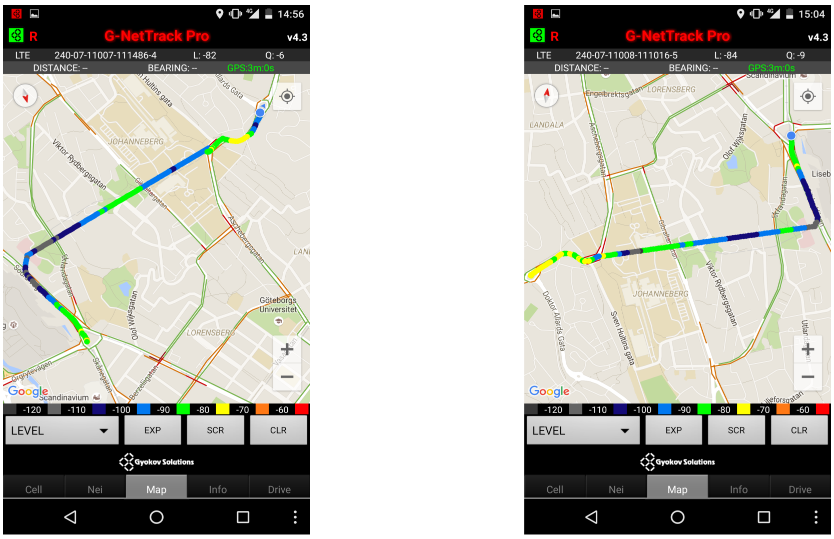
$$\begin{aligned} \text{minimize} \quad & \sum_{j=1}^{m}\sum_{i=1}^{M} \left(\frac{\omega_{VD}}{\tilde{D}} VD_{i,n} + \frac{\omega_{Air}}{MN} x_{i,n}\right) \\ \text{subject to:} \quad & \text{C1:} \sum_{i\in U_{k,n}} x_{i,n} \le 1, && \forall k \in K, n \in N \\ & \text{C2:} \tilde{D}_{i,n} - \tilde{R}_{i,n} \le 0, && \forall i \in M, n \in N \\ & \text{C3:} 0 \le x_{i,n} \le 1, && \forall i \in M, n \in N \end{aligned} \tag{3.5}$$

This linear program was then implemented in MATLAB using the linprog tool. The tool enabled us to minimise the power equation, input the constraints and input the channel characteristics to get the result. This was done both for PRA and equal share to get a good comparison.

4
Results

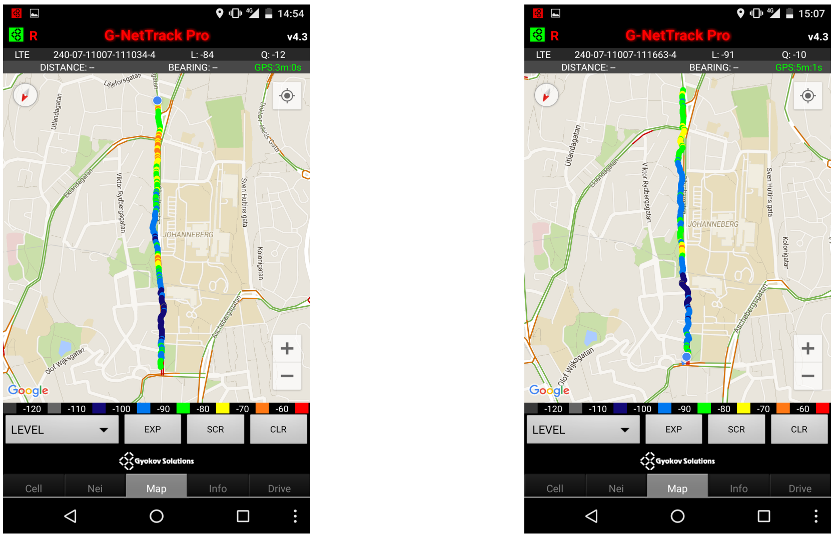
The following section presents the results obtained from all the measurement campaigns. This is followed by a section on the results obtained from the Equal share and PRA algorithm and finally culminates with an overall discussion.

Prior to delving into the measurement results a look at the app and the colour coded logs from the scenario are shown. The lighter colours yellow orange red represent that the signal strength in that area is excellent whereas as darker shades like grey, black represent poor coverage regions. A log each from the trips on tram between Korsvägen and Wavrinskys plats in Figure 4.1b and a log each from the walks between Läraregatan and Pilbågsgatan along Gibralatargatan in Figure 4.2.



(a) Korsvägen to Wavrinskys plats **(b)** Wavrinskys plats to Korsvägen

Figure 4.1: Snapshots of the colour coded logs from the app



(a) Läraregatan to Pilbågsgatan **(b)** Pilbågsgatan to Läraregatan

Figure 4.2: Snapshots of the colour coded logs from the app

4.1 Data Results

In order to understand the variations from the different scenarios, a GUI was made on MATLAB. This GUI gave the figures from all the runs averaged into into one. The GUI also provided for observation of different interesting entities like LTERSSI, RSRP, RSRQ and the SNR. A drop down menu also enabled the user to choose his/her desired resolution. The results for tram and walk scenarios presented here show the GUI in action.

The first set of results are from the measurement campaign done on the tram. A total of 33 runs from Korvagen to Wavrinkys plats and 31 runs the other way were performed. Following was the average trend found for the tunnel scenario:

4.1.1 Tram Results

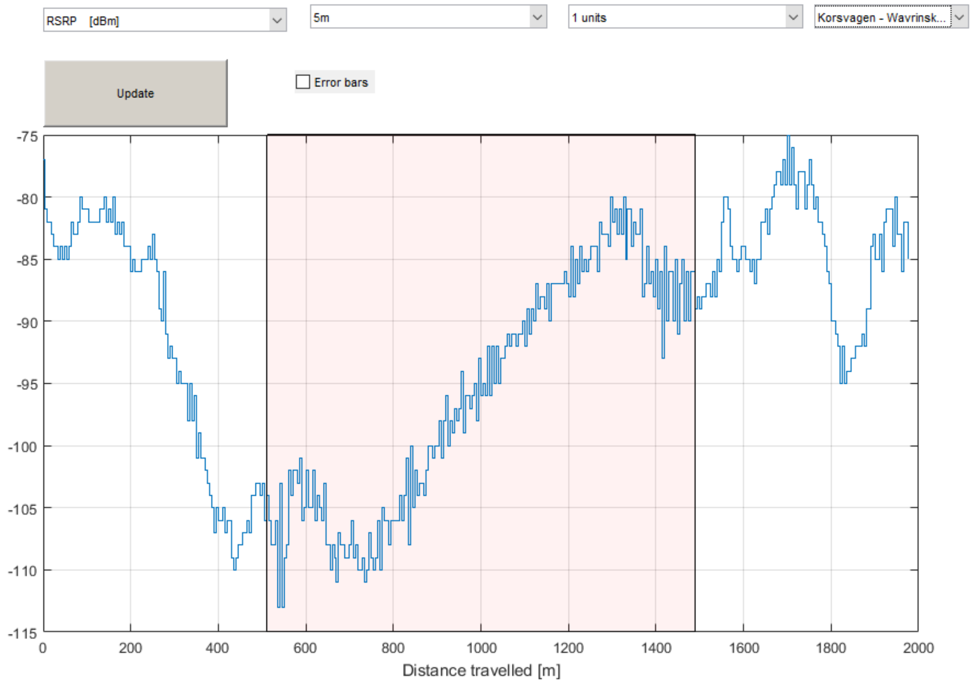


Figure 4.3: Korsvägen to Wavrinskys plats

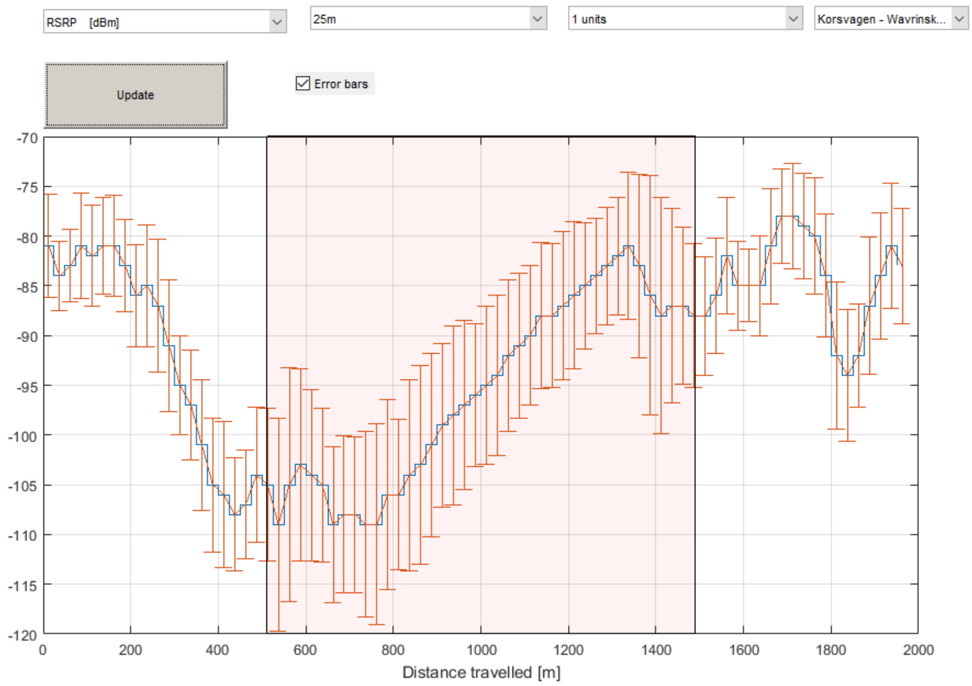


Figure 4.4: Low resolution with error bars plot visualising the data from Korsvägen to Wavrinskys plats

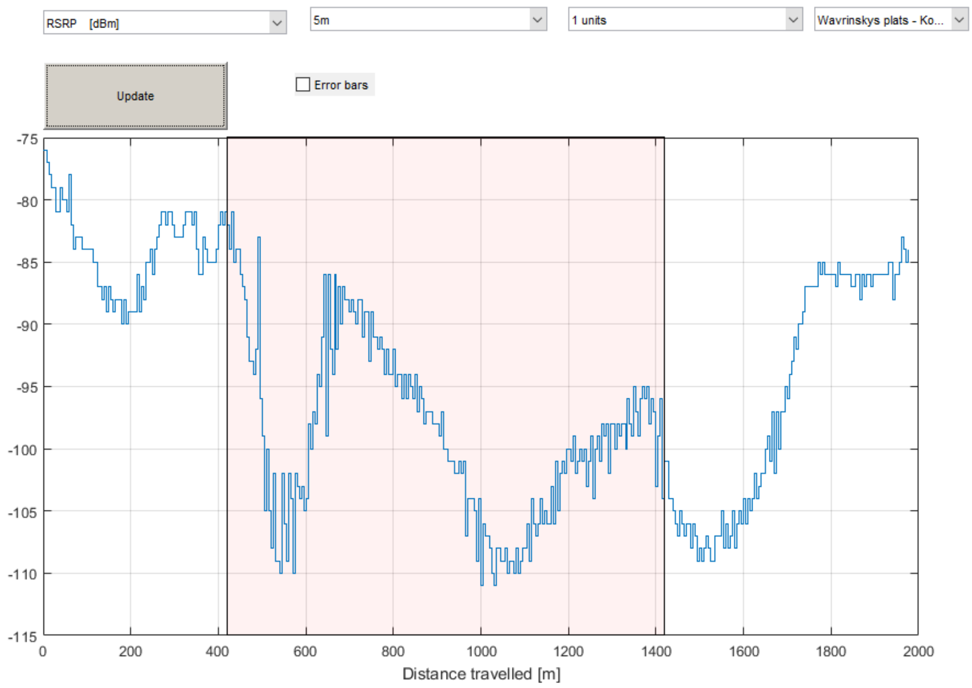


Figure 4.5: Wavrinskys plats to Korsvägen

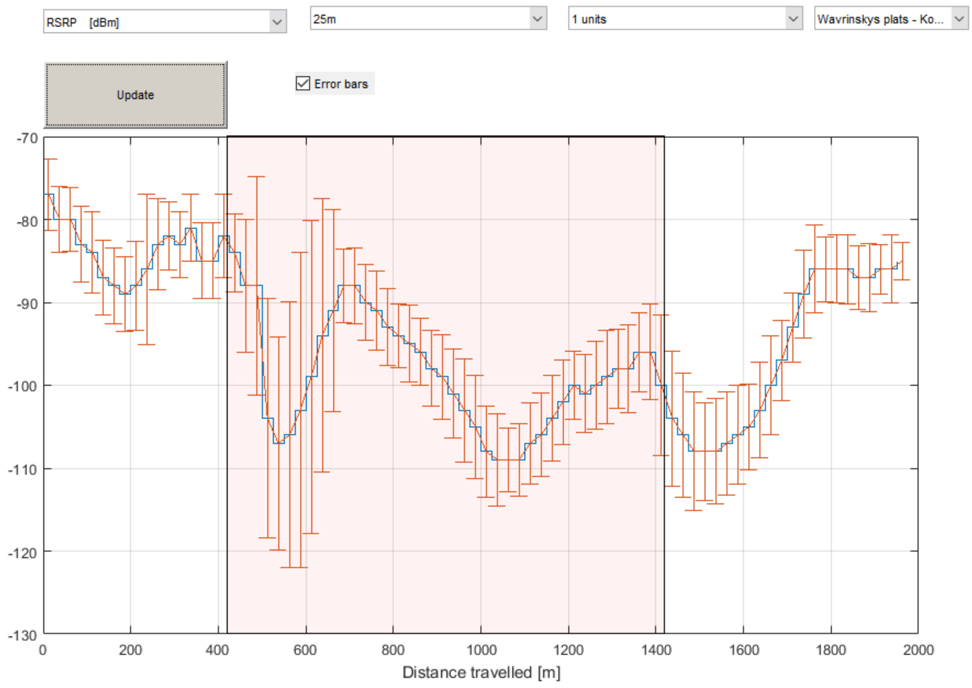


Figure 4.6: Low resolution with error bars plot visualising the data from Wavrinskys plats to Korsvägen

The results here show the variations seen for both the tunnels and the tunnel regions are marked. It can be seen that there is significant drop in the signal strength as the tram enters the tunnel for both the trips but becomes better after a while which is attributed to the base station/repeater present in the tunnel.

4.1.2 Walk Results

The second set of results are from the walking scenario. A total of 12 trips from Pilbågsgatan to Läraregatan and another 12 vice versa were performed.

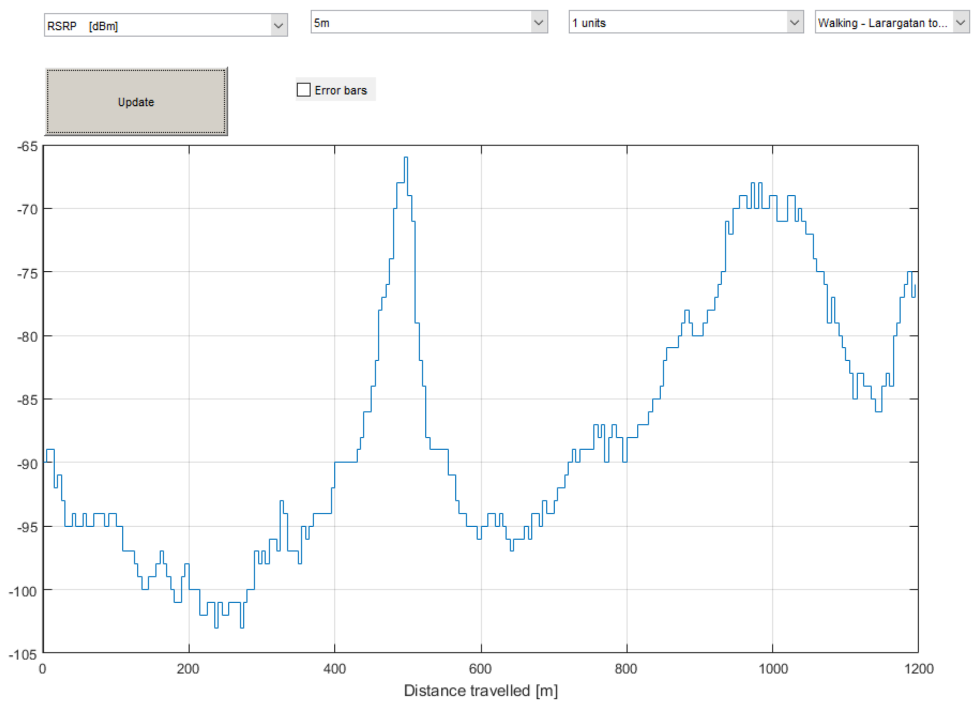


Figure 4.7: Läraregatan to Pilbågsgatan along Gibralatargatan

The Figures 4.7 and 4.8 show significant variations for the walk on Gibralatargatan and the high signal strength corresponds to the open area in front of the church and Chalmers tvärgata.

This betterment in signal strength is seen for the other direction as well depicted in Figures 4.9 and 4.10. The bad signal strengths become more pronounced walking close to Läraregatan as the line of buildings along the path causes much obstruction for the signal and thus the quality degrades.

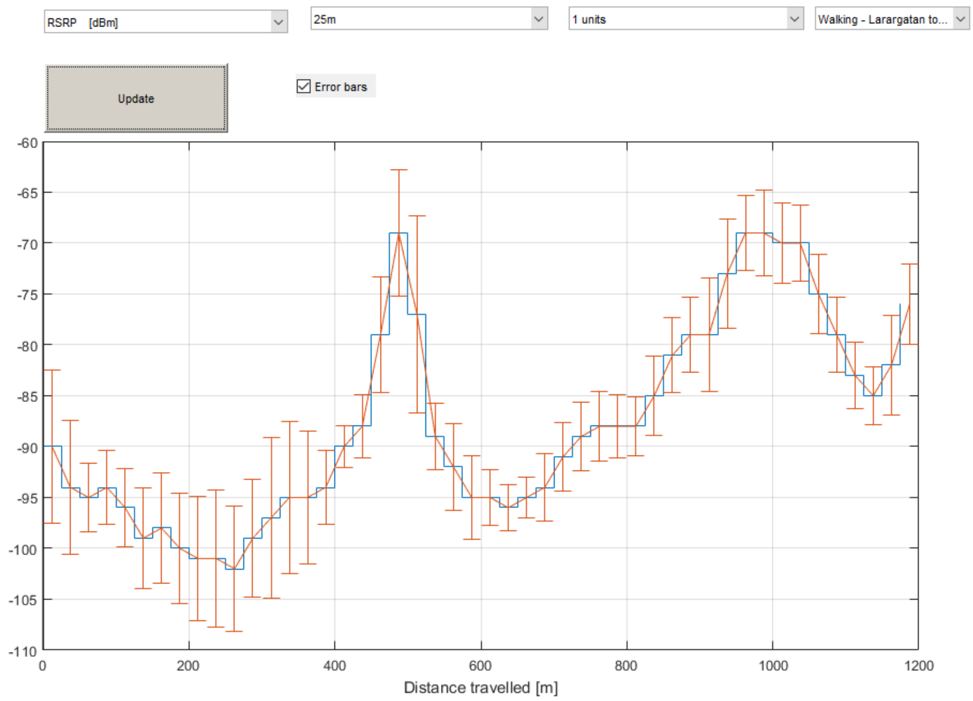


Figure 4.8: Low resolution with error bars plot visualising the data from Läraregatan to Pilbågsgatan along Gibralatargatan

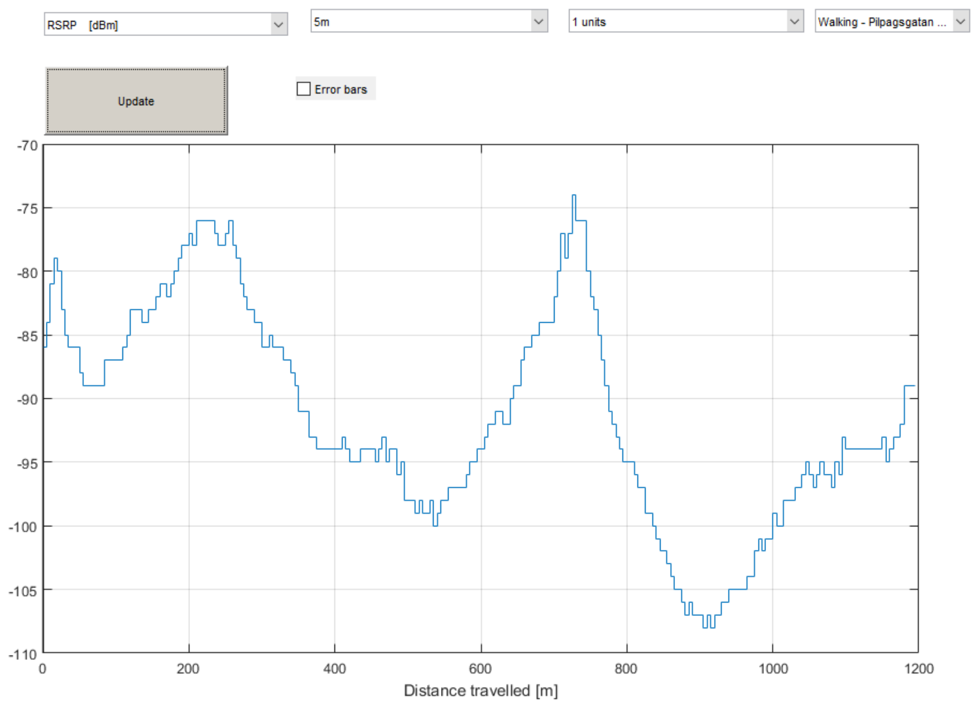


Figure 4.9: Pilbågsgatan to Läraregatan along Gibralatargatan

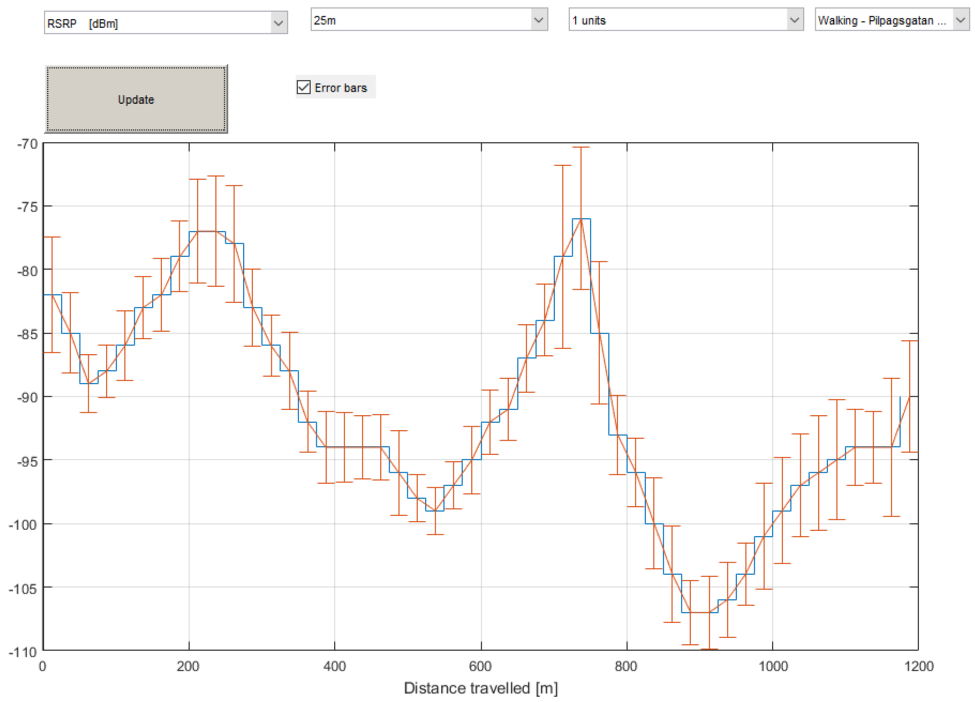


Figure 4.10: Low resolution with error bars plot visualising the data from Pilbågsgatan to Läraregatan along Gibralatargatan

4.1.3 Bus 55 Results

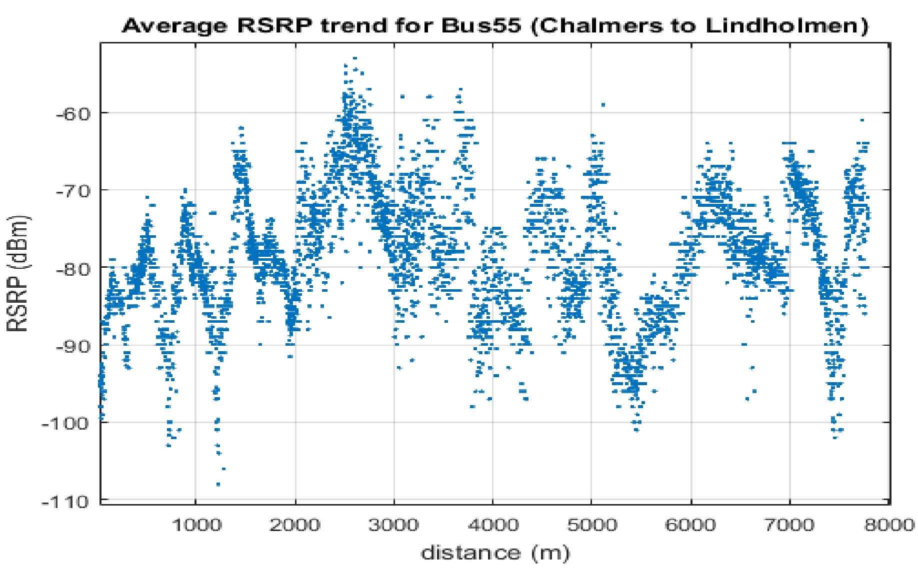


Figure 4.11: Chalmers to Lindholmen

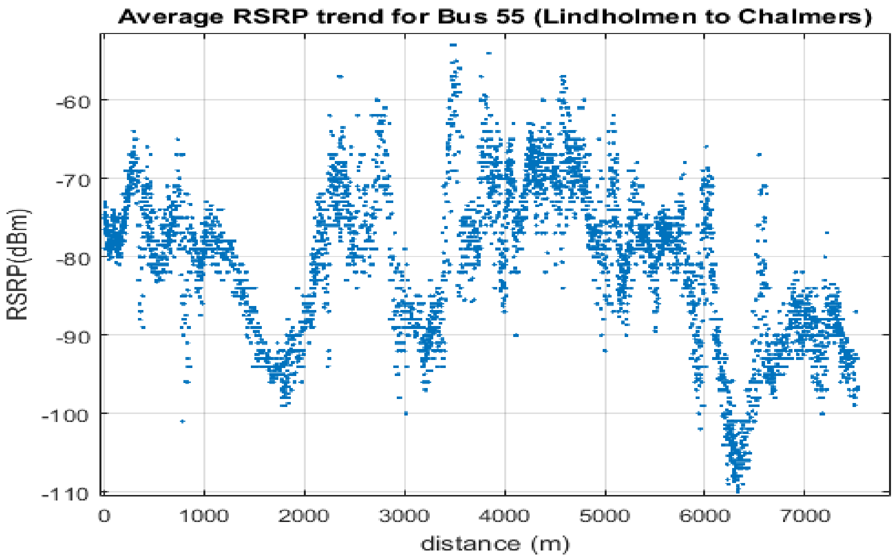


Figure 4.12: Lindholmen to Chalmers

The third set of results are from the bus. A total of 8 trips from Chalmers to Lindholmen and 8 trips from Lindholmen to Chalmers were performed by the bus. The following Figures 4.11 and 4.11show the channel for both the scenarios. The route that Bus 55 takes going from Chalmers to Lindholmen is a bit different from the one it takes back, mainly in the last leg of its journey back to Chalmers. The variations are evident as the bus moves along. The average variation is thus not completely reciprocal is somewhat seen in the walking scenario.

4.1.4 Discussion

Overall it can be seen that there is much variation moving from one point to another even in the city area. The signal strength values for the tram scenario show that the coverage becomes worse upon entering the tunnel. However, there are base stations inside the tunnels that help improve the coverage as the tram traverses through the tunnel. The large variations are evident even for walk scenario. The signal strength suffers to a great extent when walking along tall buildings. The coverage as seen for the bus scenario as well provides the case for PRA implementation.

4.2 MATLAB implementation Results

In the following section the results from the PRA MATLAB are presented.

4.2.1 Theoretical

This implementation test case was considered to validate the implementation in comparison to the case paper. The theortical implementation assumes the channel to be randomly distributed with no variance and so The results from the first set are shown below. It can be clearly seen that in that PRA performs much better than Equal share. Almost a 40% lower degradation than the equal share case. The throughput achieved is also quite significant where PRA performs better and better than equal share even though the latter saturates. With PRA there is a lower network wide power consumption from 5 to 25 users before the value caps off at 1000 W.

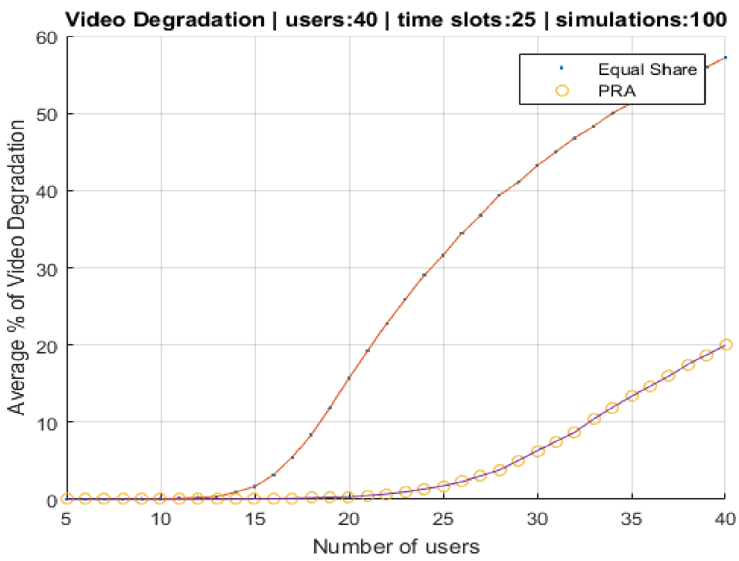


Figure 4.13: Theoretical simulation for Video Degradation

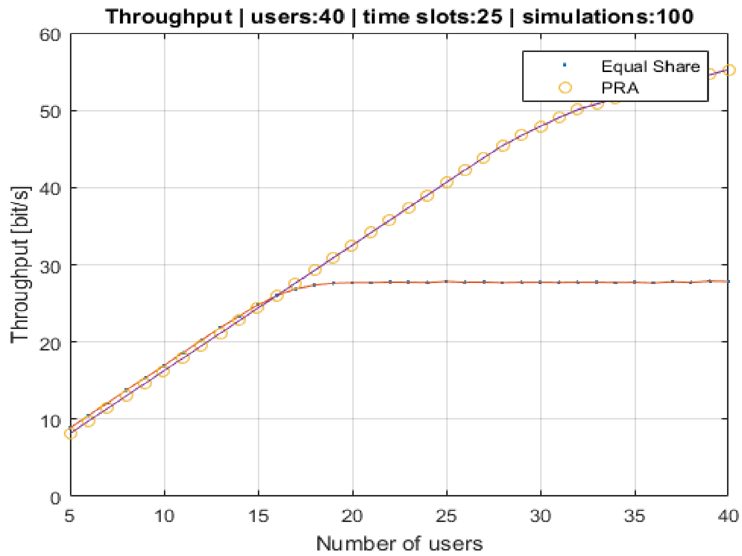


Figure 4.14: Theoretical simulation for throughput

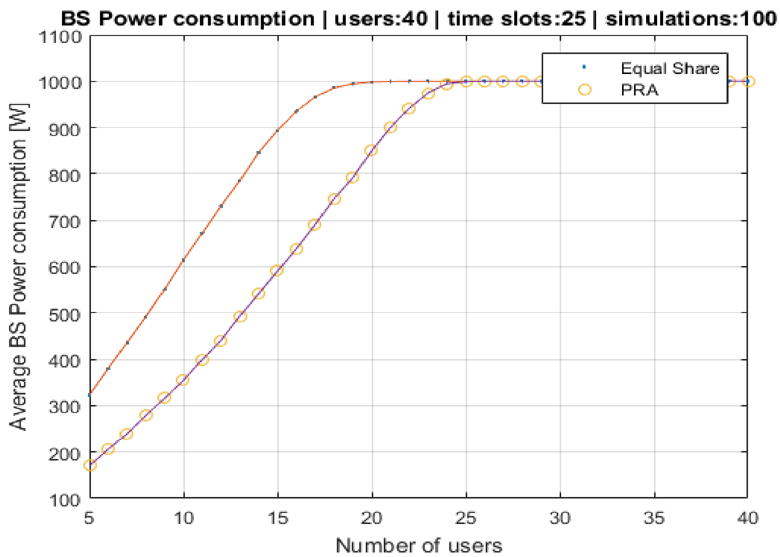


Figure 4.15: Theoretical simulation for Power

4.2.2 Real Data

The signal strength data collected from from the walk scenario are utilised to visualise real channel. The data was picked from several measurement instances to simulate different users experiencing different channels realisations. It can be seen that in comparison to the theory the results under perform with real data. There is a betterment of around 15% from the equal share case unlike the result seen in theory where the video degradation dropped by good 40% is similar trend but this time the video degradation is higher compared to the tram scenario. The throughput is also a little better than equal share. Power consumption showed a more theory like trend with PRA algorithm performing at lower power as compared to equal share.

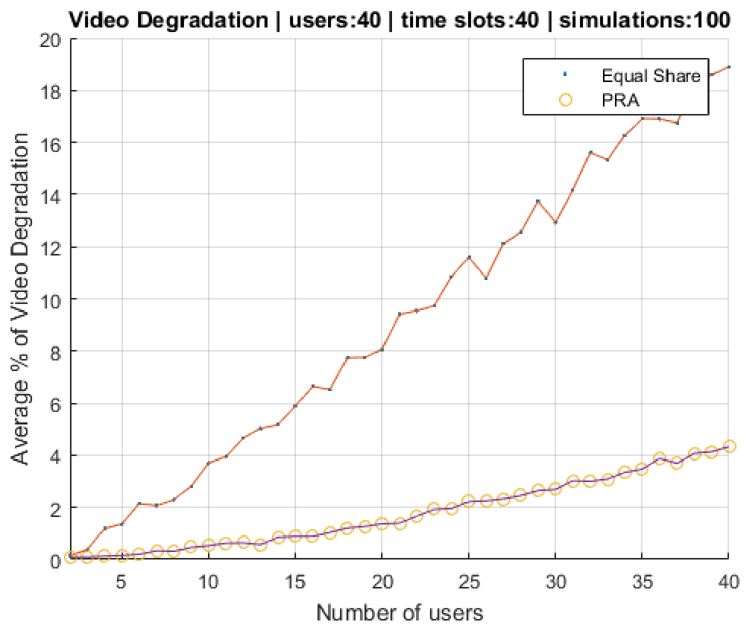


Figure 4.16: Real Data simulation for Video Degradation

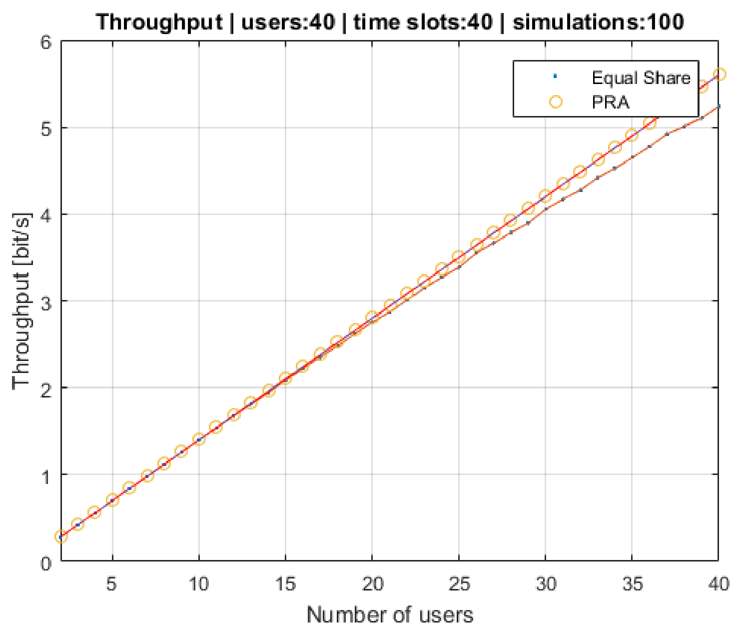


Figure 4.17: Real Data simulation for Throughput

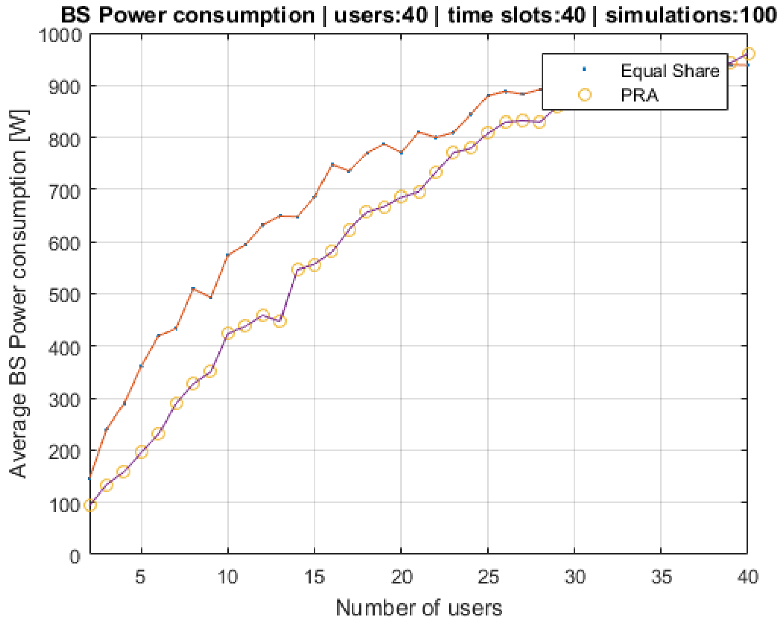


Figure 4.18: Real Data simulation for Power

4.2.3 Discussion

Overall it can be seen that PRA does perform better than Equal share. The improvement however is very restricted and not of the degree seen in the theoretical implementation. Upon closer inspection of the code, the data and the constraints used, it can formulated that this low improvement is due to the lack of variations in signal strength values. In the theoretical case the signal strength values were simulated using MATLAB's random function which ensured the variations were of good degree. Such is not the case with real data where the signal strength variations are much more gradual and of lower degree in their extremeness or peaks.

5

Conclusion

Predictive Resource Allocation as a scheme for better resource allocation by base stations proves to be a promising endeavour. Through this research based thesis, a very strong case is made for the scheme. The measurement campaigns gave an insight on how the channel looks at different locations. The tram scenario data showed a drop as the tram entered but became better soon after as the base station serving changed in the tunnel. The walk scenario showed some surprising trend where the signal strength values varied to a good degree as it was initially thought that the walk scenario would give minimum variation. On implementing the algorithm in MATLAB, the theoretical results have shown PRA to be a very promising scheme. On utilising the data collected over showed better performance than the traditional equal share scheme but this was not at par with what was seen theoretical implementation. For further studies, better algorithms implementations can see it improve more. This along with utilisation of data available at the base in tandem will only improve this scheme further and help operators save costs on power while giving better QoS on video services.

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